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RESEARCH ARTICLE

Menarche and pubertal progression: a cross-sectional analysis of timing and influencing factors in North-Eastern Ghana

Gabriel Ajediwe Alatiah[1,2], Fusta Azupogo[3,4], Ambrose Atosona[5], Frederick Vuvor[1], Matilda Steiner-Asiedu[1] and Inge D. Brouwer[6,7]

[1]Department of Nutrition & Food Science, School of Biological Sciences, College of Basic and Applied Sciences, University of Ghana, Accra, Ghana, [2]Department of Family Health, College of Health, and Well-being, Kintampo, Ghana, [3]Department of Family and Consumer Sciences, Faculty of Agriculture, Food and Consumer Sciences, University for Development Studies, Tamale, Ghana, [4]Institute for Global Nutrition, Department of Nutrition, University of California, Davis, USA, [5]Department of Nutritional Sciences, School of Allied Health Sciences, University for Development Studies, Tamale, Ghana, [6]Division of Human Nutrition, Wageningen University and Research Centre, Stippeneng 4, 6708WE, Wageningen, The Netherlands and [7]International Food Policy Research Institute, Washington DC, USA
Corresponding author: Fusta Azupogo; Email: fazupoko@uds.edu.gh

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Abstract

Menarche and pubertal onset vary across populations but understanding age-at-menarche (AAM) and pubertal growth tempo is limited in low-income settings. Identifying factors influencing pubertal development is vital for creating targeted health and education programmes supporting adolescent girls' well-being. Baseline data (n = 1045) from the Ten2Twenty-Ghana study were analysed to examine menarche attainment, pubertal development, AAM, and the associated factors among girls aged 10-17 years in the Mion district, Ghana. The data collection methods included anthropometry, body composition, haemoglobin status, a qualitative 24-hour dietary recall, a food frequency questionnaire, and a pubertal development score (PDS). Binary logistic and linear regression analyses were used to model odds ratios for menarche attainment and regression coefficients for AAM and PDS. About 19.9% of the girls had experienced menarche, with a mean AAM of 13.4 ± 1.5 years. Among post-menarche girls (n = 205/1045), 12.2% and 15.1% experienced early (AAM < 12 years) and late menarche (AAM < 15 years), respectively. The mean PDS was 1.8 ± 0.7 out of 4. Among the adolescent girls, 36.2% were prepubertal, 17.0% early –pubertal, 18.6% mid-pubertal, 27.9% late pubertal, and less than 1% were in the post-pubertal stage. An increase in fat mass (FM), fat-free mass (FFM), height-for-age-z-score (HAZ), and body mass index-for-age-z-score (BAZ) was observed with puberty progression, but a steep decline in HAZ was noticed for girls in late puberty, increasing again post-puberty. Being older (adjusted odds ratio (AOR) = 2.06, 95% C.I.: 1.83, 2.31), stunted (AOR = 0.20, 95% C.I.: 0.10, 0.40), thin (AOR = 0.30, 95% C.I.: 0.11, 0.80), and overweight/obese (AOR = 7.29, 95% C.I.: 2.60, 20.43) were the significant predictors of menarche attainment. Being older (β = 0.39, $P < 0.0001$), stunted (β = -0.92, P = 0.01), thin (β = 1.25, P = 0.01), and having a literate mother (β = -0.72, P = 0.03) were significantly associated with AMM. A higher HAZ, FM, FFM, age, and Konkomba ethnicity were positively associated with higher PDS. This study highlights the complexity of factors influencing menarche and pubertal development. These insights are essential for developing targeted health and educational programmes that address nutritional and socio-demographic disparities to promote adolescent girls' well-being and healthy pubertal development.

Keywords: Adolescent girls; menarche attainment; age-at-menarche; pubertal development; fat mass; fat-free mass; Ghana

Introduction

Adolescence, the transitional stage from childhood to adulthood, is marked by the onset of puberty (Das *et al.,* 2017). Puberty is a developmental phase during which a child's body undergoes physical, hormonal, and emotional changes, transitioning from childhood to adulthood. This process prepares the body for reproductive capability and is characterized by a series of significant biological changes. In girls, puberty usually begins between the ages of 8 and 13; breast development (thelarche), which typically starts within this age range, is the first sign of puberty in girls (Stang & Story, 2005). Following thelarche, the growth of pubic hair (pubarche) typically occurs, with a growth spurt often peaking around ages 11 to 12 years. However, it is important to recognize that pubarche is primarily driven by rising androgen levels associated with adrenarche, the maturation of the adrenal glands, and the hypothalamic-pituitary-adrenal axis. As a result, pubarche and the growth of other body hair may precede thelarche in some girls. Menarche, the first menstrual period, generally occurs about 2 to 3 years after the onset of breast development (Stang & Story, 2005).

Although evidence is still limited, adolescence is the second window of opportunity for compensatory growth (Prentice *et al.,* 2013; Soekarjo *et al.,* 2014; Thurnham, 2013). Adolescence is an important stage in human growth, although it often receives little attention as compared to the early stages of childhood regarding health issues and nutritional status (Lassi *et al.,* 2017). Adolescent nutrition is critical since inadequate nutrient intake can cause retarded growth as well as impaired development (Salam *et al.,* 2016).

The onset of puberty varies among adolescents due to factors such as genetics, body fat, nutrition and overall health status (Singh, 2016). During this period, there is a rapid growth spurt, especially during stages 2 and 3 of Tanner's pubertal development in the breast; this is accompanied by increased height within 2 years of the start of puberty (Rogol *et al.,* 2000; Singh, 2016). Tanner's stages of pubertal development are used to assess and classify physical development in children and adolescents, ranging from stage 1, which represents prepubertal status, to stage 5, indicating full maturity (post-pubertal) (Carskadon & Acebo, 1993; Petersen *et al.,* 1988; Pompéia *et al.,* 2019). These stages offer a systematic framework for evaluating and discussing the progression of puberty.

Studies indicate that menarche occurs 6 to 12 months following a significant increase in height (Rao *et al.,* 2000; Singh, 2016; Völgyi *et al.,* 2010). This timing highlights the relationship between growth and sexual maturation, wherein attaining a certain height is often associated with physiological changes. Adolescent girls who have completed puberty or have experienced menarche typically exhibit a higher height-for-age-z-score (HAZ), making stunting less likely. The biological mechanism underlying this process involves the interplay of hormonal changes, particularly the increased secretion of growth hormones and sex steroids, such as oestrogen (Kaplowitz, 2008; Rodríguez-Vázquez *et al.,* 2020; Singh *et al.,* 2011). These hormones stimulate growth plate activity in the long bones, leading to accelerated linear growth during puberty. A study by Rogol *et al.* (2000) noted that growth velocity is particularly pronounced during mid-puberty, reflecting the peak of hormonal influence on growth. Consequently, girls who have entered this developmental stage are positioned to achieve greater height before the growth plates close, thus minimizing the risk of stunting.

Menarche is the last major event that marks sexual maturity in adolescent girls. In Ghana, the average age-at-menarche (AAM) is approximately 13 years, varying between 12.5 ± 1.3 years in the Greater Accra region to about 13.7 ± 1.9 years in the Northern region (Ameade & Garti, 2016; Aryeetey *et al.,* 2011). The timing of menarche has been associated with factors such as nutrition, genetics, environmental conditions, family size, socioeconomic status, and level of education (Ameade & Garti, 2016; Goon *et al.,* 2010; Hollins-Martin *et al.,* 2014). It has long been established that adequate protein and micronutrient intake is a key factor contributing to the earlier onset of menarche (Kralj-Cerek, 1956). A study in Ethiopia observed that food-secure girls tended to come

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from smaller families, belonged to higher socioeconomic households, and exhibited a lower average AAM (Belachew *et al.*, 2011).

The age at which menarche occurs is experiencing a notable decline in developed countries, as well as in urban regions of some low- and middle-income countries (LMICs) (WHO, 1995). This trend has been linked to increasing rates of overweight and obesity, characterized by elevated body mass index (BMI) and insulin resistance. Dietary patterns high in saturated fatty acids have also emerged as contributing factors to this phenomenon in women (Hollins-Martin *et al.*, 2014; Karapanou & Papadimitriou, 2010). These lifestyle and nutritional status changes, while influencing menarcheal age, may pose significant long-term health risks, including increased susceptibility to cardiovascular diseases and type-2 diabetes among women (Karapanou & Papadimitriou, 2010; Petersohn *et al.*, 2019). Early menarche, defined as AAM <12 years, is also associated with a higher risk of developing breast cancer. On the other hand, late menarche, defined as AAM >15 years, is associated with osteoporosis, depression, and social anxiety problems (Hollins-Martin *et al.*, 2014; Karapanou & Papadimitriou, 2010).

Girls with optimal nutritional status tend to grow more rapidly and reach menarche earlier than undernourished girls, who experience slower growth and delayed menarche. In Kenya, Leenstra *et al.* (2005) found that adolescent girls with delayed menarche had lower HAZ compared to those who experienced menarche earlier. Similarly, a study in Benue State, Nigeria, reported that girls with earlier menarche had a higher body-index-for-age z-score (BAZ) than those with delayed menarche (Goon *et al.*, 2010). Overall, these findings suggest that adequate nutritional status accelerates pre-menarche growth, whereas delayed menarche is associated with growth retardation (Leenstra *et al.*, 2005). A high-fat mass is also linked to an earlier onset of menarche (Bayat *et al.*, 2012; Goon *et al.*, 2010; Karapanou & Papadimitriou, 2010). These associations illustrate the complex interplay between nutritional status, body composition, and reproductive health outcomes, highlighting the need for further research to understand the interplay.

The current literature suggests that multiple individual and household factors may influence the onset of menarche. However, there is sparse data on pubertal development and AAM among adolescent girls in rural Ghana. Three previous studies addressed this topic, all in urban settings: two in Accra (Aryeetey *et al.*, 2011; Gumanga & Kwame-Aryee, 2012) and one in Tamale (Ameade & Garti, 2016). This study is the first to examine pubertal development, menarche attainment, AAM, and associated factors among adolescent girls in a rural setting in northern Ghana. In this study, '*menarche attainment*' denotes the occurrence of a girl's first menstrual period, used to indicate pre- or post-menarche status. AAM refers to the age, in years and months, at which menarche occurred, as self-reported by participants.

Methods

Study design and setting

Baseline data from the Ten2Twenty-Ghana study were analysed. The study design, setting, and population have been described in detail elsewhere (Azupogo *et al.*, 2021). In brief, Ten2Twenty-Ghana was a randomized controlled trial that evaluated the efficacy of multiple-micronutrient fortified biscuits compared to unfortified biscuits on the micronutrient status of adolescent girls aged 10–17 years in the Mion District in north-eastern Ghana. Figure 1 shows the map of the district with the study communities. The study began with a large survey ($n = 1057$), which led to the trial ($n = 621$). The survey was conducted in November/December 2018. The research adhered to the guidelines outlined in the Declaration of Helsinki, with all procedures involving human subjects receiving approval from the Navrongo Health Research Centre Institutional Review Board (NHRCIRB323). Written informed consent was obtained from all parents, and assent was provided by the girls after receiving signed/thumb-printed informed consent from guardians/parents.

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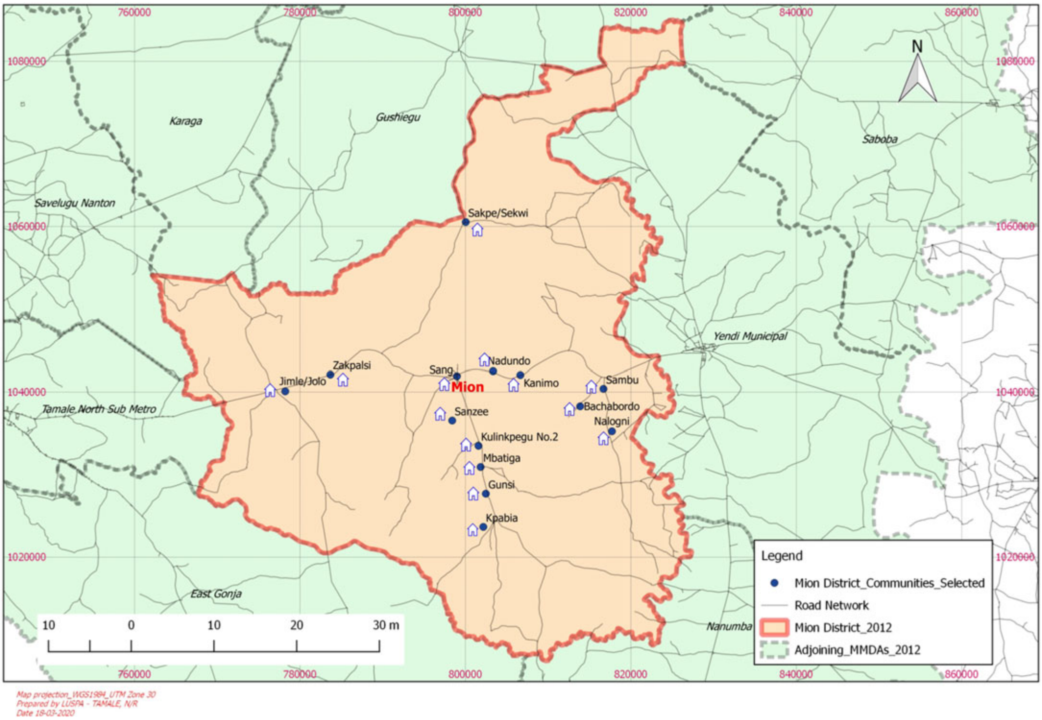

Figure 1. Map of Mion district, Ghana, with the Communities Included in the Ten2Twenty-Ghana study. *Reproduced from* Azupogo *et al.* (2021).

The Mion District has a tropical climate with two distinct seasons: a dry season from November to March and a rainy season from April to October. The district is home to approximately 94,930 people, of whom 89.6% reside in rural communities. Agriculture is the primary livelihood, supporting over 90% of the population. The area is characterized by extended family living arrangements, with large household sizes averaging about 6. The district also has high illiteracy rates, and about 20% of the female population is aged 10 to 19 (Ghana Statistical Service (GSS), 2021; 2014).

Study population and population for analysis

The study participants were adolescent girls aged 10–17 years residing in the Mion district, Northern region, Ghana. The girls were selected from 19 different elementary schools across the district. The sampling included four clusters, of which four schools in the urban district capital were chosen alongside 15 larger rural schools. A 16-item screening questionnaire ensured that all participating adolescent girls were healthy with no apparent signs of poor health, not pregnant, and not lactating at the time of the survey (Azupogo *et al.,* 2021). Adolescent girls with missing data on menarche status ($n = 12$) were excluded from the analysis of factors associated with menarche attainment and pubertal development score. Consequently, the final sample for these analyses included 1,045 girls. Of 208 girls who had attained menarche, three with missing data on AAM were excluded from the analysis of factors associated with AAM (Figure 2).

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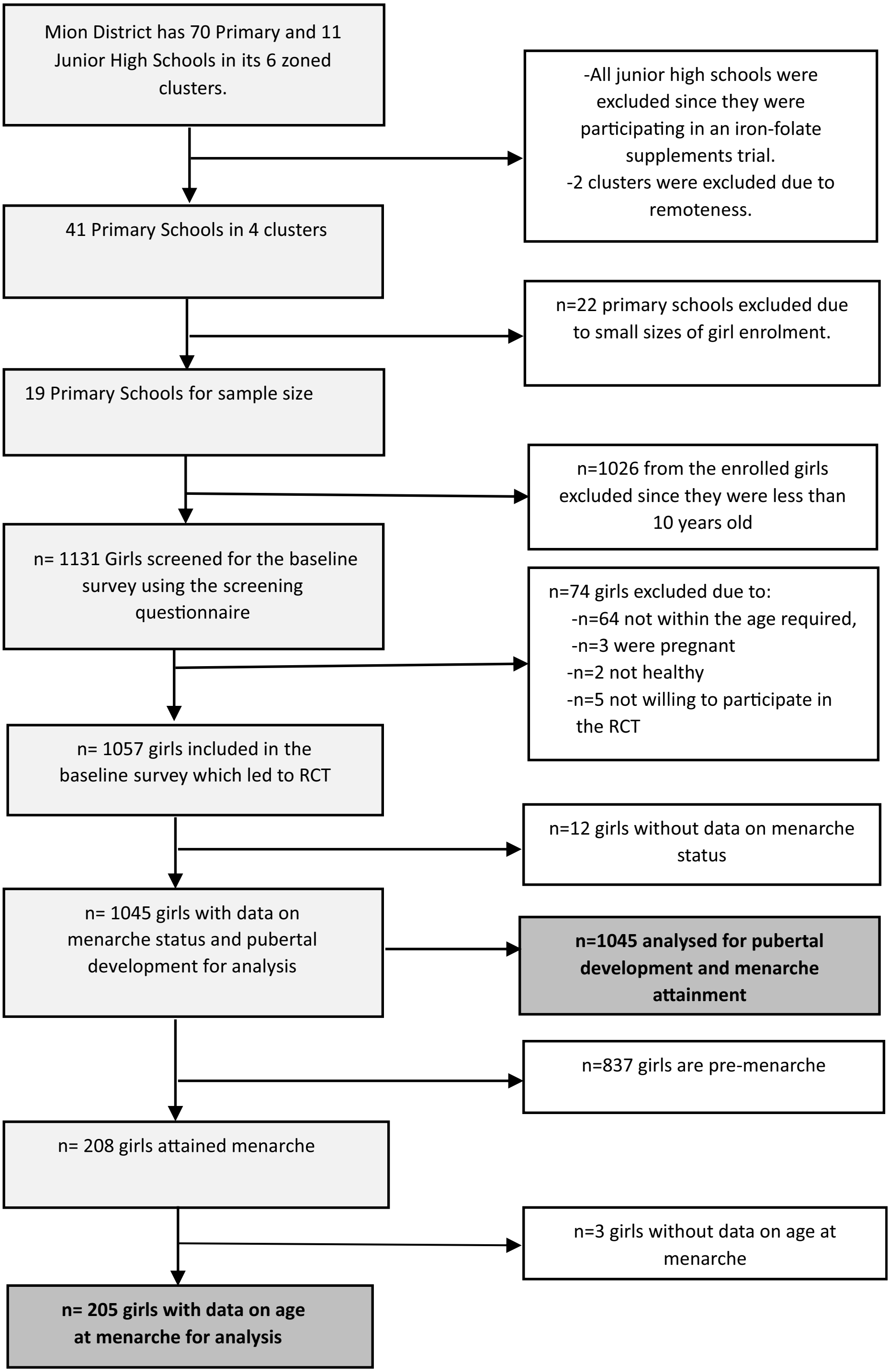

Figure 2. Flow Chart for the Population for Analysis from the Ten2Twenty-Ghana Cross-Sectional Survey.

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Data collection procedure

The data collection methods included one-on-one interviews with a semi-structured questionnaire utilizing validated scales that assessed pubertal development and menarche attainment, anthropometry, body composition assessment, haemoglobin status assessment by finger prick, a qualitative 24-hour dietary recall, and a one-month semi-quantitative food frequency questionnaire. Details of the methods are presented in the subsequent sub-headings. The questionnaire was pre-tested in the neighbouring Yendi Municipality in November 2017. Given questions like menarche were sensitive, interviewers were trained female researchers recruited from the University for Development Studies (UDS). All questionnaires were validated in the field for consistency and completeness by trained Supervisors from the UDS.

Dependent variables

The outcome variables in the present study included menarche status (dichotomous) and continuous variables of AAM and pubertal development score (PDS) of the adolescent girls. The AAM of the girls was assessed using the recall method (Carskadon & Acebo, 1993; Crockett & Petersen, 1987). The girls were initially questioned about whether they had experienced menarche. Girls who had attained menarche were next asked to recall according to the month and year when they experienced menarche or to the nearest whole years of age when they experienced menarche. When the girls had trouble remembering, calendar events such as class and term at school were utilized to help them remember the year and month they reached menarche. Early menarche was defined as AAM <12 years, while late menarche was defined as AAM >15 years (Karapanou & Papadimitriou, 2010). Although the PDS has not been validated specifically in Ghana, it has been widely employed across other LMIC settings. The test-retest Cronbach's alpha test of reliability of the PDS was 0.71, indicating acceptable internal consistency and suggesting its reliability as a measure of pubertal development in the sample.

Pubertal development was also assessed using the 5-item self-reported pubertal development scale questionnaire (Carskadon & Acebo, 1993; Crockett & Petersen, 1987). The pubertal development scale consists of five items: body hair growth, growth spurt, skin changes, breast growth and age at menarche (Crockett & Petersen, 1987). The girls were asked to respond to a 4-point Likert scale; '*not yet started (1 point)*', '*barely started (2 points)*', '*definitely started (3 points)*' or '*seems completed (4 points)*'. Menarche was coded dichotomously, either no (1 point) or yes (4 points). The PDS was computed as the mean score of the 5-stages of puberty and varied from a mean score of 1–4 (Carskadon & Acebo, 1993; Petersen *et al.*, 1988; Pompéia *et al.*, 2019). Pubertal development categories were computed using the scoring algorithms of Crockett and Petersen (Crockett & Petersen, 1987). The algorithm uses 3 physical markers of the Tanner scale: breast development, hair growth and the onset of menarche. The girls were categorized as prepubertal (score of 2 and no menarche); early pubertal (score of 3 and no menarche); mid-pubertal (score >3 and no menarche); late pubertal (score ≤ 7 and menarche) and post-pubertal (score ≥ 8 and menarche) (Carskadon & Acebo, 1993; Rasmussen *et al.*, 2015). Pubertal development was analysed using the mean score of the PDS and pubertal development stage.

Explanatory variables

Anthropometry and body composition

Anthropometric measures of height and weight were measured in duplicates to the nearest 0.1 decimal with the Seca stadiometer and digital weighing scale, respectively, following standard anthropometry guidelines (Cashin & Oot, 2018). The average of the duplicate measures was used in the analysis. HAZ and BAZ were then computed using the WHO AnthroPlus software with the WHO growth reference for 10-19-year-old adolescent girls. The WHO reference data is preferred to the United States Centre for Disease Control reference data when computing z-scores for the nutritional status of children and adolescents in Ghana due to its applicability to LMICs and the inclusion of relevant local data. WHO references are globally recognized and widely used for assessing the nutritional status of children and adolescents. This is critical for international comparisons. Stunting was defined as HAZ < -2SD, whereas BAZ was categorized as thinness (BAZ < -2SD), normal BAZ (-2SD ≤BAZ ≤ +1SD), overweight (+1SD < BAZ ≤+2SD) and obesity (BAZ > +2SD) (Onis *et al.*, 2007). Overweight and obesity were combined in this study based on the prevalence of overweight and obesity.

Bio-electric impedance using the Bodygram Plus Analyser (Akern, Germany) (AKERN, 2014) was used to assess the body composition of the girls. Measurements of body composition, precisely to the nearest 0.1 decimal, encompassed fat mass (FM) and fat-free mass (FFM) in kilograms, along with muscle mass, skeletal muscle mass, body cell mass in kilograms, and total body water, extra-cellular water, and intracellular water in litres. In the present study, only the FM and FFM of the girls were used. Anthropometric measurements were taken by a two-person team, which included a trained research assistant, and a supervisor experienced in anthropometry. For accuracy, if the height or weight measurements differed by more than 2 cm or 0.2 kg, a third measurement was taken, and the two closest values were retained. All measurements of anthropometry and body composition were conducted at a central location within each selected village/school. All research assistants and supervisors underwent two weeks of training, including five days focused on anthropometric and body composition assessments

Haemoglobin status of the girl

Experienced phlebotomists from the Tamale Teaching Hospital assessed haemoglobin status (Hb) by finger prick using a HemoCue 301 (Angelholm, Sweden; 0.1g/dL accuracy). The photometer was calibrated using certified quality control samples from the CDC/Atlanta, and measurements for 10 girls were repeated daily for quality control. Anaemia was defined as Hb<12 g/dL for girls aged 12 years and above and Hb<11.5 for girls aged < 12 years (WHO, 2011).

Dietary intake-related data

A qualitative 1-month semi-quantitative food frequency questionnaire (1-month FFQ), which utilized a 10-food group indicator (FAO, 2016), was used to assess the dietary patterns of the girls. The girls' dietary diversity score (DDS) was also evaluated using a single qualitative 24-hour dietary recall (24-HR) utilizing the 10-food group indicator. In the 24-HR, the girl was requested to list all foods, drinks, and snacks she ate the day before, both inside and outside of the home (including at school), in the last 24 hours (from wake-up to wake-up). Then, she was probed to list the components of any mixed dishes. If a girl consumed at least one food item from any food group, she received a score of 1; otherwise, a score of 0 based on a pre-defined table listing all potential food items in the 10 food groups. The scores for all the food groups were then added to provide a summated score, with a maximum score of 10. The ten dietary groups were as follows: grains, white roots, tubers, and plantains; pulses (beans, peas, and lentils); nuts and seeds; dairy; meat, poultry, and fish; eggs; dark green leafy vegetables; other vitamin A-rich fruits and vegetables; other vegetables; and other fruits. A dichotomous variable of the minimum dietary diversity (MDD-W), as recommended by the FAO (FAO, 2016), was also defined as DDS ≥5 or DDS < 5 and explored in the analysis.

Girl-level socio-demographic data

Data on the girls' ethnicity (categorical), religious affiliation (categorical), and age were collected using a household roster. Age was verified through official documentation, including a birth certificate, birth record, health insurance card, or by providing the exact age in years. The household roster was completed through a one-on-one interview with the mother.

Household-level data

The girls' households' food security status was assessed with the 8-item Food Insecurity Experience Scale (FIES) (FAO, 2015). The FIES uses yes/no responses to assess the degree of food insecurity. When the answer is 'yes', the questions are given a score of 1; otherwise, they are given a score of 0. FIES score was computed by summing the scores of the 8 items. The score ranged between 0 and 8, with a higher score denoting a more severe level of food insecurity, whereas a lower score indicated a less severe level of food insecurity. Based on the FIES score, food insecurity categories were defined as food-secure (FIES = 0), mildly food insecure (FIES score 1-3), moderately food insecure (FIES score 4-6), and severely food insecure (FIES score 7-8).

The International Wealth Index (IWI) evaluated the households' socioeconomic status. The IWI, which was developed specifically to evaluate the socioeconomic status of households in LMICs, used data from 97 LMICs and has a score range of 25 to 100 (Smits & Steendijk, 2015). In the IWI, households are ranked based on the household's access to electricity, the type of water and toilet facilities they use, and the type of flooring they have. Durable assets in the IWI include things like a TV, refrigerator, phone, bicycle, car, and household utensils that are either inexpensive (under $40) or expensive (over $250). Based on the IWI score, the households were ranked into wealth quintiles.

The household roster also collected information on parental education (categorized as none, primary, or secondary/higher), occupation (none, farmer, trader/self-employed, or formal employee), and literacy status (binary: literate or non-literate). Using the household roster, ratio variables were computed for household female-to-male, literacy, and dependency ratios, consistent with definitions from the Ghana Statistical Service (Ghana Statistical Service, 2014) and included in the analysis. The dependency ratio was defined as the ratio of the dependent population (individuals aged 0–14 and those 65 and older) to the working-age population (ages 15–64), reflecting the proportion of dependents relative to those of working age. The literacy ratio was calculated as the ratio of literate household members to non-literate members, indicating literacy prevalence within the household and overall educational level. Finally, the female-to-male ratio was expressed as the total number of females to males within the household, providing insights into gender composition. These ratios offered critical insights into household demographic and educational characteristics for the analysis.

Statistical analysis

The statistical software program SAS 9.4 (SAS Institute Inc., Cary, NC.) was used to analyse the data. Continuous variables were presented as means and standard deviations, while categorical descriptive variables were expressed as frequencies and percentages. Data normality was examined visually with the normality histogram curves and Q-Q plots. Multiple variable linear and binary logistic regression analyses were fitted to identify the factors associated with attaining menarche, AAM, and PDS. The outcome variables in the linear regression analysis were the AAM and PDS mean scores, whereas the attainment of menarche was the outcome variable for the binary logistic regression analysis. In the linear regression analysis, the regression coefficient (β), its standard error (S.E) and *P*-value were estimated for each explanatory variable. The odds ratio (95% confidence interval) and *P*-value for the attainment of menarche were estimated in the binary logistic regression analysis. In the regression analyses, bivariate models were first fitted, and all variables with *P*-values $\leq$ 0.25 were then assessed in the multivariable models using a backward regression approach. Variables were retained in all final models if they were statistically associated with the outcome variable at a *P*-value of $\leq$ 0·05. The study's design, focusing on schools, was accounted for by treating the school as a stratum in all analyses, utilizing the *PROC SURVEY* function in SAS (Berglund, 2014). The -2 log-likelihood ratio test, Wald test, and *P*-value were used to evaluate the model fit for the logistic regression, while the R-square and Root MSE were used to evaluate the model fit for the linear regression. Multicollinearity was found between the anthropometric variables of HAZ/stunting, BAZ or its categories (normal BAZ vs thin, overweight/obese) and the body composition variables (FM and FFM) using a tolerance value (TOL) < 0.1 and the variance inflation factor (VIF) <10 in a linear regression step. Since the model fit was best with the anthropometric variables of HAZ and BAZ or nutritional status (stunting status and BAZ category), FM and FFM were removed from the analysis for menarche attainment and AAM (Please see **Tables S4 and S5**). Using a general linear model, trends in nutritional status indices (HAZ and BAZ) and body composition (FM and FFM) were evaluated across pubertal stages. In these models, pubertal development stages were ranked in ascending order from prepubertal to post-pubertal, with each stage assigned a numerical rank from 0 (prepubertal) to 4 (post-pubertal).

Results

Population characteristics

The study population consisted of 1,045 adolescent girls aged 10–17 years, assessed for menarche attainment and pubertal development. Of these, 205 girls who had experienced menarche and provided data on AAM were analysed to identify factors associated with AAM. The mean age of the participants was 12.3 ± 1.6 years (Table 1). Approximately two-thirds of the girls were of Dagomba ethnic origin (63.0%) and practised Islam (64.2%). Only 7.8% of the mothers were literate, and the average household size was 12.1 ± 5.2 members. The household literacy ratio was 0.6 ± 1.0, and the female-to-male ratio was 1.6 ± 1.3. About 19.2% of the girls' households were food-secured, with a little over half (54.6%) moderately or severely food-insecured. The mean DDS was 6.0 ± 1.3 out of a maximum of 10. The adolescent girls consumed fruits and vegetables an average of 11.6 ± 5.8 days and animal-sourced foods 8.5 ± 3.9 days in the last month. On average, they engaged in vigorous physical activity 2.5 ± 2.3 days in the last week. The mean HAZ was -0.9 ± 1.0, with nearly 20.0% of the girls being stunted. The mean BAZ was -0.7 ± 1.0, with 7.6% of the girls classified as thin and only 2.5% being overweight or obese. The mean FM and FFM were 5.9 ± 2.9 kg and 30.4 ± 6.1 kg, respectively. The mean Hb was 11.9 ±1.3 g/dL, and the burden of anaemia among the girls was severe (≥ 40%).

Pubertal development and menarche

The average PDS was 1.8 ± 0.7 out of a maximum score of 4 (Table 2). Approximately 36.2% of the adolescent girls were classified as prepubertal, 17.0% were in the early pubertal stage, and 18.6% were in the mid-pubertal stage. Additionally, 27.9% were in the late pubertal stage, while less than 1.0% were post-pubertal. One-fifth (19.9%) of the girls in the study had attained menarche, with a mean AAM of 13.4 ± 1.5 years. Among those who had reached menarche, 12.2% (n = 25/205) experienced early onset, while 15.1% (n = 31/205) had delayed menarche.

A significant increasing trend in FM (F = 82.0, *P-trend* < 0.0001) and FFM (F = 237.0, *P-trend* < 0.0001) with advancing pubertal stages was observed, as illustrated in Figure 3. Likewise, HAZ (F = 29.1, *P-trend* < 0.0001) and BAZ (F = 17.8, *P-trend* < 0.0001) also increased with pubertal progression, though both slightly declined in the late pubertal stage before consistently increasing again in the post-pubertal phase (Figure 4). The decline in HAZ was more marked than in BAZ during the later stages of puberty.

Table 3 demonstrates that non-stunted girls had significantly higher scores for BAZ (mean difference: 0.64; 95% CI: 0.51, 0.78), FM (mean difference: 1.74; 95% CI: 1.28, 2.21), and FFM (mean difference: 6.92; 95% CI: 5.98, 7.86) compared to stunted peers.

Table 1. Baseline Characteristics of the Population

Characteristics	Frequency(n/N)	Mean ± SD or Percentage
Sample size for analysis		
Sample size for menarche attainment and pubertal development analysis	1045	
Sample size for age-at-menarche (AAM) analysis[1]	205/1045	
Vital and personal characteristics		
Age, yrs.		12.3 ± 1.9
Typical number of days for vigorous physical activity in the last week		2.5 ± 2.3
Religion of girl		
Islam	671/1045	64.2
Christianity	360/1045	34.4
Other	14/1045	1.3
Ethnicity of girl		
Dagomba	658/1045	63.0
Konkomba	370/1045	35.7
Other	17/1045	1.6
Nutritional status		
Height-for-age-z-score (HAZ)		−0.92 ± 0.97
Stunted (HAZ $<$ -2SD)	195 /1045	18.7
Body mass index-for-age-z-score (BAZ)		−0.73 ± 0.97
Body mass index-for-age-z-score category		
Thin (BAZ $<$ -2 SD)	78/1045	7.5
Overweight/obese (BAZ $>$ + 1SD)[2]	25/1045	2.4
Fat mass (kg)		5.9 ± 2.9
Fat-free mass (kg)		30.4 ± 6.1
Haemoglobin, g/dL		11.9 ± 1.3
Anaemia (haemoglobin $<$ 11.5/120 g/L)[3]	432/1045	41.3
Dietary characteristics		
Dietary diversity score		6.0 ± 1.3
Mean frequency of consuming fruits and vegetables in the last month		11.6 ± 5.8
Mean frequency of consuming animal-sourced foods in the last month		8.5 ± 3.9
Household-level factors		
Mother is literate	78/1045	7.8
Dependency ratio[4]		1.2 ± 0.65
Literacy ratio		0.6 ± 0.97
Female/male ratio		1.6 ± 1.3
Household Food Security		
Food security	201/1045	19.2
Mild food insecurity	273/1045	26.2

(*Continued*)

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Table 1. (*Continued*)

Characteristics	Frequency(n/N)	Mean ± SD or Percentage
Moderate-severe food insecurity	571/1045	54.6
Household wealth index		
Quintile 1	187/1045	17.9
Quintile 2	212/1045	20.4
Quintile 3	229/1045	22.0
Quintile 4	212/1045	20.3
Quintile 5	205/1045	19.7

[1]The analysis was limited to only girls who had experienced menarche.
[2]Overweight and obesity were combined because only 4/1045 (0.4%) were obese.
[3]Hb $<$ 11.5 g/dL for girls aged $<$ 12 yrs. and Hb $<$ 12.0g/dL for girls aged $\geq$ 12 yrs. (WHO, 2011).
[4]The ratio of the dependent population (individuals aged 0–14 and those 65 and older) to the working-age population (ages 15–64), reflecting the proportion of dependents relative to those of working age. n, frequency of occureance; N = total sample.

Table 2. The Pubertal Development and Menarche Status of the Adolescent Girls

Pubertal development and menarche	Frequency (n/N)	Mean ± SD or Percentage
Pubertal development score[1]	1045	1.8 ± 0.7
Pubertal development stage		
Prepubertal	378/1045	36.2
Early pubertal	178 /1045	17.0
Mid-pubertal	194/1045	18.6
Late pubertal	292 /1045	27.9
Post-pubertal	3 /1045	0.3
Attained menarche	208/1045	19.9
Age-at-menarche (years) (n = 205)		13.4 ± 1.5
Timing of menarche (n = 205)[1]		
Early	25/205	12.2
Normal	149/205	72.7
Late	31/205	15.1

[1]The timing of menarche refers to whether the onset of menstruation occurred early or late. In this context, early menarche is defined as age at menarche (AAM) less than 12 years, while late menarche is defined as an AAM greater than 15 years. n, frequency of occureance; N = total sample.

Factors associated with the attainment of menarche

In a univariate analysis, significant predictors of menarche attainment included age (odds ratio (OR) = 1.96, 95% confidence interval (C.I.): 1.76, 2.19), HAZ (OR = 1.54, 95% C.I.: 1.36, 1.75), BAZ (OR = 2.43, 95% C.I.: 1.97, 3.01), stunting status (OR = 0.24, 95% C.I.: 0.13, 0.43), BAZ category ($P = 0.001$), FM (OR = 1.59, 95% C.I.: 1.46, 1.73), FFM (OR = 1.32, 95% C.I.: 1.26, 1.38), religion ($P = 0.001$), and ethnicity ($P = 0.001$) (**Table S1**). From the multiple logistic regression (Table 4), only age (adjusted odds ratio (AOR) = 2.06, 95% C.I.:1.83, 2.31), stunting (AOR = 0.20, 95% C.I.: 0.10, 0.40) and the BAZ category ($P < 0.0001$) of the girl remained significantly associated with menarche attainment. In detail, a unit increase in age doubled the

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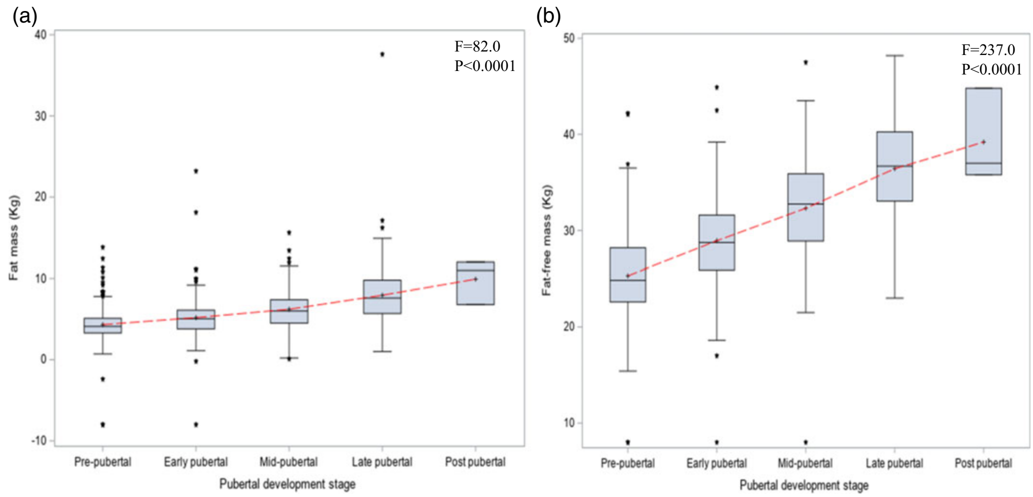

Figure 3. The Trend in Fat Mass (a) and Fat-Free Mass (b) By Pubertal Development Stage Among Adolescent Girls.

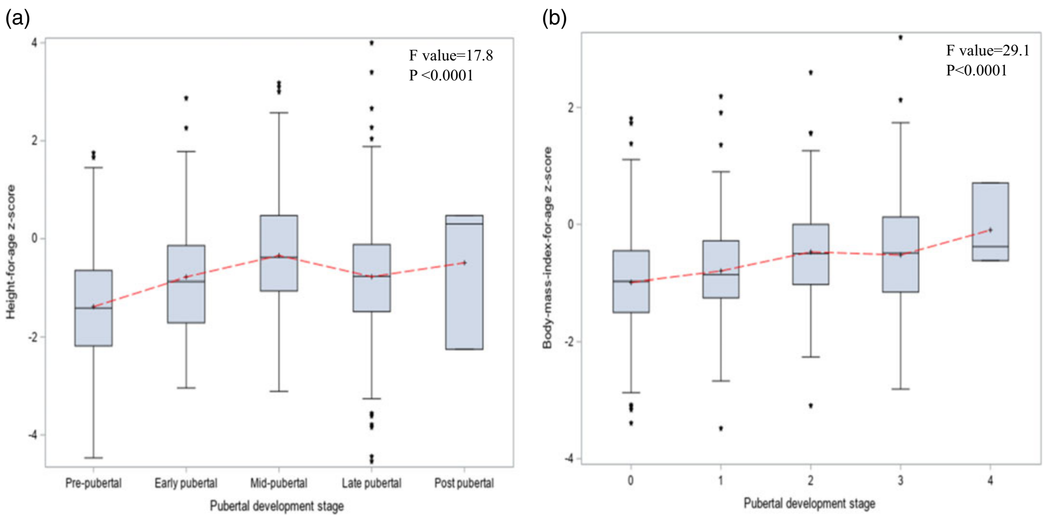

Figure 4. The Trend in Height-for-Age-Z-Score (a) And Body Mass Index-for-Age-Z-Score (b) By Pubertal Development Stage Among Adolescent Girls.

odds of attaining menarche and compared to non-stunted girls, the odds of attaining menarche were reduced by 80.0% for stunted girls. Furthermore, compared to girls with normal nutritional status, thin girls (AOR = 0.30, 95% C.I.: 0.11, 0.80) were 70.0% less likely to have attained menarche while the odds of attaining menarche were more than 7-fold (AOR = 7.29, 95% C.I.: 2.60, 20.43) for girls who were overweight/obese.

Factors associated with age-at-menarche (AAM) and pubertal development

As shown in Table S2, univariate predictors of the PDS included age ($\beta = 0.20 \pm 0.01$; $P < 0.0001$), HAZ ($\beta = 0.13 \pm 0.01$; $P < 0.0001$), stunting ($\beta = -0.33 \pm 0.04$; $P < 0.0001$), BAZ ($\beta = 0.20 \pm 0.02$; $P < 0.0001$), BAZ category (*P-trend* < 0.0001), FM ($\beta = 0.10 \pm 0.01$;

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Table 3. Differences in Body Composition and Body Mass Index for Age by Stunting Status

Variable	Stunted-A (n = 195) Mean (95% C.I)	Non-stunted-B (n = 850) Mean (95% C.I)	Mean difference (B-A)[1] (95% C.I)	P-value
Body mass index-for-age-z-score	−1.3 (−2.6, 0.0)	−0.6 (−1.9, 0.7)	0.64 (0.51, 0.78)	<0.0001
Fat mass (kg)	4.4 (1.9, 8.4)	6.2 (2.6, 11.6)	1.74 (1.28, 2.21)	<0.0001
Fat-free mass (kg)	24.7 (18.5, 32.1)	31.7 (6.4, 42.3)	6.92 (5.98, 7.86)	<0.0001

B = Non-stunted, A = stunted.
[1]Mean difference was estimated with non-stunted as the reference group (B-A)

Table 4. Factors Associated with the Occurrence of Menarche (n = 1045)

Variable	AOR (95 % C.I)	P-value
Age	2.06 (1.83, 2.31)	<0.0001
Stunted		
No (n = 850)	Ref.	
Yes (n = 195)	0.20 (0.10, 0.40)	<0.0001
Body mass index-for-age-z-score category		<0.0001
Normal (n = 942)	Ref.	
Thin (n = 78)	0.30 (0.11, 0.80)	0.016
Overweight/obese (n = 25)	7.29 (2.60, 20.43)	0.0002
Model fit		
F-value of -2 Log L	71.87	<0.0001

AOR = Adjusted odds ratio

$P < 0.0001$), FFM ($\beta = 0.06 \pm 0.02$; $P < 0.0001$), religion ($P < 0.0001$), and ethnicity ($P < 0.0001$). Household factors associated with PDS in the univariate analysis included dependency ratio (β = -0.05 ± 0.02; $P = 0.03$), literacy ratio (β = -0.04 ± 0.02; $P = 0.01$), and household wealth quintile (*P-trend* = 0.02). The univariate analysis also identified several significant predictors of AAM (Table S3), including age ($\beta = 0.38 \pm 0.06$; $P < 0.0001$), stunting (β = -0.70 ± 0.35; P = 0.046), BAZ (β = -0.29 ± 0.12; $P = 0.022$), FFM ($\beta = 0.05 \pm 0.02$; $P = 0.004$), and belonging to an ethnic group other than Dagomba (β = -1.33 ± 0.12; $P < 0.0001$).

The multiple linear regression analysis showed that for every additional increase in the girl's age, the AAM increased significantly by 0.39 (95% C.I.: 0.28, 0.50) years. Further, AAM decreased significantly by -0.92 (95% C.I.: -1.63, -0.20) years for stunted girls compared to non-stunted girls (Table 5). Compared to girls with normal nutritional status, AAM increased significantly by 1.25 (95% C.I.: 0.32, 2.17) years for thin girls. Furthermore, AAM decreased by -0.72 years (95% C.I.: -1.34, -0.06) for girls with literate mothers compared to peers with non-literate mothers.

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Table 5. Factors Associated with Age-at-Menarche and Pubertal Development Score

	Age at menarche[1] (n = 205)			Pubertal development (*n* = 1045)		
Variable	β (95% C.I)	S. E	P-value	β (95% C.I)	S. E	P-value
Age	0.39 (0.28, 0.50)	0.06	<0.0001	0.12 (0.09, 0.15)	0.01	<0.0001
Height-for-age-z-score (HAZ)	N/A			0.05 (0.01, 0.09)	0.02	0.01
Stunted				N/A		
No	Ref.					
Yes	−0.92 (−1.63, −0.20)	0.36	0.01			
Body mass index-for-age-z-score category				N/A		
Normal	Ref.					
Thin	1.25 (0.32, 2.17)	0.47	0.01			
Overweight/obese	0.41(−0.19, 1.01)	0.30	0.18			
Fat mass (Kg)	N/A			0.03 (0.02, 0.04)	0.01	<0.0001
Fat-free mass (Kg)	N/A			0.03 (0.02, 0.04)	0.01	<0.0001
Religion of girl	N/A					0.05
Islam				Ref.		
Christianity				−0.20 (−0.39, −0.02)	0.10	0.04
Other				−0.30 (−0.58, −0.02)	0.14	0.03
Ethnicity of girl	N/A					0.02
Dagomba				Ref.		
Konkomba				0.27 (0.08, 0.46)	0.10	0.01
Other				0.06 (−0.10, 0.22)	0.08	0.48
Mother is literate						
No	Ref.			N/A		
Yes	−0.70 (−1.34, −0.06)	0.32	0.03			
Model fit statistics						
R-square		0.26				0.60
Root MSE		1.38				0.37

[1]Analysis was conducted for only girls who attained menarche and had data for age-at menarche. N/A, not applicable, implying the variable was not selected in the multivariate backward regression.

Table 5 also shows that a unit increase in age and HAZ significantly increased the PDS by 0.12 (95% C.I.: 0.09, 0.15) and 0.05 (95% C.I.: 0.01, 0.09) units, respectively. Every additional increase in the FM (β = 0.03, 95% C.I.: 0.02, 0.04) and FFM (β = 0.03, 95% C.I.: 0.02, 0.04) of the girls also significantly increased the PDS of the girls by 0.03 units each. Compared to practising Islam, being a Christian (β = -0.20, 95% C.I.: -0.39, -0.02) and practising other religions (β = -0.30, 95% C.I.: -0.58, -0.02) decreased the PDS significantly by -0.20 and -0.30 units, respectively. Compared to girls who belonged to the Dagomba ethnic group, the PDS of girls of the Konkoba ethnicity increased significantly by 0.27 (95% C.I.: 0.08, 0.46) units.

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Discussion

The present study examined pubertal development, menarche attainment, and AAM, as well as the factors associated with these, among rural adolescent girls in the Mion District, Northern Ghana. The findings of the present study shed light on the complex interplay of biological, nutritional, and socio-demographic factors influencing menarche and pubertal development among adolescent girls. In the present study, the population was relatively younger, which explains that only one-fifth of the population had attained menarche. Variations in pubertal progression and menarche attainment associated with stunting, thinness, and overweight/obesity emphasize the importance of understanding how different growth patterns affect puberty.

The mean recall AAM in the current study (13.4 ± 1.5 yrs.) was comparable to the study of Ameade and Garti (2016) in Tamale, Ghana (13.7 ± 1.9 yrs.). However, the mean AAM was lower than the AAM (14.0 ± 1.4 yrs.) in the study of Adadevoh *et al.* (1989) in Accra, Ghana, which was the first study to examine the menarcheal age of Ghanaian girls. A recent study in rural Bangladesh by Hur *et al.* (2021) also reported a mean AAM consistent with the present findings. However, the mean AAM observed in this study is lower than the mean AAM of other African countries including Nigeria (15.3 ± 2.1 yrs.) (Tunau *et al.*, 2012) and Ethiopia (14.1 ± 1.4 yrs.) (Gultie *et al.*, 2014), but higher than those of some high-income countries like Canada (12.7 ± 1.1 yrs.) and Britain (12.7 ± 1.5 yrs.) (Morris *et al.*, 2010). Although the present study did not compare the AMM of rural and urban girls, it is reasonable to speculate, based on the present findings and existing studies, that there is no difference between the AMM of girls in rural and urban settings in northern Ghana.

Evidence strongly supports a positive association between a higher BAZ and/or overweight/obesity and early menarche onset (Asrullah *et al.*, 2022; Rodríguez-Vázquez *et al.*, 2020). The observed association between overweight/obesity and menarche attainment likely indicates that increased fat mass acts as a biological trigger for initiating puberty. In fact, each unit increase in FM was associated with a 0.05-year reduction in AAM (95% CI: -0.10, -0.05), suggesting that excess adiposity may accelerate pubertal onset (*results not shown*). However, FM was excluded from the statistical models due to multicollinearity with the nutritional status indices. Overall, these findings highlight the important role of body composition in pubertal timing and suggest the need for further investigation into adiposity-related mechanisms influencing menarche.

In this study, stunting and thinness were inversely associated with menarche attainment, with thinness significantly delaying menarche onset and increasing the AAM by 1.25 years (95% CI: 0.32, 2.17). This finding suggests that undernutrition and poor growth may delay pubertal onset, contributing to physical and psychosocial development disparities. The results align with studies from Bangladesh (Malitha *et al.*, 2020), Iran (Bayat *et al.*, 2012), and Trinidad (Uche-Nwachi *et al.*, 2007), which similarly reported later menarche among girls with lower BAZ. The biological pathway underlying this association likely involves leptin, a hormone strongly correlated with BMI, which links adipose tissue to the gonadal-hypothalamic axis, a critical driver of pubertal onset (Kaplowitz, 2008; Rodríguez-Vázquez *et al.*, 2020; Singh *et al.*, 2011). Supporting evidence from Ethiopia (Yetubie *et al.*, 2010) and Nigeria (Goon *et al.*, 2010) also demonstrates that girls with lower BAZ experience delayed menarche compared to peers with higher BAZ, underscoring the importance of adequate nutrition and growth for timely pubertal development. These findings highlight the need for early nutritional interventions to promote healthy body composition and mitigate delays in pubertal timing associated with undernutrition.

The finding that stunting was inversely associated with AAM is unexpected and contrasts with previous literature, suggesting that stunted girls generally experience delayed menarche, resulting in a higher AAM (Nti *et al.*, 2024; Svefors *et al.*, 2019). This discrepancy may be influenced by psychosocial stress, which has been shown to play a complex role in pubertal timing. Research

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suggests that psychosocial stress can sometimes accelerate puberty, potentially serving as an adaptive response to adverse environments (Ellison *et al.,* 2012). This may indicate that early pubertal onset could coincide with stunted growth in contexts of high stress or adversity, reflecting a trade-off between growth and reproductive timing. However, the mechanisms connecting psychosocial stress to stunting are equally complex. Chronic stress in childhood has been associated with impaired growth, as it may limit nutrient absorption and disrupt hormonal pathways essential for height attainment (Mousikou *et al.,* 2023). The present study indicates that stunted girls have significantly lower FM, FFM, and BAZ compared to non-stunted girls, suggesting that poor nutritional status may limit both body composition and overall growth potential. However, the cross-sectional design precludes establishing causality, making it unclear whether early menarche contributed to stunting or if stunted growth preceded pubertal onset. Longitudinal studies are essential to clarify these relationships and further explore how nutritional status and psychosocial stress interact to influence menarche timing. Insights from such studies could inform public health initiatives targeting malnutrition and stress management to support healthier reproductive development in adolescent girls.

The present study also found that girls with literate mothers had a lower AAM compared to girls with non-literate mothers. The influence of parental education on AAM has been documented in several studies (Belachew *et al.,* 2011; Karapanou & Karapanou, 2010). These studies indicated that girls with literate mothers are more likely to have access to adequate and nutritious meals, leading to better nutritional status, which is associated with an earlier AAM.

The present study found that with each increase in FM and FFM, there was a significant rise in the PDS among the girls. This result is consistent with findings from Kirchengast & and Göstl (2006) and Huang et al. (2023), who also reported a positive association between pubertal progression and both FM and FFM. Biologically, puberty in girls is associated with an increase in body FM due to elevated oestrogen levels (Rogol *et al.,* 2002). Additionally, leptin concentrations, which are typically higher in females during puberty, may further explain the positive association between FM and pubertal development (Horlick *et al.,* 2000). This link between FM and puberty could also account for the significantly higher PDS observed in girls of Konkomba ethnicity compared to those of Dagomba ethnicity in this study. Notably, the mean FFM of Konkomba girls (31.9 ± 0.4 kg) was significantly ($P < 0.0001$) higher than that of Dagomba girls (29.6 ± 0.2 kg). It is worth mentioning that elevated oestrogen levels are also known to promote fat accumulation (Brown & Clegg, 2010).

The observed increase in both FM and FFM with advancing pubertal stages highlights the significant physiological changes that occur during puberty, impacting overall body composition. The more pronounced increase in FFM, typically reflecting muscle and lean tissue growth, underscores the heightened nutritional and energy needs during this critical period of rapid growth and development (Spear, 2002). This observation supports prior studies that highlight puberty as a period of accelerated growth, emphasizing the critical need for adequate nutrition to meet the increased demands of the developing body (Prentice *et al.,* 2013; Soekarjo *et al.,* 2014; Thurnham, 2013). Rogol *et al.* (2000) noted that growth velocity is particularly pronounced during mid-puberty, reflecting the peak of hormonal influence on growth. Consequently, girls who have entered this developmental stage are positioned to achieve greater height before the growth plates fuse, thus minimizing the risk of stunting. It suggests that adolescents may benefit from tailored dietary and physical activity recommendations that address the increased demand for macronutrients and micronutrients essential for muscle and bone development.

The pattern of increasing HAZ and BAZ has previously been reported by Rogol *et al.* (2000). The marginal decline in the late stages of puberty could indicate a biological adjustment in growth rates as individuals approach the genetic potential for height and body size. This is also the period

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during which the growth plates are fusing (Ellison *et al.,* 2012). The steady rise in HAZ and BAZ during the post-puberty stage of development on Tanner's scale suggests a recovery phase, during which individuals may attain adult stature and body composition. The more noticeable decline in HAZ during the late pubertal stage might reflect a variation in the timing of growth spurts among adolescents, potentially influenced by factors such as nutritional status, health conditions, and genetic predispositions. The study of Rogol *et al.* (2000) also reported a peak in height velocity during mid-puberty. This underscores the importance of monitoring growth and nutritional status throughout puberty to identify deviations from expected growth patterns early, allowing timely interventions to support optimal health and development.

The correlation between religion and pubertal PDS found in this study, where Christian and other religious affiliations showed lower PDS compared to Muslim affiliation, suggests a possible influence of socio-cultural factors on pubertal timing. This finding may partly be due to the higher mean weight recorded among girls who were Christians or belonged to other religions compared to those who practised Islamic religion (37.9 ± 8.7 and 36.3 ± 9.2 vs 35.5 ± 8.2 kg, respectively; *results not shown*).

A key strength of this study was the use of a multistage sampling procedure, which minimized selection bias and ensured a representative sample. Additionally, conducting interviews in the girls' native language facilitated clearer and more accurate responses. Given the sensitive nature of questions about pubertal development, female interviewers were employed to create a more comfortable setting for participants. The study also collected a wide range of data, including individual demographics, household socioeconomic factors, and several potential covariates related to AAM and pubertal development, allowing for a thorough analysis of factors influencing pubertal timing.

Despite the strengths, some limitations should be considered. The cross-sectional study design used was a limitation as a causal relationship could not be established. Also, recall bias was likely as dietary intake and especially AAM of participants were self-reported and based on recall. However, calendar events, such as class and term at school when the girl experienced menarche, were utilized to help them remember the year and month they reached menarche. Because most of the girls had not yet reached menarche, the sample size for the factors associated with the AAM group was quite small. It would have been more appropriate to collect data from girls in junior high schools as most may have already experienced menarche. However, this was not feasible for the Ten2Twenty-Ghana research project since UNICEF was running an iron supplementation programme for female junior high school students in Northern Ghana at the time of the present study. Nevertheless, considering that girl child school enrolment rates in Ghana are about 84.4% (Ghana Ministry of Education, 2022), the selected study population likely represents the broader demographic of adolescent girls in the Mion district of Ghana and comparable contexts.

Conclusion

In conclusion, this study provides valuable insights into the factors influencing AAM and pubertal development among adolescent girls in a low-income context. The mean AAM was 13.4 ±1.5 years, with early and late menarche occurring in 12.2% and 15.1% of post-menarche girls, respectively. The findings highlight that body composition, nutritional status, and socio-demographic factors, such as ethnicity and maternal literacy, significantly influence the timing and progression of puberty. Specifically, increased FM, FFM, and BAZ were associated with advancing pubertal stages, while stunting and thinness delayed menarche. The strong associations between these variables and pubertal milestones underscore the role of nutrition and growth in shaping adolescent development. The findings suggest a need for public health interventions targeting nutritional and socioeconomic disparities to promote healthy development. Early-life nutrition programmes could improve adolescent health and reproductive outcomes. Longitudinal studies are recommended to clarify the links between growth, body composition, pubertal timing, and socio-cultural factors across populations.

Supplementary material. For supplementary material accompanying this paper visit https://doi.org/10.1017/S0021932025000021

Data availability statement. All relevant data and supporting information files are included in the paper. The datasets analysed are available from the corresponding author upon reasonable request.

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Author contribution. Conceived and designed the study: FA and IDB. The data were collected by FA, AA, and IDB. GAA and FA did the statistical analysis; wrote the first draft of the manuscript: GAA, FA, and AA. Contributed to the writing of the manuscript: FV, MSA, and IDB. All authors approved of the final content.

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Competing interests. There are no conflicts of interest declared by the authors.

Ethical standard. The study protocol was approved by the Navrongo Health Research Centre Institutional Review Board (NHRCIRB323). Parents and guardians provided signed/thumb-printed informed consent for the girl child to participate in the study. Assent was also provided by the girls before participating in the study.

Abbreviations. AAM: Age-at-menarche
FM: Fat mass
FFM: Fat-free mass
PDS: Pubertal development scale
HAZ: Height-for-age-z-score
BAZ: Body mass index-for-age-z-score
BMI: Body mass index
FIES: Food insecurity access scale
DDS: Dietary diversity score
MDD-W: Minimum dietary diversity score
LMICs: Low- and middle-income countries
Hb: Haemoglobin
IWI: International Wealth Index

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