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The accuracy of a novel stunting risk detection application based on nutrition and sanitation indicators in children aged under five years

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Abstract

Background Adaptive and innovative technologies to prevent stunting are being developed continuously in various countries. This study aimed to develop and evaluate the accuracy of a stunting risk detection application based on nutrition and sanitation indicators in children aged under five years.

Methods This cross-sectional study was conducted between June and September 2023 and involved 316 mother-child pairs selected by simple random sampling from urban (n = 244) and rural (n = 72) areas in Bogor, West Java Province, Indonesia. An application was developed to detect stunting risk based on 25 indicators: eight indicators of maternal and child characteristics, eight nutrition indicators, and nine indicators of personal hygiene and sanitation. The nutrition and sanitation indicators were determined according to the World Health Organization conceptual framework for stunting. The accuracy of the stunting prediction model was analyzed using the Area Under Curve (AUC) and the Receiver Operating Characteristics (ROC) Curve method.

Results Of the 316 included children, 29.5% were stunting. The developed stunting risk detection application exhibited good sensitivity (88.3%) and specificity (83.3%). It accurately detected children at risk of stunting with an AUC of 89.6%. In urban areas, eight indicators were significantly predictive of stunting: mother's height, child's age, exclusive breastfeeding, frequency of protein consumption, balanced diet, washing hands with soap, availability of complete room functions in the house, and good household waste management. In rural areas, eight indicators were significantly predictive of stunting: mother's height, history of infectious disease, early initiation of breastfeeding, frequency of protein consumption, complementary feeding, washing hands with soap, availability of safe food storage, and availability of clean water sources for drinking. Mother's height was the dominant factor in predicting stunting in urban (adjusted odds ratio [aOR] = 3.321, 95% confidence interval [CI] = 1.202–3.051, p = 0.006) and rural (aOR = 3.927, 95% CI = 1.132–4.281, p = 0.001).

Conclusion The developed application exhibited good accuracy and quickly assessed the risk of stunting in children, enabling it to provide appropriate recommendations to prevent stunting. However, it must be improved by simplifying the number of included indicators and re-testing on a broader scale.

Keywords Application, Children under five, Stunting risk detection, Nutrition, Sanitation

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Introduction

Stunting during childhood is the most significant obstacle to human development globally. Stunting refers to the impaired growth and development that children experience due to poor nutrition, repeated infection, and inadequate psychosocial stimulation. The 2006 World Health Organization (WHO) growth standards define stunting in children aged < 5 years as a height below the age-based average according to the WHO Multicentre Growth Reference Study [1, 2]. The long-term consequences of stunting are decreased physical growth, low educational attainment, increased risk of degenerative diseases, decreased labor productivity, and state income [1, 3]. Therefore, reducing the prevalence of stunting is one of the main agendas for global health development, including in Indonesia [4].

The 2022 Indonesian Nutrition Status Study reported that the prevalence of stunting has decreased gradually by 2.9% from 2021 (24.4%) to 2023 (21.5%) [5]. However, this decrease is below the government's annual target of 3.8% per year to achieve the national target [5]. Previous studies have shown that the prevalence of stunting remains high in urban and rural areas of Indonesia [6, 7, 8, 9]. In 2018, Indonesian Basic Health Research showed that the prevalence of stunting in Indonesia was higher in rural (34.9%) than in urban (27.3%) areas [10].

One province that still has a high prevalence of stunting is West Java. The prevalence of stunting in urban areas (Bogor City) increased by 1.8% from 2021 (16.9%) to 2022 (18.7%). In contrast, the prevalence of stunting in rural areas (Bogor District) decreased by 3.7% from 2021 (28.6%) to 2022 (24.9%) [5]. Nonetheless, this prevalence is considered high based on the cut-offs for public health significance set by the WHO (20% to < 30%) [11]. Mauludyani and Khomsan also reported that the prevalence of stunting in urban (30%) and rural (33%) areas of West Java Province exceeded 30% in 2022 [12]. Previous studies have shown differences in the risk of stunting in the two areas due to differences in sociodemographic characteristics, health facility services, sanitation facilities, and information technology use [12, 13].

Previous studies have shown that the main predictors of stunting include mother-child, nutritional, and sanitation factors [6, 14, 15, 16, 17, 18]. Previous studies in Indonesia detecting stunting risk using Android applications have generally not measured sanitation factors optimally. While several ministries/institutions have developed applications related to stunting prevention, measurements focus on maternal health conditions and monitoring child growth. The National Population and Family Planning Agency has developed an application called Electronic Ready for Marriage and Pregnancy since 2022. It is used to identify prospective brides and grooms at risk of having stunted children. Stunting risk is detected based on age, nutritional status, and smoking behavior [19]. Three other ministries have also developed stunting prevention applications. The Ministry of Communication and Information has created the Healthy Children application to help monitor pregnancy and children's growth and development from birth to two years of age. In addition, the Ministry of Health created an e-community Nutrition Recording and Reporting application to monitor children's nutritional development [20]. Moreover, the Ministry of Villages created the e-Human Development Worker (e-HDW) application, a data collection, monitoring, recording, and reporting tool for targeted households to prevent stunting in villages [19]. Another stunting prevention application in Indonesia is the Nutrition Monitoring (Nutrimo) application developed by Permana et al. in 2021 in Tangerang City, Banten Province, which is used to help monitor nutritional status through anthropometric data [21].

In 2022, Elisanti et al. also developed an application system with a microcontroller and an embedded Android-based Arduino device to detect stunting early using the waterfall method [22]. In 2023, Nurisna et al. developed an Android-based application (Nosting) for detecting stunting early and screening growth and development in children aged 12–24 months with an effectiveness rate of 89% [23]. Furthermore, in 2024, Muflihatin et al. developed a smart application system for detecting stunting early based on anthropometric standards to help identify stunting in the community [24]. However, these applications have not included personal hygiene and sanitation factors as predictors of stunting.

Personal hygiene factors, especially washing hands with soap, and sanitation factors are important predictors of stunting. Unsanitary conditions are associated with the transmission of fecal-oral pathogens, such as recurrent diarrhea and environmental enteric dysfunction, and other infectious diseases, such as respiratory tract infections, which can inhibit child growth and lead to stunting [25, 26, 27]. Therefore, applications that can detect stunting by comprehensively measuring the main predictors are still needed, including mother-child characteristics, nutritional indicators, and sanitation indicators.

Stunting can be effectively prevented through accurate detection. The existing applications to detect stunting risk have proven effective in the early detection and prevention of stunting. They have shown relatively good accuracy and reasonably good sensitivity and specificity of > 70%. However, both values are not equivalent, with the sensitivity lower than the specificity or vice versa [14, 15, 16]. Early detection of stunting based on nutrition and sanitation indicators, which integrate both specific and sensitive interventions. Specific interventions, including nutrition indicators, focus on the direct causes of stunting. Meanwhile, sensitive interventions, which include sanitation indicators, address the indirect causes. Approximately 70% of success in overcoming stunting issues comes from sensitive interventions including those related to sanitation indicators, compared to 30% from specific interventions related to nutrition. Successful implementation also requires political commitment, cross-sector involvement, and the capacity to execute these interventions effectively [28].

This study develops a stunting risk detection application based on nutrition and sanitation indicators in children aged < 5 years, distinguishing it from existing applications, and evaluates its accuracy. It exhibits good accuracy and almost equivalent sensitivity and specificity > 80%. In addition, the indicators used by this application to detect stunting are more comprehensive, consisting of mother-child characteristics, nutrition indicators, and sanitation indicators. Nonetheless, further studies comparing the accuracy of various stunting detection applications developed in Indonesia are still needed. This study's application can facilitate data collection and analysis, recommending fast and appropriate interventions, monitoring and evaluation, and creating and improving policies to reduce the prevalence of stunting [16, 17].

Methods

Study area and stages

This study was conducted in urban (Bogor City) and rural (Bogor District) areas in West Java, Indonesia, between June and September 2023. Bogor City and Bogor District border one another, with a distance between government centers of 10–15 km and a travel time of around 40–60 min. These two areas are relatively close to the country's capital (50–60 km), the Special Capital Region of Jakarta. This study defined urban (Bogor City) and rural (Bogor District) areas according to the criteria in the Regulation of the Head of the Central Statistics Agency Number 37 of 2010 concerning Urban and Rural Classification in Indonesia, including population density, percentage of agricultural households, and the existence/access to urban facilities owned by a village/subdistrict [29].

The consideration for using these two areas is that the prevalence of stunting is still relatively high in both areas and does not meet the national target: 18.7% in Bogor City and 24.9% in Bogor District in 2022. Indeed, in Bogor City, the prevalence of stunting increased by 1.8% from 2021 to 2022 [5]. However, in 2023 the prevalence of stunting in Bogor City decreased slightly to 18.2%, while in Bogor Regency it increased quite high to 27.6% where the stunting rate in Bogor Regency ranked highest among other regions in West Java Province [6].

Specific issues related to stunting in both areas, although relatively close, there are regional disparities and differences in sociodemographic characteristics. Bogor City, which is an urban area with population characteristics mainly mothers, has a better level of education, knowledge, income, access to health services, nutrition, and sanitation compared to Bogor Regency (rural area). Meanwhile, Bogor Regency has a larger area, but in this area, there are still many rural areas with remote locations that have limited infrastructure and have a direct impact on the fulfillment of children's nutrition and monitoring of growth and development by health workers. Bogor City/Regency is one of the priority locations for stunting reduction acceleration intervention by the central government. These two areas include districts/cities that the central government has selected to be stunting intervention loci: eight sub-districts have been identified as stunting loci in the urban area (Bogor City), and 10 villages have been identified as stunting loci in the rural area (Bogor District). Thus, Bogor City/Regency is a strategic and relevant location for stunting research, especially in conducting early detection efforts for stunting risks based on Android applications.

Design and samples

A cross-sectional study was conducted to detect the risk of stunting using applications based on nutrition and sanitation indicators in urban (Bogor City) and rural (Bogor District) areas in West Java Province, Indonesia. Its target population was mother-child pairs (children aged 0–59 months) living in urban (Bogor City) and rural (Bogor Regency) areas in West Java Province, Indonesia. Mother-child pairs from the sample units who met the inclusion and exclusion criteria were enrolled in this study.

Inclusion and exclusion criteria

The inclusion criteria for mother-child pairs were mothers with children aged 0–59 months who had lived in a sub-district/village in the study location for at least six months. The specified time was intended to ensure that participants had been exposed to the lifestyle where they lived (urban/rural) and adapted to the sociodemographic environmental conditions in each area. The other inclusion criteria were that the mother had and used an Android smartphone so she could download and complete the stunting risk detection application. The exclusion criteria were mothers who had children with serious illnesses or congenital disabilities that would affect their nutritional and health conditions.

Sample size determination

The required sample size was estimated using the two-sample test of proportions with a two-sided alternative hypothesis (Eq. 1) and the following assumptions: 5% significance level, 90% power, P1 and P2 values obtained from previous studies (64.3% of stunted children were exposed to risk factors, and 34.7% of stunted children were not exposed to risk factors) 28, and 10% contingency for loss to follow-up. Therefore, the minimum sample size was estimated as 65 mother-child pairs in each area, giving a total sample size of 130 mother-child pairs. This study included 316 mother-child pairs from urban ($n = 244$) and rural ($n = 72$) areas.

$$n = \frac{\{Z_{1-\alpha/2}\sqrt{P_1(1-P_0)} + Z_{1-\beta}\sqrt{P_2(1-P_a)}\}^2}{(P_1 - P_2)^2} \quad (1)$$

Sampling technique and procedure

This study examined two areas with different characteristics, an urban area (Bogor City) and a rural area (Bogor District), allowing the application's usage to be compared between them. It selected 316 mother-child pairs as participants using the simple random sampling (SRS) technique. Each individual in the population had an equal chance of being selected, ensuring that the sample was representative of the population. In implementing the SRS technique, a sampling frame was created from community health centers, ensuring no duplications, with each member only registered once. A minimum sample size was estimated using a two-sample test of proportions with a two-sided alternative hypothesis, with samples taken from two areas (urban and rural). During sample selection, randomization was conducted using Microsoft Excel. Next, data was collected from the sample units (community health centers) according to the number of samples that must be obtained. Three community health centers were selected for the urban (Bogor City) and rural (Bogor District) areas (six community health centers in total).

As public health services, community health centers in urban (Bogor City) and rural (Bogor District) areas were selected based on stunting loci in each area. Each selected community health center had at least one sub-district/village designated as a stunting locus within its work area. In the urban area (Bogor City), three community health centers with a total of five sub-districts were selected as stunting loci (a total of five stunting loci): two with two stunting loci and one with one stunting locus. The number of stunting loci was greater in the urban area than in the rural area. This consideration was based on the stunting rate in the urban area, which showed an increase from 2021 to 2022. In addition, an initial study obtained data on the number of mothers with Android smartphones in urban compared to rural areas. Internet access is also better in urban than in rural areas. Moreover, mothers' ability to perform Android functions was better in urban than in rural areas.

In the rural area (Bogor District), three community health centers were also selected, each with one village selected as a stunting locus (a total of three stunting loci). Within the five stunting loci in the urban area and three stunting loci in the rural area, there were 347 and 168 mother-child pairs, respectively, who were eligible to participate. Of these, 244 mother-child pairs in the urban area (49 from four sub-districts and 48 from one sub-district) and 72 mother-child pairs in the rural area (24 from each village) met the eligibility criteria (Fig. 1).

Stunting detection information system application based on nutrition and sanitation indicators

Application development, data collection, and measurements

This study developed a stunting prevention information technology system based on nutrition and sanitation indicators, Si Centing Sazi (in Indonesian), which is an extension of Sistem Informasi Pencegahan Stunting Berdasarkan Indikator Sanitasi dan Gizi (Stunting Prevention Information System based on Sanitation and Nutrition Indicators). This application was developed by an informatics engineering graduate with experience creating applications in the health sector. This Android-based application can be accessed freely on Android smartphones through the Google Play Store. Its minimum specifications are Android operating system version 4.1.1 (Jelly Bean) or above, 2 GB RAM, Quad-core 1.6 GHz Cortex-A9 processor or above, 8 MP camera, 15.7 MB of storage space, and a screen resolution of 720 × 1280 to 2560 × 1600 pixels.

This application was developed using the waterfall software development method, known as the software development life cycle (SDLC), which comprises five systematic and sequential stages: assessment of requirements, design, implementation, testing, deployment, and maintenance [21].

Study stages and data collection

The study stages followed the SDLC:

1) ***Assessment of Requirements***: This stage analyzes problems in detecting the risk of stunting and the required features. It was conducted to record problems that often occur when detecting stunting. User needs were identified through focus group discussions with mother-child pairs, stakeholders in the health sector (heads of health services, heads of community health centers, nutrition workers, and sanitarians), government officials (district heads and village heads), and integrated service post cadres. Based on the identified requirements, stunting is generally detected based on anthropometric measurements but not other main predictors,

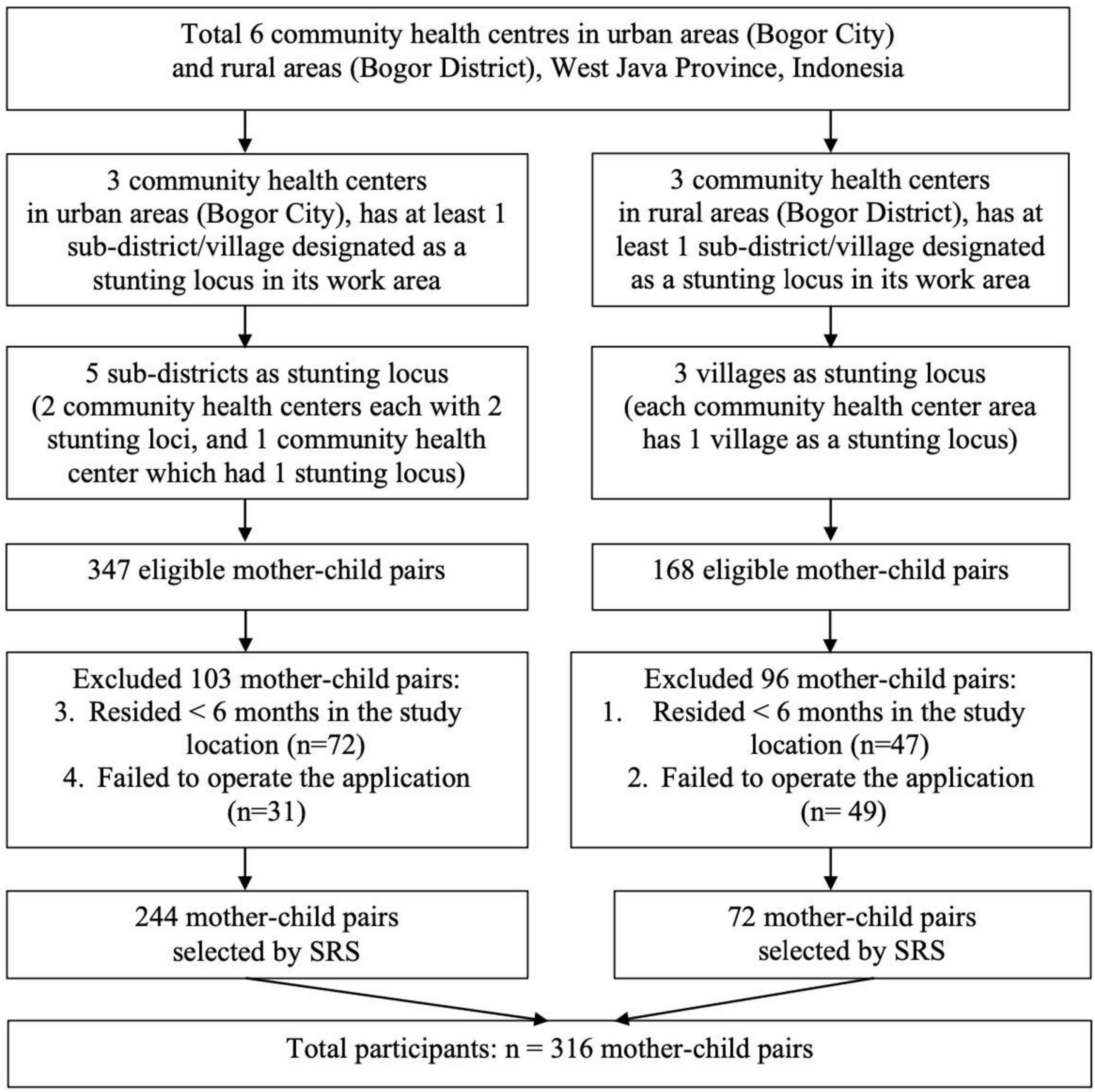

Fig. 1 Sampling procedure of mother-child pairs. SRS = Simple Random Sampling

> especially sanitation indicators, which contribute to determining the health status of children aged < 5 years. Based on the identified problems, a mobile application must be developed to detect stunting based on more comprehensive predictors, such as nutrition and sanitation indicators, to ensure high accuracy.

Fundamentally, the 2016 WHO conceptual framework for stunting identified nutrition and sanitation indicators as risk factors for stunting, which occurs due to the combined effects of poor nutrition, repeated infection, and inadequate psychosocial stimulation. In addition, contextual risk factors for stunting include the health and healthcare system; education; society and culture; agriculture and food systems; and water, sanitation, and environment. Therefore, nutrition and sanitation factors are strongly and closely linked to stunting [30].

The mother-child characteristics were assessed using the 2023 Indonesia Health Survey conducted by the Ministry of Health of the Republic of Indonesia, which can be accessed freely [9]. The nutrition indicators reflect the principles of implementing balanced nutrition. The sanitation indicators were based on the 2023 Indonesia Health Survey and the Decree of the Minister of Health of the Republic of Indonesia Number 829/MENKES/SK/VII/1999 concerning housing health requirements. Regulations regarding housing health requirements are also outlined in the Regulation of the Minister of Health of the Republic of Indonesia Number 2 of 2023 concerning the Implementing Regulation of Government Regulation Number 66 of 2014 concerning Environmental Health.

Home thermal comfort was measured using environmental meters, including air quality, temperature, air humidity, air exchange, noise, CO_2 gas concentration, SO_2 gas concentration, and CO gas concentration, in the early stages of this study (the previous year). These measurements were not conducted for all children but were limited to stunted children due to the limited availability of the equipment. The thermal comfort measurements were not included in the binary logistic modeling analysis due to the limited data. In addition, the application used to detect stunting cannot yet measure thermal comfort.

Therefore, based on scientific references and previous studies, in the initial stages of this study, 86 question items were prepared to obtain predictors related to the incidence of stunting [7, 31]. The 86 indicators can be classified into three groups: mother-child characteristics (24 indicators), nutrition (32 indicators), and personal hygiene and sanitation in the home environment (30 indicators). Furthermore, in the multiple logistic regression analysis of the 86 indicators, 25 were significantly associated with the incidence of stunting. Of the 86 indicators used to detect stunting, a selection process was conducted using statistical tools, particularly during the candidate selection phase of the multiple logistic regression analysis. Of the 86 indicators, 30 did not meet the necessary criteria at this stage (p-value > 0.25). This group included 8 out of 24 indicators related to mother-child characteristics, 10 out of 32 nutrition indicators, and 12 out of 30 indicators of personal hygiene and home environmental sanitation. As a result, these 30 indicators were not included in the first modeling in the multiple logistic regression analysis.

One reason these variables did not advance in the selection process is due to the homogeneous nature of the data. For instance, within the personal hygiene and sanitation indicators, one variable assessed the usage of feces disposal facilities. The data for this indicator showed little variation; over 90% of respondents, both from urban dan rural areas, reported having toilets in their homes and using them correctly. Furthermore, 56 variables that passed the candidate selection were analyzed in the first modeling of multiple logistic regression multivariate analysis consisting of 16 indicators related to mother-child characteristics, 22 nutritional indicators, and 18 indicators of personal hygiene and home environmental sanitation. Of the 56 indicators included in the initial modeling, 25 indicators were obtained that were significantly related to stunting until the final modeling stage of multiple logistic regression analysis, so these indicators were inputted into the application to detect stunting.

Therefore, the 25 questions/indicators assessed were prepared based on questionnaires in studies conducted in the previous year. They examined: (1) mother-child characteristics (eight indicators: mother's age, mother's height, mother's education, mother's occupation, child's age, birth weight, basic immunization history, and history of infectious diseases), (2) nutrition (eight indicators: availability of animal food sources, early initiation of breastfeeding (EIB), exclusive breastfeeding, complementary feeding, frequency of protein consumption, frequency of carbohydrate consumption, balanced diet, and vitamin A supplementation), and (3) personal hygiene and home environment sanitation (nine indicators: washing hands with soap, ease with which building materials become overgrown by fungus, ease of cleaning the walls of the house, availability of complete room functions in the house [living room, family room, dining room, bedroom, kitchen, bathroom, and children's playroom], presence of animals that transmit diseases [e.g., rats, cockroaches, and flies], availability of adequate ventilation, household waste management, availability of clean water for drinking according to the number of family members, and availability of safe food storage). Furthermore, these indicators are assessed to detect stunting risk using applications.

Measurement of each indicator for stunting detection in the application is grouped into 2 categories, namely: (1) mother-child characteristics, consisting of eight indicators, namely: mother's age, categorized into mothers aged ≥ 25 years, and mothers aged < 25 years; mother's education, categorized into mothers who have completed a minimum formal education or more than senior high school, and mothers who have completed formal education lower than senior high school; mother's occupation, categorized into mothers who do not work or housewives, and mothers who work; mother's height, grouped into mothers with a height of ≥ 150 cm, and mothers with a height of < 150 cm; child's age, grouped into children aged ≥ 24 months, and children aged < 24 months; birth weight, grouped into babies with normal birth weight (≥ 2500 g), and babies with low birth weight (< 2500 g); basic immunization history is categorized into babies who were given complete basic immunization (complete), and babies who were not given complete basic immunization (incomplete); history of infectious diseases, categorized into children who do not have a history of infectious diseases (no), and children who have a history of infectious diseases such as diarrhea, Acute Respiratory Infection (ARI), and pneumonia (yes); (2) nutrition, which consists of eight indicators: availability of animal food sources, categorized into the availability of animal food sources for children (yes), and the unavailability of animal food sources in the household for children to consume (no); early initiation of breastfeeding (EIB), categorized as children given EIB immediately after birth up to the first hour (yes), or children not given EIB (no); exclusive breastfeeding, categorized as given exclusive breastfeeding (yes), namely children given only breast milk, with no other foods or liquids, except for drops or syrups of vitamins, minerals, or medicines, and oral rehydration solution, from birth to 6 months of age, and children not given exclusive breastfeeding (no); complementary feeding, categorized as children who are given complementary foods when they are more than 6 months old, and children who are given complementary foods early, namely less than 6 months old; frequency consumption of protein source, categorized as children with a high frequency of protein source consumption (≥ 3x/day), and a low frequency of protein source consumption (< 3x/day); frequency of carbohydrate consumption, grouped into children who consume high carbohydrate sources (≥ 3x/day), and children who consume low carbohydrate sources (< 3x/day); a balanced diet for children, categorized as children who receive balanced nutrition (yes), and children who do not receive balanced nutrition (no); and vitamin A supplementation, grouped into children who are given vitamin A supplementation (yes), and children who are not given vitamin A supplementation (no); (3) personal hygiene and home environment sanitation consists of nine indicators, where each indicator is categorized into 2 groups: (a) the answer 'yes', namely if the indicator meets the requirements of a healthy home indicator, and (b) the answer 'no', if the requirements of a healthy home indicator are not met.

2) ***Design***: The system architecture, user interface, database, and software module designs aimed to create clear guidelines for implementing the application. The application can be used after registering (creating a username and password). Before the user can enter the main page, they can complete a statement of willingness to become a respondent and complete the data on the main page (Fig. 2). The menu on the main page consists of (1) an application usage guide, (2) stunting risk detection (completing indicators of mother-child characteristics, nutrition, and sanitation) and recommendations for detection results, and (3) measuring nutritional status by completing anthropometric measurements.
3) ***Implementation***: This stage involves the coding or actual implementation of the application based on its created design using the Android Software Development Kit and Java Development Kit. The risk of stunting was detected in the application by multiplying the score for an indicator by its weight. The answers to the questions were scored as 1 if they indicated high risk and 0 if they indicated low risk. The weighting of the answer to each question was based on the aOR obtained from multiple logistic regression based on previous studies. Of the 25 indicators used to detect the risk of stunting, six had an aOR of ≥ 2 (the maximum aOR obtained in previous studies was < 3), so their weighing was 2: mother's height, child's age, frequency of protein consumption, washing hands with soap, and availability of complete room functions in the house (living room, family room, dining room, bedroom, kitchen, bathroom, and children's playroom). The other 19 indicators had an aOR of < 2, so their weighting was 1. The total score of all indicators ranged from 0 to 31 ($31 = 1 \times 19 + 2 \times 6$). The total score is categorized based on the mean as a low risk of stunting (0–18) and a high risk of stunting (19–31).
4) ***Testing***: This stage is the validation stage of the application. This stage tests the application's function, performance, and errors that may be encountered so that they can be corrected before it is used by respondents and stakeholders. The application validation stage consists of 3 stages, namely technical validation, content validation, and usability and user experience testing validation.

   a. Technical Validation: This stage ensures that the application runs well functionally. The steps taken are: (1) system testing, which ensures that all features such as data entry forms, data input, local/cloud storage, and data synchronization run well; (2) compatibility testing, which ensures that the application can run according to its specifications (minimum specifications are Android operating system version 4.1.1 or above); (3) data security testing, which ensures that data encryption, user authentication, and storage meet security standards; and (4) stability testing (stress testing), which tests when inputting large amounts of data or in poor network conditions.
   b. Content Validation: This stage is carried out with expert judgment. This stage aims to conduct a scientific assessment of the substance related to the indicators used to detect the risk of stunting and test the application's function to align with the research objectives. This stage involved four

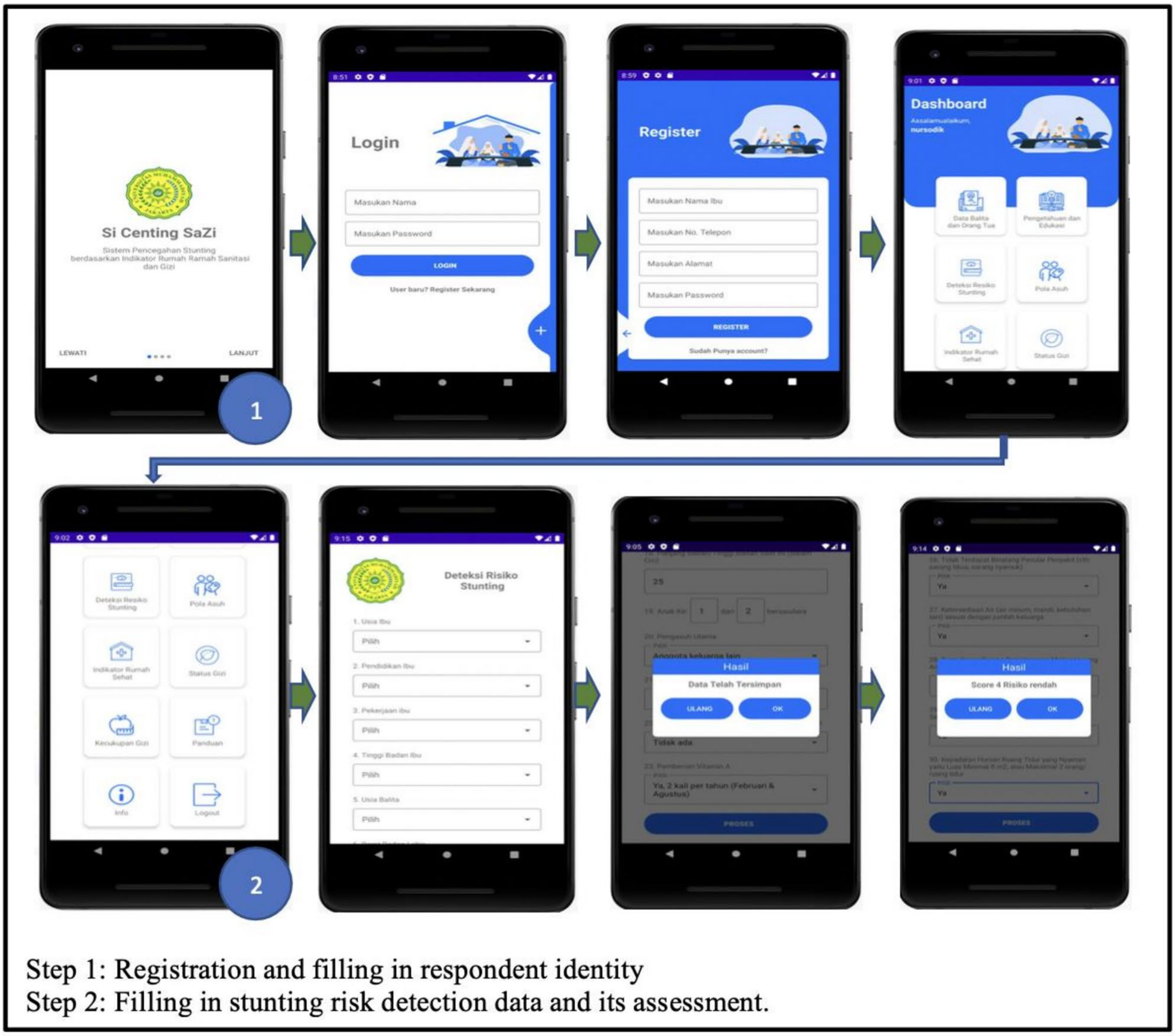

Fig. 2 Menu of the stunting risk detection application

experts, three from scientific fields relevant to stunting (a nutrition expert, community epidemiologist, and civil and environmental engineering expert) to qualitatively and quantitatively assess the 25 indicators used as predictors of stunting, and one from the field of information technology to ensure the application functions properly to detect stunting risk.

A qualitative assessment was conducted to assess the essentiality of all included indicators, including wording, assessment scale, and suitability as predictors of stunting. Its results indicated that the 25 indicators were relevant predictors of stunting, easy to understand, and used a simple assessment scale (binary: yes and no). In addition, based on the interviews, the information technology expert assessed that the application had a simple appearance. Therefore, it must be improved to increase its attractiveness to respondents when completing the data. In addition, the application's functionality was quite limited in detecting stunting risk, and its features/menus must be developed according to user needs.

A quantitative assessment was conducted to assess each indicator's necessity, relevance, clarity, and simplicity, assessed using a four-point Likert scale from 1 (very not needed/very irrelevant/very unclear/very not simple) to 4 (very necessary/very relevant/very clear/straightforward). Each indicator had a content validity ratio (CVR) and content validity index (CVI) of 0.8–1.0 (an indicator with a CVR of < 0.6 is deleted, and a CVI of ≥ 0.8 indicates that the indicator is valid). In this study, the 25 indicators were assessed as meeting the CVR and CVI criteria.

c. Usability and User Experience Testing: The application was tested with 34 mothers (approximately 10% of the minimum number of respondents) from stunting loci not selected as study locations. They had similar characteristics to those of respondents in the actual study. This test was conducted to determine the ease of use of the application, including the (1) availability of an internet network, (2) clarity of instructions for its use, (3) ease of understanding each question/indicator (self-explanatory) and its assessment scale, and (4) predicting the time required to complete data collection, so that improvements could be made to the application and anticipate obstacles that may be encountered in the field. Pearson's product-moment correlation coefficient (r) and the item correlation–total correlation indicated that the 25 questions/indicators were valid and reliable. At a 5% significance level, the calculated r is adjusted to the r product moment Table (0.349). The corrected item-total correlation for each indicator was between 0.746 and 0.813 (r count value > r table), and Cronbach's alpha was 0.894. Furthermore, the application was used to detect the risk of stunting in children aged < 5 years in the actual study at the eight chosen stunting loci (five in the urban area and three in the rural area).

In addition, interviews were conducted with the coordinators of the integrated health post cadres and health workers at each stunting locus (8 loci) regarding the use of the application. They considered that the application has a fairly attractive appearance, is practical and easy to use, the questions are easy to understand, and can be filled in quickly by respondents.

5) ***Deployment and Maintenance***: This stage involves application maintenance, updates, and improvements. This stage has not been conducted in this study because the application is being used for the first time in a limited area. This stage will be conducted by referring to the results of this study to highlight areas where the application's functions could be improved, such as updating its appearance to make it more attractive and adding features/menus, especially for nutrition education services, sanitation, and other health services for stunting prevention.

Stunting measurement

Stunting is assessed by the user inputting anthropometric measurement data. The stunting risk detection application is completed in conjunction with regular (monthly) child-weighing activities at integrated service posts in each sub-district/village. Stunting is assessed using the Length-for-Age Z-Score (LAZ) or Height-for-Age Z-Score (HAZ). The anthropometric measurements are performed by skilled and experienced health workers, such as midwives and nutrition officers, at community health centers in the study area. For children aged < 2 years or unable to stand, length is measured using the SECA 210 length board (10–99 cm measurement range and 5 mm graduated measuring rod). For children aged > 2 years or already able to stand, height is measured using a GEA stature meter (2 m maximum height). The length and height of each child are measured twice and then averaged, requiring a difference of < 0.2 cm. The length and height measuring instruments are calibrated before use and have an accuracy of 0.1 cm. Stunting is categorized according to the WHO child growth standards using the WHO Anthro software: severe stunting (< −3 standard deviations [SDs]), stunting (−3 to < −2 SDs), normal (−2 to +3 SDs), and tall (> +3 SDs).

Quality assurance of data collection

This study was approved by The Ethics Commission of Health Research of the Faculty of Medicine and Health, Universitas Muhammadiyah Jakarta (approval number: 90/PE/KE/FKK-UMJ/VI/2023). Its data were collected by five enumerators, two in the rural area and three in the urban area. One supervisor accompanied the enumerators in each area to ensure the data collection complied with procedures and maintained quality. The enumerators had a bachelor's degree in nutrition, while the supervisors had a master's degree in nutrition; both had experience in data collection. The researcher asked the enumerators and supervisors to explain the study's purpose, methods, stages, and timeline, as well as describe each task. They were also given training on data collection techniques for all instruments used in this study to ensure the consistency and quality of the collected data.

Before data collection, all respondents are required to fill in the informed consent form. Informed consent is displayed when the respondent has registered. The application displays a special screen that presents informed consent before the data collection process begins, namely a statement of agreement from respondents after they receive information listed on the application page including the title of the study, purpose of the study, researcher's expectations regarding respondent involvement in the study, potential risks and benefits, duration of the study, privacy and confidentiality of data, voluntary participation and the right to withdraw, compensation received by respondents for their involvement in the study, and contact information for questions. Signing the informed consent on this application is done by checking the confirmation checkbox on the respondent's statement of agreement ('I have read and understood all information about the study and agree to participate in this study voluntarily'). If respondents do not check the confirmation checkbox, they cannot proceed to the next section to fill in research data.

In this study, the potential biases include measurement and recall biases. Measurement biases include bias from instruments and enumerators. Measurement instrument bias was overcome by ensuring all measuring instruments were accurate and calibrated. The instruments used to measure anthropometry (height and length) met the required standards and had been calibrated. The questions in the application had also been tested by experts and assessed for validity and reliability. All enumerators and supervisors were given explanations and training related to data collection techniques, including how to complete the questionnaire. Systematic measurement bias was overcome by experts (midwives and nutrition officers) from community health centers in the study area performing the anthropometric measurements; refresher training in anthropometric measurement techniques had been previously provided at these centers.

Recall bias, which is a bias that can potentially arise when mothers answer questions related to past behaviors, such as their child's food consumption and balanced nutrition practices. Each part of the question is accompanied by instructions for answering using clear and simple sentences to facilitate participant understanding. When completing the questionnaire, the participants were accompanied by an enumerator to ensure all questions were completed correctly and completely. In addition, the supervisor monitored and evaluated their answers to ensure and verify the accuracy and completeness of the collected data before being inputted into statistical software for analysis.

Data processing and analysis

All data entered into the application were recorded on a local server. The data were analyzed using SPSS (version 22.0). Univariate analyses were conducted to obtain the number and percentage of each category of the research variables. Bivariate analyses of the relationship between independent and dependent variables, which were categorical, used the chi-square test. Statistical significance was assessed using a 95% confidence level and a p-value of <0.05. Multivariate binary logistic regression was conducted to identify the dominant factors associated with stunting. The accuracy of the stunting prediction model was assessed using the area under the receiver operating characteristic (ROC) curve (AUC).

Results

Classification of nutritional status

The primary findings presented in Table 1 indicate that out of the 316 children, 29.7% were stunting. Among these, 20.5% were stunting, while 9.2% were severely stunting. The prevalence of stunting was slightly higher in rural areas, with 39.5%, compared to 29.5% in urban areas.

Table 1 shows the distribution of nutritional status among the children based on the length/height-for-age index, with most falling in the normal nutritional category. Among the children in the urban area, 9.8% were categorized as severely stunting, 19.7% as stunting, 66.4% as normal, and 4.1% as tall. Among the children in the rural area, 6.9% were categorized as severely stunted, 23.6% as stunted, 63.9% as normal, and 5.6% as tall. Overall, among the participating children, 9.2% were categorized as severely stunting, 20.5% as stunting, 65.8% as normal, and 4.5% as tall.

Stunting risk detection using the application based on Mother-Child characteristics, nutrition indicators, and sanitation indicators in children aged < 5 years

The main findings of this study presented in Table 2, namely for the analysis of all respondents ($N=316$) for urban and rural, showed that out of 25 indicators, 17 indicators are significantly related ($p<0.05$) to stunting. The other eight indicators show no significant relationship with stunting ($p>0.05$). Of the eight indicators that are not significantly related to stunting, 3 indicators regarding mother-child characteristics (the mother's education, mother's occupation, and birth weight); two indicators regarding nutrition (frequency of consumption of carbohydrate sources, and vitamin A supplementation); and three indicators regarding personal hygiene and sanitation (whether building materials are quickly grown by fungi, ease of cleaning the walls of the house, and availability of adequate ventilation). However, several indicators show a significant relationship ($p<0.05$) with stunting in children in urban areas, but on the contrary,

Table 1 Classification of nutritional status in children aged < 5 years ($N=316$)

Nutritional Status (LAZ or HAZ)*	Urban ($n=244$)		Rural ($n=72$)		Total ($n=316$)	
	n	**%**	***n***	**%**	***n***	**%**
Severely stunting (< −3 SD)	24	9.8	5	6.9	29	9.2
Stunting (-3 SD to < −2 SD)	48	19.7	17	23.6	65	20.5
Normal (−2 SD to +3 SD)	162	66.4	46	63.9	208	65.8
Tall (> +3 SD)	10	4.1	4	5.6	14	4.5

*LAZ = Length-for-Age Z-Score; HAZ = Height-for-Age Z-Score

Table 2 Associations of mother-child characteristics, nutrition indicators, and sanitation indicators with stunting risk in urban and rural areas ($N = 316$)

Indicator	Urban ($n = 244$)		Total Urban n(%)	*P*-value	OR (95% CI)	Rural ($n = 72$)		Total Rural n(%)	*P*-value	OR (95% CI)	Urban and Rural		Total Urban and Rural N (%)	*P*-value	OR (95% CI)
	Stunting	Not Stunting				Stunting	Not Stunting				Stunting	Not Stunting			
	n (%)	*n* (%)				*n* (%)	*n* (%)				*n* (%)	*n* (%)			
A. **Mother and Child Characteristics**															
Mother's age				0.024*	1.21 (1.11–4.52)				0.048*	1.97 (1.0.47–4.56)				0.044*	1.45 (1.08–4.22)
≥ 25 years	51 (26.6)	141 (73.4)	192 (78.7)			10 (27.0)	27 (73.0)	37 (51.4)			61 (26.6)	168 (73.4)	229 (72.5)		
< 25 years	21 (40.4)	31 (59.6)	52 (21.3)			12 (34.3)	23 (65.7)	35 (48.6)			33 (37.9)	54 (62.1)	87 (27.5)		
Mother's education				0.162	0.98 (0.41–1.43)				0.476	1.18 (0.32–2.72)				0.531	1.33 (0.75–1.72)
≥ Senior high school	44 (36.4)	77 (63.6)	121 (49.6)			7 (31.8)	15 (68.2)	22 (30.6)			51 (35.7)	92 (64.3)	143 (45.3		
< Senior high school	28 (22.8)	95 (77.2)	123 (50.4)			15 (30.0)	35 (70.0)	50 (69.4)			43 (24.9)	130 (75.1)	173 (54.7)		
Mother's occupation				0.049*	1.74 (1.22–5.66)				0.125	1.24 (0.57–2.16)				0.183	1.27 (0.86–2.86)
Unemployed	48 (23.5)	156 (76.5)	204 (83.6)			14 (26.9)	38 (73.1)	52 (72.2)			62 (24.2)	194 (75.8)	256 (81.0)		
Employed	24 (60.0)	16 (40.0)	40 (16.4)			8 (40.0)	12 (60,0)	20 (27.8)			32 (53.3)	28 (46.7)	60 (19.0)		
Mother's height				0.014*	3.72 (1.61–4.59)				0.028*	3.67 (1.14–4.89)				0.000*	3.29 (1.34–3.04)
≥150 cm	18 (15.7)	97 (84.3)	115 (47.1)			5 (14.7)	29 (85.3)	34 (47.2)			23 (15.4)	126 (84.6)	149 (47.2)		
<150 cm	54 (41.9)	75 (58.1)	129 (52.9)			17 (44.7)	21 (55.3)	38 (52.8)			71 (42.5)	96 (57.5)	167 (52.8)		
Children's age				0.045*	1.95 (1.35–4.84)				0.021*	2.86 (1.39–3.15)				0.001*	2.24 (1.15–3.45)
≥24 months	53 (36.1)	94 (63.9)	147 (60.2)			17 (37.0)	29 (63.0)	46 (63.9)			70 (36.3)	123 (63.7)	193 (61.1)		
<24 months	19 (19.6)	78 (80.4)	97 (39.8)			5 (19.2)	21 (80.8)	26 (36.1)			24 (19.5)	99 (80.5)	123 (38.9)		
Birth weight				0.049*	1.75 (1.17–3.72)				0.036*	1.87 (1.17–5.83)				0.051	1.69 (1.14–4.58)
Normal birth weight (≥ 2500 g)	62 (28.4)	156 (71.6)	218 (89.3)			17 (28.3)	43 (71.7)	60 (83.3)			79 (28.4)	199 (71.6)	278 (88.0)		
Low birth weight (< 2500 g)	10 (38.5)	16 (61.5)	26 (10.7)			5 (41.7)	7 (58.3)	12 (16.7)			15 (39.5)	23 (60.5)	38 (12.0)		
History of Basic Immunization				0.031*	2.13 (1.58–5.73)				0.026*	1.92 (1.49–5.77)				0.046*	1.87 (1.44–5.76)
Complete	45 (23.8)	144 (76.2)	189 (77.5)			13 (25.5)	38 (74.5)	51 (70.8)			58 (25.6)	169 (74.4)	227 (71.8)		
Incomplete	27 (49.1)	28 (50.9)	55 (22.5)			9 (42.9)	12 (57.1)	21 (29.2)			36 (40.4)	53 (59.6)	89 (28.2)		
History of Infectious Diseases				0.026*	2.24 (1.36–4.27)				0.042*	2.15 (1.05–4.22)				0.048*	1.95 (1.36–4.73)
No	43 (26.2)	121 (73.8)	164 (67.2)			8 (22.2)	28 (77.8)	36 (50.0)			51 (25.5)	149 (74.5)	200 (63.3)		
Yes	29 (36.2)	51 (63.8)	80 (32.8)			14 (38.9)	22 (61.1)	36 (50.0)			43 (37.1)	73 (62.9)	116 (36.7)		

Table 2 (continued)

Indicator	Urban (*n* = 244)		Total Urban *n*(%)	*P*-value	OR (95% CI)	Rural (*n* = 72)		Total Rural *n*(%)	*P*-value	OR (95% CI)	Urban and Rural		Total Urban and Rural *N* (%)	*P*-value	OR (95% CI)
	Stunting	Not Stunting				Stunting	Not Stunting				Stunting	Not Stunting			
	n (%)	*n* (%)				*n* (%)	*n* (%)				*n* (%)	*n* (%)			
B. Nutrition															
Availability of animal-source food				0.022*	2.45 (1.51–6.43)				0.017*	2.98 (1.51–3.82)				0.039*	2.12 (1.14–4.62)
Yes	56 (27.5)	148 (72.5)	204 (83.6)			6 (16.7)	30 (83.3)	36 (50.0)			62 (25.8)	178 (74.2)	240 (75.9)		
No	16 (40.0)	24 (60.0)	40 (16.4)			16 (44.4)	20 (55.6)	36 (50.0)			32 (42.1)	44 (57.9)	76 (24.1)		
Early Initiation of Breastfeeding				0.044*	1.76 (1.63–4.58)				0.012*	3.42 (1.66–4.94)				0.049*	1.98 (1.49–5.25)
Yes	34 (24.6)	104 (75.4)	138 (56.6)			7 (19.4)	29 (80.6)	36 (50.0)			41 (23.6)	133 (76.4)	174 (55.1)		
No	38 (35.9)	68 (64.1)	106 (43.4)			15 (41.7)	21 (58.3)	36 (50.0)			53 (37.3)	89 (69.7)	142 (44.9)		
Exclusive Breastfeeding				0.039*	1.99 (1.49–5.71)				0.154	0.78 (0.63–2.72)				0.042*	1.85 (1.15–4.67)
Yes	18 (20.9)	68 (79.1)	86 (35.2)			6 (24.0)	19 (76.0)	25 (34.7)			24 (21.6)	87 (78.4)	111 (35.1)		
No	54 (34.2)	104 (65.8)	158 (64.8)			16 (34.0)	31 (66.0)	47 (65.3)			70 (34.1)	135 (65.9)	205 (64.9)		
Complementary feeding				0.033*	2.25 (1.47–4.90)				0.029*	2.47 (1.11–4.70)				0.041*	2.17 (1.38–5.15)
>6 months	18 (21.7)	65 (78.3)	83 (34.0)			7 (25.0)	21 (75.0)	28 (38.9)			25 (22.5)	86 (77.5)	111 (35.1)		
≤6 months	54 (33.5)	107 (66.5)	161 (66.0)			15 (34.1)	29 (65.9)	44 (61.1)			69 (33.7)	136 (66.3)	205 (64.9)		
Frequency consumption of protein source				0.041*	2.16 (1.61–3.19)				0.035*	2.14 (1.37–3.44)				0.048*	2.20 (1.43–4.66)
High (≥ 3x/day)	51 (26.0)	145 (74.0)	196 (80.3)			6 (14.3)	36 (85.7)	42 (58.3)			57 (23.9)	181 (76.1)	238 (75.3)		
Low (< 3x/day)	21 (43.7)	27 (56.3)	48 (19.7)			16 (53.3)	14 (46.7)	30 (41.7)			37 (47.4)	41 (52.6)	78 (24.7)		
Frequency consumption of carbohydrate sources				0.264	0.56 (0.82–3.43)				0.470	0.68 (0.53–2.65)				0.182	0.57 (0.27–1.20)
High (≥ 3x/day)	58 (28.3)	147 (71.7)	205 (84.0)			13 (28.3)	33 (71.7)	46 (64.0)			71 (28.3)	180 (71.7)	251 (79.4)		
Low (< 3x/day)	14 (36.0)	25 (64.0)	39 (16.0)			9 (34.6)	17 (65.4)	26 (36.0)			23 (35.4)	42 (64.6)	65 (20.6)		

Table 2 (continued)

Indicator	Urban (*n* = 244)		Total Urban *n*(%)	*P*-value	OR (95% CI)	Rural (*n* = 72)		Total Rural *n*(%)	*P*-value	OR (95% CI)	Urban and Rural		Total Urban and Rural *N* (%)	*P*-value	OR (95% CI)
	Stunting	Not Stunting				Stunting	Not Stunting				Stunting	Not Stunting			
	n (%)	*n* (%)				*n* (%)	*n* (%)				*n* (%)	*n* (%)			
Balanced diet practices for children				0.018*	2.14 (1.17–5.40)				0.049*	1.96 (1.68–6.81)				0.047*	2.02 (1.29–4.71)
Yes	35 (23.3)	115 (76.7)	150 (61.5)			7 (25.0)	21 (75.0)	28 (38.9)			42 (23.6)	136 (76.4)	178 (56.3)		
No	37 (39.4)	57 (60.7)	94 (38.5)			15 (34.0)	29 (66.0)	44 (61.1)			52 (37.7)	86 (62.3)	138 (43.7)		
Vitamin A supplementation				0.038*	2.04 (1.63–6.47)				0.042*	1.87 (1.25–4.11)				0.052	1.76 (1.53–5.18)
Yes	59 (28.1)	151 (71.9)	210 (86.1)			10 (23.3)	33 (76.7)	43 (59.7)			69 (27.3)	184 (72.7)	253 (80.1)		
No	13 (38.2)	21 (61.8)	34 (13.9)			12 (41.4)	17 (58.6)	29 (40.3)			25 (39.7)	38 (60.3)	63 (19.9)		
C. Personal Hygiene and Sanitation															
The habit of hand washing with soap				0.018*	2.32 (1.36–4.98)				0.043*	0.87 (0.14–0.98)				0.045*	2.19 (1.38–4.23)
Yes	52 (27.1)	140 (72.9)	192 (78.7)			12 (26.1)	34 (73.9)	46 (63.9)			64 (26.9)	174 (73.1)	238 (75.3)		
No	20 (38.5)	32 (61.5)	52 (21.3)			10 (38.5)	16 (61.5)	26 (36.1)			30 (38.5)	48 (61.5)	78 (24.7)		
Building Materials Are Not Easily Grown by Fungus				0.614	0.12 (0.84–4.13)				0.478	0.64 (0.44–1.92)				0.548	0.73 (0.87–3.51)
Yes	46 (31.1)	102 (68.9)	148 (60.7)			10 (25.6)	29 (74.4)	39 (54.2)			56 (29.9)	131 (70.1)	187 (59.2)		
No	26 (27.1)	70 (72.9)	96 (39.3)			12 (36.4)	21 (63.6)	33 (45.8)			38 (29.5)	91 (70.5)	129 (40.8)		
Easy-to-Clean Walls				0.477	1.24 (0.64–4.69)				0.341	1.21 (0.65–2.42)				0.512	1.16 (0.57–2.09)
Yes	45 (28.5)	113 (71.5)	158 (64.8)			15 (32.6)	31 (67.4)	46 (63.9)			60 (29.4)	144 (70.6)	204 (64.6)		
No	27 (31.4)	59 (68.6)	86 (35.2)			7 (26.9)	19 (73.1)	26 (36.1)			34 (30.4)	78 (89.6)	112 (35.4)		
Availability of complete room functions in the house				0.033*	2.5 (1.67–3.88)				0.092	1.14 (0.76–1.55)				0.048*	1.91 (1.42–4.16)
Yes	46 (26.4)	128 (73.6)	174 (71.3)			11 (25.6)	32 (74.4)	43 (59.7)			57 (26.3)	160 (73.7)	217 (68.7)		
No	26 (37.1)	44 (62.9)	70 (28.7)			11 (37.9)	18 (62.1)	29 (40.3)			37 (37.3)	62 (62.7)	99 (31.3)		
There are no animals that transmit diseases.				0.049*	1.99 (1.27–6.43)				0.036*	2.10 (1.54–4.89)				0.044*	1.86 (1.47–5.63)
Yes	43 (27.9)	111 (72.1)	154 (63.1)			9 (26.5)	25 (73.5)	34 (47.2)			52 (27.7)	136 (72.3)	188 (59.5)		
No	29 (32.2)	61 (67.8)	90 (36.9)			13 (34.2)	25 (65.8)	38 (52.8)			42 (32.8)	86 (67.2)	128 (40.5)		

Table 2 (continued)

Indicator	Urban ($n = 244$)		Total Urban	*P*-value	OR (95% CI)	Rural ($n = 72$)		Total Rural	*P*-value	OR (95% CI)	Urban and Rural		Total Urban and Rural	*P*-value	OR (95% CI)
	Stunting	Not Stunting	*n*(%)			Stunting	Not Stunting	*n*(%)			Stunting	Not Stunting	*N* (%)		
	n (%)	*n* (%)				*n* (%)	*n* (%)				*n* (%)	*n* (%)			
Availability of Adequate Ventilation				0.031*	1.87 (1.52–4.17)				0.272	1.19 (0.39–1.80)				0.331	1.54 (0.89–1.47)
Yes	41 (24.6)	126 (75.4)	167 (68.4)			10 (25.6)	29 (74.4)	39 (54.2)			51 (24.8)	155 (75.2)	206 (65.2)		
No	31 (40.3)	46 (59.7)	77 (31.6)			12 (36.4)	21 (63.6)	33 (45.8)			43 (39.1)	67 (60.9)	110 (34.8)		
Good household waste processing				0.047*	1.88 (1.43–3.69)				0.082	1.46 (0.96–5.84)				0.049*	1.74 (1.07–4.56)
Yes	49 (26.6)	135 (73.4)	184 (75.4)			9 (24.3)	28 (75.7)	37 (51.4)			58 (26.2)	163 (73.8)	221 (69.9)		
No	23 (38.3)	37 (61.7)	60 (24.6)			13 (37.1)	22 (62.9)	35 (48.6)			36 (37.9)	59 (62.1)	95 (30.1)		
Clean water is available for drinking according to the number of family members.				0.044*	1.95 (1.24–2.73				0.038*	1.99 (1.78–6.41)				0.041*	1.92 (1.19–4.66)
Yes	52 (27.2)	139 (72.8)	191 (78.3)			13 (27.1)	35 (72.9)	48 (66.7)			65 (27.2)	174 (72.8)	239 (75.6)		
No	20 (37.7)	33 (62.3)	53 (21.7)			9 (37.5)	15 (62.5)	24 (33.3)			29 (37.7)	48 (62.3)	77 (24.4)		
Availability of safe food storage				0.039*	2.11 (1.54–2.78)				0.014*	2.87 (1.77–4.06)				0.045*	2.08 (1.35–4.18)
Yes	44 (25.9)	126 (74.1)	170 (69.7)			10 (26.3)	28 (73.7)	38 (52.8)			54 (26.0)	154 (74.0)	208 (65.8)		
No	28 (37.8)	46 (62.2)	74 (30.3)			12 (35.3)	22 (64.7)	34 (47.2)			40 (37.0)	68 (63.0)	108 (34.2)		

Notes: OR = odds ratio, CI = confidence interval, * = statistically significant ($p < 0.05$)

these indicators do not show a significant relationship ($p > 0.05$) with stunting in children in rural areas, for example, mother's occupation, exclusive breastfeeding, availability of complete room functions in the house, availability of adequate ventilation, and household waste process. Furthermore, based on multiple regression logistic analysis, it shows that of the 25 indicators, the dominant factor associated with stunting in children living in both urban and rural areas is the mother's height (Table 3).

Table 2 shows the characteristics, nutritional intake, and personal hygiene and sanitation of the participating mother-child pairs, which serve as indicators to estimate the risk of stunting in urban and rural areas. In the urban area, seven mother-child characteristics significantly influenced stunting risk: mother's age ($p = 0.024$), where mothers aged < 25 years (40.4%) had a greater risk of having stunted children than mothers aged ≥ 25 years (26.6%); mother's occupation ($p = 0.049$), where working mothers (60.0%) had a greater risk of having stunted children than non-working mothers (23.5%); mother's height ($p = 0.014$), where mothers < 150 cm (41.9%) had a greater risk of having stunted children than mothers ≥ 150 cm (15.7%); child's age ($p = 0.045$), where children aged ≥ 24 months (36.1%) had a greater risk of stunting than children aged < 24 months (19.6%); birth weight ($p = 0.049$), where children with low birth weight, namely < 2500 g (38.5%) had a greater risk of stunting than children with normal birth weight, namely ≥ 2500 g (28.4%); a history of basic immunization ($p = 0.031$), where children with incomplete immunization (49.1%) had a greater risk of stunting than children with complete immunization (23.8%); and a history of infectious diseases ($p = 0.026$), where children with a history of infections (36.2%) had a greater risk of stunting than children without a history of infections (26.2%).

In addition, seven nutrition indicators significantly influenced stunting risk: the availability of animal food sources ($p = 0.022$), where children without access to animal food sources (40.0%) had a greater risk of stunting than children with access to animal food sources (27.5%); EIB ($p = 0.039$), where children without EIB (35.9%) had a greater risk of stunting than children with EIB (24.6%); exclusive breastfeeding ($p = 0.039$), where children not exclusively breastfed (34.2%) had a greater risk of stunting than children who were exclusively breastfed (20.9%); complementary feeding ($p = 0.033$), where children who received complementary feeding before or equal to six months of age (33.5%) had a greater risk of stunting than children who received complementary feeding after six months of age (21.7%); the frequency of protein consumption ($p = 0.041$), where children with a

Table 3 Final binary logistic regression model for detecting stunting risk

Indicator	*P*-value	Adjusted OR	95% CI	
			Lower	Upper
Urban				
A. **Mother and child characteristics**				
Mother's height	0.006	3.321	1.202	3.051
Children's age	0.031	0.568	0.339	0.650
B. **Nutrition**				
Exclusive breastfeeding	0.001	3.148	1.402	4.647
Frequency of protein foods source	0.024	2.827	1.145	4.572
Balance diet practices	0.039	2.125	1.249	5.768
C. Personal Hygiene and Sanitation				
The habit of washing hands with soap	0.038	2.149	1.183	3.816
Availability of complete room functions in the house	0.005	3.235	1.315	4.509
Good household waste processing	0.048	1.892	1.156	3.748
Rural				
A. **Mother and child characteristics**				
Mother's height	0.001	3.927	1.132	4.281
History of infectious disease	0.031	2.134	1.268	3.652
B. **Nutrition**				
Early breastfeeding initiation	0.021	2.548	1.239	3.760
Frequency of protein foods source	0.038	2.227	1.243	3.678
Complementary feeding	0.014	3.674	1.178	5.491
C. **Personal Hygiene and Sanitation**				
The habit of washing hands with soap	0.049	1.987	1.071	4.920
Availability of safe food storage	0.034	2.514	1.083	3.905
Availability of clean water sources for drinking	0.039	2.167	1.058	2.671

lower frequency (< 3x/day) of daily protein consumption (43.7%) had a greater risk of stunting than children with a higher frequency (≥ 3x/day) of daily protein consumption (26.0%); balanced nutrition practices ($p = 0.018$), where children who do not practice balanced nutrition (39.4%) had a greater risk of stunting than children who practiced balanced nutrition (23.3%); and vitamin A supplementation ($p = 0.038$), where children who do not receive vitamin A supplements (38.2%) had a greater risk of stunting than children who receive vitamin A supplements (28.1%).

Moreover, seven personal hygiene and sanitation indicators influenced stunting risk: washing hands with soap ($p = 0.018$), where children who do not wash their hands with soap (38.5%) had a greater risk of stunting than children who do wash their hands with soap (27.1%); availability of complete room functions in the house ($p = 0.033$), where children living in homes without complete room functions in the house (living room, family room, dining room, bedroom, kitchen, bathroom, and children's playroom; 37.1%) had a greater risk of stunting than children living in homes with complete room functions in the house (26.4%); disease-carrying animals in and around the house ($p = 0.049$), where children living in homes with disease-carrying animals (32.2%) had a greater risk of stunting than children living in homes without disease-carrying animals (27.9%); adequate ventilation ($p = 0.031$), where children living in homes with inadequate ventilation (40.3%) had a greater risk of stunting than children living in homes with adequate ventilation (24.6%); household waste management ($p = 0.047$), where children living in homes with poor waste management (38.3%) had a greater risk of stunting than children in homes with proper waste management (26.6%); availability of clean water at home ($p = 0.044$), where children without access to clean water (37.7%) had a greater risk of stunting than children with access to clean water (27.2%); and safe food storage ($p = 0.039$), where children living in homes with unsafe food storage (37.8%) had a greater risk of stunting than children living in homes with safe food storage (25.9%).

In the rural area, six indicators of mother and child characteristics influenced stunting risk: mother's age ($p = 0.048$), where mothers aged < 25 years (34.3%) had a greater risk of having stunting children than mothers aged ≥ 25 years (27.0%); mother's height ($p = 0.028$), where mothers < 150 cm (44.7%) had a greater risk of having stunting children than mothers ≥ 150 cm (14.7%); child's age ($p = 0.021$), where children aged ≥ 24 months (37.0%) had a greater risk of stunting than children aged < 24 months (19.2%); birth weight ($p = 0.036$), where children with low birth weight, namely < 2500 g (41.7%) had a greater risk of stunting than children with normal birth weight, namely ≥ 2500 g (28.3%); a history of basic immunization ($p = 0.026$), where children with incomplete immunization (42.9%) had a greater risk of stunting than children with complete immunization (25.5%); and a history of infectious diseases ($p = 0.042$), where children with a history of infections (38.9%) had a greater risk of stunting than children without a history of infections (22.2%).

In addition, six nutrition indicators significantly influenced stunting risk: the availability of animal food sources ($p = 0.017$), where children without access to animal food sources (44.4%) had a greater risk of stunting than children with access to animal food sources (16.7%); EIB ($p = 0.012$), where children without EIB (41.7%) had a greater risk of stunting than children with EIB (19.4%); complementary feeding ($p = 0.029$), where children who received complementary feeding before or equal to six months of age (34.1%) had a greater risk of stunting than children who received complementary feeding after six months of age (25.0%); frequency of protein consumption ($p = 0.035$), where children with a lower frequency (< 3x/day) of daily protein consumption (53.3%) had a greater risk of stunting than children with a higher frequency (≥ 3x/day) of daily protein consumption (14.3%); balanced nutrition practices ($p = 0.049$), where children who do not practice balanced nutrition (34.0%) had a greater risk of stunting than children who practice balanced nutrition (25.0%); vitamin A supplementation ($p = 0.042$), where children who do not receive vitamin A supplements (41.4%) had a greater risk of stunting than children who receive vitamin A supplements (23.3%).

Four personal hygiene and sanitation indicators significantly influenced stunting risk: washing hands with soap ($p = 0.043$), where children who do not wash their hands with soap (38.5%) had a greater risk of stunting than children who do wash their hands with soap (26.1%); disease-carrying animals in and around the house ($p = 0.036$), where children living in homes with disease-carrying animals (34.2%) had a greater risk of stunting than children living in homes without disease-carrying animals (26.5%); the availability of clean water at home ($p = 0.038$), where children without access to clean water (37.5%) had a greater risk of stunting than children with access to clean water (27.1%); and safe food storage ($p = 0.014$), where children living in homes with unsafe food storage (35.3%) had a greater risk of stunting than children living in homes with safe food storage (26.3%).

Table 2 also shows that of the 25 indicators examined, 17 were significantly related to stunting ($p < 0.05$): five related to mother-child characteristics (mother's age, mother's height, child's age, history of basic immunization, and history of infectious diseases), six related to nutrition (availability of animal food sources, EIB, exclusive breastfeeding, complementary feeding, frequency of protein consumption, and child's balanced diet), and six related to personal hygiene and sanitation (hand washing with soap, availability of complete room functions in the house, disease-carrying animals in and around the house, household waste management, availability of clean water in the home for drinking according to the number of family members, and availability of safe food storage).

Based on Table 2, one indicator related to mother and child characteristics that was significantly associated with stunting risk was the mother's height (odds ratio [OR] = 3.29, 95% confidence interval [CI] = 1.34–3.04, $p = 0.000$), where mothers with below-average height (< 150 cm) had a 3.29-fold greater risk of having a stunted child than mothers with a normal height (≥ 150 cm). One indicator related to nutrition that was significantly associated with stunting risk was the frequency of protein consumption (OR = 2.20, 95% CI = 1.43–4.66, $p = 0.048$), where children who infrequently consume protein-rich foods (< 3x/day) had a 2.20-fold greater risk of stunting than children who frequently consume protein-rich foods (≥ 3x/day). One indicator related to personal hygiene and sanitation that was significantly associated with stunting risk was hand washing with soap (OR = 2.19, 95% CI = 1.38–4.23, $p = 0.045$), where children who wash their hands with soap had a 2.19-fold greater risk of stunting than children who do not wash their hands with soap.

The main findings in Table 3 are that mother's height is the dominant factor associated with stunting in children in both urban and rural areas. mothers < 150 cm, are at about 3 times greater risk of having stunted children than mothers ≥ 150 cm, where this figure is almost the same for children living in urban and rural areas.

Based on the final binary logistic regression model, eight indicators were significant predictors of stunting risk in children aged < 5 years in urban and rural areas (Table 3). In the urban area, the eight significant indicators included two related to mother-child characteristics (mother's height and child's age), three related to nutrition (exclusive breastfeeding, frequency of protein consumption, and balanced diet), and three related to personal hygiene and sanitation (washing hands with soap, availability of complete room functions in the house, and household waste management). In the rural area, the eight significant indicators included two related to mother-child characteristics (mother's height and history of infectious diseases), three related to nutrition (EIB, frequency of protein consumption, and complementary feeding), and three related to personal hygiene and sanitation (washing hands with soap, availability of safe food storage, and availability of clean water sources for drinking).

Mother's height was the dominant factor in predicting stunting in both urban and rural areas. In the urban area, mothers with a below-average height (< 150 cm) had a 3.321-fold greater risk of having stunting children than mothers with a normal height (≥ 150 cm; aOR = 3.321, 95% CI = 1.202–3.051, $p = 0.006$). In the rural area, mothers with a below-average height (< 150 cm) had a 3.927-fold greater risk of having stunting children than mothers with a normal height (≥ 150 cm; aOR = 3.927, 95% CI = 1.132–4.281, $p = 0.001$).

The main findings presented in Table 4 are the application's validity, namely its ability to correctly determine stunted status. Validity is described by sensitivity and specificity. This application has good sensitivity (88.3%) and specificity (83.3%). Therefore, this application had good validity, with a sensitivity and specificity of > 80%, correctly detecting stunted and not stunted children from the entire population. The true positive value was 83 (stunting children who are detected as stunting), the false positive value was 37 (not stunting children detected as stunting), the true negative value was 185 (not stunting children who are detected as not stunting), and the false negative value was 11 (stunted children detected as not stunting).

The positive predictive value (PPV) is the probability that a person with a positive prediction has the examined condition. This application had a PPV of 68.3% to predict stunting in children aged < 5 years. Therefore, it is likely true that children aged < 5 years exposed to the included indicators experience stunting. The negative predictive value (NPV) is the probability that a person with a negative prediction does not have the examined condition. This application had an NPV of 5.6% (Table 4).

Table 4 Stunting risk detection in children aged < 5 years using the application

Stunting Risk Detection	True Characteristics in Population		Total
	Stunting	Not Stunting	
Positive	83	37	120
Negative	11	185	196
Total	94	222	316

- Sensitivity = 88.3% (83/94)*100; Specificity = 83.3% (185/222)*100
- True Positive = 83; False Positive = 37; True Negative = 185; False Negative = 11
- Positive Predictive Value (PPV) = 83/120 = 68.3%
- Negative Predictive Value (NPV) = 11/196 = 5.6%
- Positive Likelihood Ratio = Sensitivity/(1−Specificity) = (0.88)/(1-0.83) = 5.18
- Negative Likelihood Ratio = (1−Sensitivity)/Specificity = (1-0.88)/0.83 = 0.14

Table 5 AUC analysis of the receiver operating characteristics (ROC) of the application in detecting stunting risk

AUC	*P*-value	95% CI
0.896	< 0.001	0.691–0.924

Table 4 also presents the positive likelihood ratio, which compares the probability of a positive prediction between those with and without the examined condition. The greater the positive likelihood ratio, the greater the possibility of correctly predicting the examined condition. This application had a positive likelihood ratio of 5.18, indicating good diagnostic value. The negative likelihood ratio compares the probability of a negative prediction between those with and without the examined condition. The smaller the negative likelihood ratio, the greater the possibility of correctly predicting the absence of the examined condition. This application had a negative likelihood ratio of 0.14, indicating good detection ability. Therefore, this application is valid and accurate in detecting stunting risk in children aged < 5 years.

The main findings in Table 5 show that the application has a good level of overall accuracy based on ROC analysis. The ROC curve can illustrate the overall accuracy of the application in predicting the examined condition, which can be summarized using the AUC. Among the 316 children, 83 were predicted to be at risk of stunting. This application had an AUC of 0.896 (95% CI = 0.691–0.924, $p < 0.001$). Statistically, this AUC is classified as good based on the confidence interval of the hypothesis test, which compared the AUC between this application and random chance (AUC = 0.500).

Analysis of the ROC curve on application can be demonstrated by the overall accuracy of the application screening diagnostic test which can be explained in the area under the ROC turtle Area Under the Curve (AUC). AUC values range from 50 to 100%. Table 5 shows the ROC results based on application detection. Based on the number of 316 children, it was found that 83 children were detected at risk of stunting. The results of diagnostic tests using statistics show that the AUC value of this screening is 0.896 (89.6%) with an OR 95% CI value of 0-691-0.924, p-value = < 0.001. Statistically, the AUC value is classified as good based on the confidence interval of the hypothesis test carried out, namely to compare the AUC obtained from the application as an index of the 50% AUC value, so it can be concluded that there is a significant difference with the 50% AUC value.

Discussion

Our results indicate that about one-third of the 316 children aged < 5 years from the urban (Bogor City) and rural (Bogor District) areas suffer from stunting (29.7%: 9.2% were severely stunted, and 20.5% were stunted). This prevalence exceeds the national average in Indonesia, which stands at 21.5%, according to the 2023 Indonesia Health Survey [9]. The stunting prevalence in our study indicates little difference between urban and rural areas, which was 29.5% in the urban area and 30.5% in the rural area.

Previous studies have shown that while the overall prevalence of stunting in children aged < 5 years has declined significantly over the past three decades, stunting is still common among children in both urban and rural areas and is more common in rural than in urban areas. Stunting is potentially less common in urban than in rural areas due to their greater development, which increases the availability of antenatal care, comprehensive healthcare centers, and access to nutritional needs. The differences in wealth index and maternal education between urban and rural areas also contribute to the stunting disparities between them [32, 33, 34]. In 2022, Maulidyani and Khomsan reported similar findings in West Java Province, showing a stunting prevalence of around 31% among 300 children in Sukabumi (urban) and 33% in Cianjur (rural). The sociodemographic characteristics in the urban and rural areas are quite similar between their study and ours, with most mothers being housewives and falling within the early adulthood age range. In both studies, more mothers in rural areas had lower education levels (less than senior high school) than in urban areas. Furthermore, their study found that rural mothers had worse nutritional knowledge than urban mothers, particularly regarding feeding practices for children [12].

Siramaneerat et al. reported similar results based on a multilevel analysis of the Indonesian Family Life Survey in 13 provinces between 2014 and 2015, showing that the prevalence of stunting remains high in both urban (30.58%) and rural (41.85%) areas. Their study found that the higher prevalence of stunting in rural areas was linked to factors such as early childhood nutrition, maternal nutrition and health, access to healthcare, and environmental conditions [35]. However, Nashira et al. analyzed the prevalence and risk factors of stunting in 395 toddlers in rural and urban areas in Sungai Penuh City, Jambi Province, using the 2022 Indonesian Nutritional Status Survey, showing that 79.5% of children living in urban areas and 20.5% of toddlers living in rural areas experienced stunting. The variation in stunting prevalence between urban and rural areas illustrates the gap in access to nutrition, health services, and other socioeconomic factors. However, Nashira et al. reported similarities in the risk factors for stunting in urban and rural areas: birth length (OR = 2.30, 95% CI, $p < 0.05$) and maternal education (OR = 2.22, 95% CI, $p < 0.05$). However, the similarities in the risk factors for stunting in the two areas can be explained by their close proximity, making public access to nutritional information, food, information, and health services relatively affordable for the community [32].

Based on the 25 indicators used to detect stunting risk, our study observed differences in the risk factors for stunting between the urban and rural areas. Of the 25 examined indicators, eight were identified as strong predictors in the urban and rural areas. In the urban area, they were mother's height, children's age, exclusive breastfeeding, frequency of protein consumption, balanced diet, washing hands with soap, availability of complete room functions in the house (living room, family room, dining room, bedroom, kitchen, bathroom, and children's playroom), and household waste management. In contrast, in the rural area, they were mothers' height, history of infectious diseases, EIB, frequency of protein consumption, complementary feeding, washing hands with soap, availability of safe food storage, and availability of clean water sources for drinking. Mother's height was the dominant factor in detecting stunting risk in both the urban and rural areas. In the urban area, mothers with below-average height (< 150 cm) had a 3.321-fold greater risk of having stunting children than mothers with normal height (≥ 150 cm). In the rural area, mothers with below-average height (< 150 cm) had a 3.927-fold greater risk of having stunting children than mothers with normal height (≥ 150 cm).

Mother's height is a common determinant of stunting across regions. Other factors significantly influencing stunting are birth weight, nutritional fulfillment in early life, personal hygiene, sanitation, household income, and maternal education, which play an important role and may have different impacts in urban and rural contexts [7, 33, 34]. Ali et al. examined 425 children in the Central Gonja District, Northern Ghana, reporting that 28% were stunted, with maternal height strongly associated with stunting. They reported that shorter mothers (< 150 cm) had a 3.87-fold greater risk of having stunting children than taller mothers (≥ 150 cm) [36]. Amaha and Woldeamanuel reported similar findings based on their analysis of children aged < 5 years based on data from the 2016 Ethiopian Demographic Health Survey. They found that shorter mothers (< 150 cm) had a 2.56-fold greater risk of having stunted children than taller mothers (> 160 cm) [37]. According to the WHO, mothers shorter than 150 cm are categorized as short-statured, indicating chronic malnutrition in the past, even before pregnancy, leading to macronutrient and micronutrient deficiencies during pregnancy and breastfeeding, which increases the risk of giving birth to stunting children [36].

In our study, most mothers in the urban and rural areas had lower-middle economic backgrounds. Additionally, more than half of the mothers in the urban and rural areas had low education levels (below senior high school; <12 years). However, the proportion of highly educated mothers was higher in the urban area than in the rural area. Mothers from low-income families have limited purchasing power for food and healthcare services. Our findings reinforce evidence that shorter mothers experience nutritional problems throughout their lives, leading to intergenerational malnutrition [7, 36, 37].

Another important finding of our study is that the developed application could detect the risk of stunting with good validity, with a sensitivity of 88.3% and a specificity of 83.3%. It could correctly identify stunted children as stunted and not stunted children as not stunted in the entire population. Therefore, it could accurately predict stunting (AUC = 89.6%). This good accuracy supports using this application to predict stunting early so that effective prevention efforts can be initiated to address the cause(s) [38].

One advantage of the application developed in this study to detect stunting risk is that it was designed based on a stunting prediction model comprising strong predictors of stunting obtained through scientific studies. The indicators used to predict stunting in this application are comprehensive, including indicators of mother-child characteristics, nutrition, and personal hygiene and sanitation. One unique feature of this application is its inclusion of personal hygiene and sanitation indicators, which were determined based on the WHO conceptual framework, the 2023 Indonesian Health Survey, the Decree of the Minister of Health of the Republic of Indonesia Number 829/MENKES/SK/VII/1999 concerning housing health requirements. Regulations regarding housing health requirements are also outlined in the Regulation of the Minister of Health of the Republic of Indonesia Number 2 of 2023 concerning the Implementing Regulation of Government Regulation Number 66 of 2014 concerning Environmental Health.

Scientific evidence on the role of personal hygiene and sanitation in the incidence of stunting has been consistently reported [39, 40, 41]. The findings in this study indicate that there are three indicators related to personal hygiene and sanitation that are significant to stunting based on the final binary logistic regression model in both urban and rural areas, namely: (1) indicators in urban areas include the habit of washing hands with soap, the availability of complete room functions in the house, and good household waste management; (2) Indicators in rural areas include the habit of washing hands with soap, the availability of food storage places, and the availability of clean water sources for drinking.

This study shows that stunting in children living in urban and rural areas, the risk is about 2 times greater in mothers and children who do not practice the washing hands with soap compared to those who practice washing hands with soap. This is in line with a study conducted by Pradana et al. in 2023 in children under five years of age in Kendal Regency, Central Java, Indonesia, showed that mothers and children who practice poor personal hygiene, especially those who do not practice the habit of washing hands with soap, can increase the risk of stunting in children by 5.76 times compared to mothers and children who practice good personal hygiene. Washing hands with soap can prevent children from exposure to disease. Hands are a part of the human body that has the potential to transfer germs through direct contact, namely between hands or through objects that are held. Hand contact with feces, animal waste, non-sterile human body fluids, or from other sources of exposure, then touching food or drinks without washing hands with soap, can cause food or drinks to be contaminated with germs so that the germs enter the mouth and digestive tract. This condition can cause infections in the digestive system such as diarrhea. Children who suffer from diarrhea experience malabsorption of nutrients. Furthermore, if this condition is experienced frequently and is allowed to continue without being balanced with balanced nutritional intake and not being given proper health care, then the child can experience chronic malnutrition which has an impact on stunting [40].

In this study, the sanitation indicator related to stunting in children living in urban areas is the availability of complete room functions in the house. Stunting is at risk 3.24 times greater in children living in houses with incomplete house functions compared to children living in houses with complete functions, namely the house has a living room, family room, dining room, bedroom, kitchen, bathroom, and children's playroom. Yani et al. explained that the type of house is related to the incidence of stunting [42]. Population density that is not balanced with the availability of land for housing, as well as the high price of houses in urban areas, causes the size and function of space in the house to be limited. This is related to inadequate air circulation, less than optimal lighting, and limiting the movement of children who are growing and developing. Incomplete house space, for example, there is no children's bedroom, children's play area, and other room functions such as living room, family room, dining room, and bedroom, has the potential to cause stress in children which can reduce their immune system and have an impact on their growth and development [39, 42]. This study also found that other sanitation indicators that were significantly related to stunting in children living in urban areas were household waste processing. A study conducted by Anwar et al. in Jepara Regency, Central Java Province showed that stunting was 3.6 times greater in children living in homes with poor household waste management compared to children living in homes with good household waste management. A study conducted by Anwar et al. in Jepara Regency, Central Java Province, Indonesia showed that stunting was 3.6 times greater in children living in homes with poor household waste management compared to children living in homes with good household waste management. Poor household waste management and processing creates an unhealthy environment as a source of diseases, such as diarrhea, typhoid, and other infectious diseases that negatively impact nutrient absorption and child growth [43].

In rural areas, the findings of this study indicate that in addition to the habit of washing hands with soap, other sanitation indicators that are significantly related to stunting are the availability of safe food storage and the availability of clean water sources. Stunting in children is at risk of 2.51 times greater in families who do not have a safe place to store food compared to families who have a safe place to store food. A study conducted by Sanin et al. in 2022 showed something similar, that mothers who have a clean food storage place, the right storage temperature, and are safe from disease-carrying animals such as rats, cockroaches, and flies are more likely to prevent stunting compared to mothers who do not have safe food storage at home. Food storage can be in the form of storing food in a container or store-cooked food using a cover. This is associated with food safety practices, including the handling, preparation, and storage of food materials in ways that prevent foodborne illness [44]. Unhygienic food preparation and unsafe food storage from exposure to contamination by disease-carrying animals can cause gastrointestinal diseases. At the age of growth, the child's immune system is not yet mature, making it susceptible to infection by foodborne pathogens, and can increase the risk of children experiencing infectious diseases such as diarrhea and other similar diseases. This condition is directly related to malabsorption of macro and micronutrients, fluid loss, and decreased appetite. Furthermore, if this condition occurs for a long time, it can cause stunting [44, 45].

The importance of safe drinking water, sanitation, and hygiene (WASH) has been proven to play a role in overcoming global public health problems, including stunting. The results of this study also show that the sanitation indicator that is significantly related to stunting is the availability of clean water sources for drinking. This study shows that stunting in children is 2.17 times more likely to occur in families that do not have enough clean water for all their members compared to families that have sufficient clean water for all their members. In line with a study conducted by Novianti et al. in West Java, Indonesia, which reported that stunting in children is 3.3 times more likely to occur in families who do not have clean drinking water available compared to families who have a source of clean drinking water available [46]. In this study, more than half of the households in rural areas used refilled gallon water, where there is the potential for physical contamination in the form of glass fragments, metal pieces, or plastic, which can enter the water during unhygienic production, processing, or packaging processes. In addition, microbiological contamination such as bacterial growth, namely E. coli and coliform bacteria also have the potential to be found in refilled gallon water. Contaminated drinking water sources can carry various pathogens that can cause diarrheal diseases including campylobacteriosis, giardiasis, gastroenteritis, amoebiasis, and cholera. These diseases can increase the risk of stunting in children because they cause malabsorption of macro and micro nutrients that interfere with their growth and development [41, 46].

Another advantage of this application is that it is Android-based, so it can be accessed easily, practically, and quickly via smartphones to detect stunting risk. Therefore, this application can reach a broader population in society more rapidly. Given its advantages and benefits, this application can be used widely by the government through data integration and synchronization with applications it has built to optimize primary health services in the future. Moreover, its stunting risk detection can form the basis for making appropriate and fast decisions in early stunting prevention to contribute to reducing stunting prevalence.

In addition to its good accuracy in predicting stunting, this stunting risk detection application is Android-based. Many people use Android-based applications as their primary choice to obtain information via the internet [47]. Most of the global population (around 80%) has access to smartphones, with the proportion of internet users reaching almost 60% of the global population in 2021 [48]. In addition, over 90% of mobile device users regularly access the internet [49]. In Indonesia, data from the Central Statistics Agency shows that the proportion of households that owned/used smartphones by province and regional classification in 2023 was 91.61%, with a higher proportion in urban (93.77%) and rural (88.58%) areas. Therefore, almost all households have/use smartphones, so most of the population could potentially use this application [50].

Consequently, applications provide an opportunity to identify health problems and provide widespread health services in both urban and rural communities easily and quickly [51]. Android-based applications are a form of adaptive and innovative technology that is very much needed to facilitate data collection, recommend interventions, implement stunting prevention and management programs, monitor and evaluate, and adopt and improve appropriate and responsive health policies to address stunting problems in the community [23].

Previous studies have developed applications to predict stunting in several countries, with varying accuracies [14, 15, 16]. However, studies reporting on android applications for early detection of stunting risk based on nutritional and sanitation indicators are still limited. In general, applications that have been developed use nutritional indicators, namely by measuring children's anthropometry. In 2014, Hasegawa et al. examined 264 mother-child pairs in Southern Province, Zambia, to develop a tool to detect malnutrition. They reported that the predictors of malnutrition in children aged < 2 years included birth weight, feeding status, history of sibling death, twin births, and maternal education level. Their tool's sensitivity and specificity were reported as 96% and 69%, respectively [14]. While this malnutrition screening tool had high sensitivity, its specificity was lower. Some of the predictors of stunting risk were identified in both their study and ours, such as birth weight and complementary feeding history. In 2019, Hanieh et al. examined stunting prediction models but did not design an application to detect stunting. Their study in Northern Vietnam's Hanam Province reported an accuracy of 85% (95% CI = 0.80–0.90) for the prediction model [16].

In 2022, Elisanti et al. used anthropometric measurements to predict stunting in children (age, height, and weight). The measurement data is displayed on a liquid crystal display and smartphone. In addition, the Arduino microcontroller, which has input/output pins, was used to send the anthropometric measurements via the circuit and serial communication using Bluetooth. Therefore, the data can be presented on a smartphone and easily used by cadres or health workers to help detect stunting in real time [22].

In 2023, Nurisna et al. assessed the effectiveness of an Android-based application (Nosting) to detect stunting for early and screen growth and development in children aged 1–2 years. This application detection the risk of stunting based on *z*-score measurements and exhibited an effectiveness rate of 89.0% in detecting stunting [23]. Also in 2023, Ndagijimana et al. analyzed stunting prediction models for children aged < 5 years in Rwanda, showing that the model could classify stunting cases correctly, identify stunted children accurately, and categorize non-stunted children correctly, with a sensitivity of 79.3%, specificity of 94.4%, and AUC of 0.89. They identified strong predictors of stunting, including the mother's height, watching television, child's age, province, mother's education, birth weight, and childbirth size [15]. In 2024, Muflihatin et al. developed a smart application system called The Early Detection of Stunting (EDOS) based on anthropometric standards to help cadres and the community detect stunting in Kemuning Lor Village, Jember, East Java Province [24]. However, they did not report the accuracy of the EDOS application.

Compared to those developed in previous studies, the stunting risk detection application developed in this study demonstrated more balanced sensitivity and specificity. Moreover, the previous applications did not include personal hygiene and sanitation indicators in stunting risk detection. In reality, stunting occurs due to multiple contributing factors, not only related to maternal and child health and nutrition but also to personal hygiene and sanitation.

Health workers require adaptive and innovative technology to facilitate community involvement and establish partnerships between government and non-government agencies. This technology could be inter-connected, where technologies used by families are connected to technologies used by society and the government. Social interactions are established harmoniously to help prevent and manage stunting in an integrated manner [52, 53]. Stunting must be detected early to establish appropriate prevention and intervention measures to address its causes. These results can be linked to specific and sensitive integrated interventions. Stunting can be prevented through specific nutrition interventions. Specific interventions aim to address the causes of stunting related to healthcare, such as food intake, infection prevention, maternal nutrition status, infectious diseases, and environmental health. In contrast, sensitive interventions aim to address causes generally outside of healthcare, such as drinking water and sanitation, nutrition and health services, increasing awareness of care and nutrition, and increasing access to nutritious food [54]. Prevention during this period is a systematic effort and intervention according to its life cycle, starting from pregnancy through birth, childhood, adolescence, and early adulthood, namely the pre-conception period of stunting to break the stunting cycle [55].

The use of nutritional and sanitation indicator-based applications from this study can encourage practical handling of stunting, namely through the use of this application in an integrated manner with maternal and child health service applications in government-owned primary health facilities. This study has an impact on national policy, namely in line with the government's program to increase the digitalization of health services. This application can be integrated with the health service system at the health center. Furthermore, this application can be integrated with the national health information system to facilitate early detection of stunting risk. The use of this application is in line with the national strategy in accelerating stunting prevention, especially for strengthening national nutritional surveillance, namely accelerating the process of collecting and analyzing stunting data, allowing for faster and more targeted interventions. In addition, this application also supports efforts to accelerate stunting control effectively, convergent, and integrated by involving cross-sectors at the central, regional, community, and household levels. In a broader context, this study contributes to global efforts to achieve the Sustainable Development Goals (SDGs), especially Goals 2 (Zero Hunger) and 3 (Good Health and Well-Being). By increasing early detection of stunting, this application supports efforts to reduce malnutrition and improve children's health.

Conclusions

The application developed in our study exhibited good accuracy in detecting the risk of stunting in children aged < 5 years in urban and rural areas. The involvement of health workers in collecting anthropometric data and assisting mothers in entering data accurately in the application is needed to ensure accuracy in detecting the risk of stunting in children. Of the 25 indicators examined, eight were significant predictors of stunting in urban and rural areas. Three of these indicators were common to both areas: mother's height, frequency of protein consumption, and washing hands with soap. Mother's height was the dominant factor influencing the risk of stunting in children in both urban and rural areas.

The application developed in this study still had some limitations, such as the relatively large number of assessment indicators and its lack of customization to urban and rural areas. In addition, access to this application is limited to mothers with an Android smartphone. Therefore, short-term improvements to the application are needed, such as reducing the number of assessment indicators and adjusting them to urban and rural areas, adding more attractive features, and adding features for education services. Notably, as part of its future development, this application could be integrated with health services to help community nutrition surveillance and detect the risk of stunting quickly, preventively, and accurately. In addition, this application could be an interactive educational media as a promotive and preventive effort to prevent stunting.

Recommendations

This application is an innovation to detect the risk of stunting based on nutrition and sanitation indicators in children under five years of age. This application is designed for sustainable use, taking advantage of the widespread use of smartphones in the community. However, this application requires improvements for both short-term and long-term optimization. In the short term, several things that are recommended for improvement are: (1) simplifying indicators, adjusting indicators to suit the unique characteristics of urban and rural communities; (2) improving the user interface display, improving the application display to make it more attractive, and increasing the functionality of health service features; and (3) data entry assistance, providing assistance from health workers when entering data into the application, namely when measuring and inputting anthropometric data to make it more accurate. In the event of an emergency, mothers are expected to be able to input data from the last anthropometric measurement results, which are then validated by health workers. Meanwhile, for long-term use, this application must be integrated into comprehensive health services involving various sectors—government, local government, and households—to effectively monitor community nutrition and identify and address stunting risks efficiently.

This application is recommended to continue to be used because of several advantages, namely (1) for the government or policymakers: (a) this application comprehensively assesses important indicators for detecting stunting, including indicators related to mothers and child characteristics, nutrition indicators, and personal hygiene and sanitation. This comprehensive approach supports specific and sensitive interventions, and (b) this application provides accurate, practical, and rapid stunting detection for use by health workers so that it can function as an early warning system for nutritional surveillance in the community. However, this application is recommended to be integrated into the maternal and child health service application at primary health facilities so that one-stop or integrated services can be provided, and; (2) for the community, this application can be easily accessed and provides information related to the risk of stunting in children, as well as providing educational services related to the prevention and handling of stunting so that they can increase their knowledge and concern for the health of their children. Overall, this study can make a significant contribution to stunting prevention efforts and influence public health policies, especially government initiatives that aim to reduce the prevalence of stunting by 14% in Indonesia.

Limitations of the study

The application used to detect the risk of stunting still requires further development. Its relatively large number of indicators needs to be reduced, focusing on essential indicators to predict stunting. While the indicators used in our study are relatively essential, they are not yet practical for detecting stunting in the community because the number is quite large, so it takes longer to enter the data into the application. Therefore, focusing on essential indicators to predict stunting in urban and rural areas, which each had eight essential indicators, could simplify and accelerate data entry into the application by mothers or help improve health services in health facilities.

This study also has limitations, namely that the application can only be accessed by mothers with Android smartphones. This requirement may exclude mothers from low socioeconomic backgrounds who may not have access to this technology. Therefore, the use of this application by a broader population could be achieved gradually by considering its affordability. While nationally, more than 90% of households in urban and rural areas in Indonesia own and can use a smartphone properly, the widespread use of this application in the community is still challenging, especially in disseminating the benefits of using its use to detect and prevent stunting early.

Another limitation of this study is the geographical limitation because the number of mothers who own and are skilled at using smartphones in urban areas is greater than in rural areas. In addition, the availability of internet providers and their access is better in urban areas than in rural areas, so the application process is easier in urban areas. Therefore, our study also had disproportionate representation among its participants, where more children were from the urban than the rural area, so it does not reflect the diversity of experiences and conditions faced by children in both areas with different characteristics. In this study, there is a potential bias in the sampling method, as the sample may not accurately represent the overall population. Specifically, the number of respondents from rural areas is only one-third of those from urban areas. However, this potential bias is mitigated by calculating a minimum sample size that is representative of the population, based on established scientific methods and the results of previous studies. Additionally, the research locations for each region are consistent, with three health centers selected in each area. The sampling is conducted using simple random sampling, ensuring that each respondent has an equal opportunity to be selected or not selected as part of the study. Therefore, further research should be able to balance the number of respondents from urban and rural areas and represent the sociodemographic characteristics of the population from both regions. In addition, it is also necessary to examine the variation in stunting risk factors in various regions in Indonesia, where socio-economic conditions, cultural practices, and access to health services can vary greatly.

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Author contributions

TAEP: have study ideas, draft, and design research, perform statistical analysis and interpretation of results, and draft a manuscript. The author reviewed and approved the manuscript. YCH: compiling and designing the study, performing statistical analysis and interpretation of the results, and preparing the manuscript. The author reviews and approves the manuscript. ERN: drafting and designing the study, conducting statistical analysis and interpretation of results, drafting a manuscript. The author reviewed and approved the manuscript. ANS: compiling and designing research, performing statistical analysis and interpretation of the results, and preparing the manuscript. The author reviews and approves the manuscript. DAF: compiling and designing the study, performing statistical analysis and interpretation of the results, and preparing the manuscript. The author reviews and approves the manuscript.

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Data availability
The data sets used and/or analyzed in this study are currently available from the concerned authors on a reasonable request.

Declarations

Ethics approval and consent to participate
This research has been approved by The Ethics Commission of Health Research of the Faculty of Medicine and Health Universitas Muhammadiyah Jakarta (approval number: 90/PE/KE/FKK-UMJ/VI/2023, approval date: 5 June 2023). Data collection was carried out by the main researcher and assisted by enumerators (students of the Faculty of Medicine and Health Universitas Muhammadiyah Jakarta). In this study, the author confirms that all methods are carried out following the relevant guidelines and regulations (Helsinki Declaration). This research is not experimental or intervention research.

Consent for publication
Not applicable.

Informed consent
was obtained from all individual participants included in this study. Participants were fully informed about the purpose, procedures, and potential risks of the research before they consented to take part. All participants voluntarily agreed to participate, and their rights to withdraw at any point were respected.

Competing interests
The authors declare no competing interests.

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