



Predictors of Iron Supplement Adherence and Hemoglobin Levels Among Adolescent Girls in Bali: A PLS-SEM Analysis

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ABSTRACT

Introduction: Anemia among adolescent girls remains a global public health concern. Adolescence is a critical window of rapid growth and increased iron requirements. The World Health Organization recognizes adolescent anemia as a priority. Although weekly iron supplementation programs have been widely implemented, adherence remains suboptimal. Previous studies have primarily identified associated factors using bivariate or conventional regression approaches, with limited application of multivariate pathway modelling to simultaneously examine determinants of adherence and hemoglobin outcomes. This study aimed to examine predictors of iron tablet adherence and their association with hemoglobin levels among adolescent girls using Partial Least Squares Structural Equation Modeling (PLS-SEM) approach.

Methods: A quantitative study with a pretest–posttest one-group design without a control group was conducted. Data were collected using validated questionnaires from adolescent girls ($n = 772$), of whom 483 participated in final analysis attending schools in Bali, Indonesia, between August and November 2024. Statistical analyses and PLS-SEM were performed to identify key predictors of adherence and hemoglobin levels.

Results: A total of 483 adolescent girls participated in the study (response rate: 62.6%). The structural model explained 4.6% of the variance in iron tablet adherence ($R^2 = 0.046$) and 38.4% of the variance in hemoglobin levels ($R^2 = 0.384$). Family support ($\beta = 0.051$; $p = 0.041$), school support ($\beta = 0.131$; $p = 0.011$), and attitude ($\beta = -0.071$; $p = 0.003$) significantly predicted adherence. In turn, adherence showed a positive association with hemoglobin levels ($\beta = 0.570$; $p < 0.000$).

Conclusion: Family support, school support, and attitude were significantly associated with iron supplement adherence among adolescent girls. Although the explanatory power of the model for adherence was modest, adherence was positively associated with hemoglobin levels at post-test measurement. These findings should be interpreted as exploratory and hypothesis-generating. Multifactorial strategies that strengthen social support and sustained monitoring may enhance the effectiveness of anemia prevention programs among adolescent girls.

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INTRODUCTION

Anemia remains one of the major global health concerns, particularly among children and adolescents. The World Health Organization (WHO) estimates that approximately two billion people worldwide suffer from anemia. Among these, 47.4% are preschool-aged children under five years old, 41.8% are pregnant women, and 25.4% are school-aged children, most of whom are adolescents. Iron deficiency stands as the predominant underlying cause across these populations (1,2). In Southeast Asia, where prevalence of anemia is still high. Prevalence among preschool-children reaches 65.5% and among pregnant women 48.2%. Among adolescents, prevalence rates vary considerably, from 17% to 90%, reflecting substantial differences across countries and population studied (2).

Indonesia country as one of the Southeast Asia, mirrors this regional pattern. National data from Indonesian Basic Health Research (Riskesdas) indicate a striking rise in adolescent anemia prevalence from 6.9% in 2007 to 32% in 2018, representing a 25.1 percentage point increase over ten years and signaling a deteriorating trajectory in adolescent nutritional health (3–5). Among adolescent girls specifically, several national studies report prevalence estimates between 32.4% and 61.0% (6). Higher risk of anemia is observed among adolescent girls compared to boys, primarily due to iron losses resulting from menstruation. This sex-based disparity with anemia affecting 22.7% of adolescent girls compared to 12.4% of boys (5,6).

The consequences of untreated anemia are wide-ranging. Anemia may cause affected individuals like experience fatigue, impaired concentration, cognitive difficulties, and weakened immunity. Chronically, anemia undermines work productivity, physical development, and reproductive health outcomes, contributing to low birth weight, preterm delivery, stunted infant growth, and elevated maternal and infant mortality (2,6–10). Recognizing this burden, the Indonesian government established a weekly iron and folic acid (IFA) supplementation program for adolescent girls and women of reproductive age (6).

In this program, each participant is intended to receive 52 tablets annually, one per week, with each tablet containing a minimum of 60 mg elemental iron and 400 mcg folic acid (6). This intervention aims to reduce anemia prevalence and improve nutritional status. Result of program, distribution coverage has reached 50%, exceeding the program target (>30%) (11,12). Although distribution is relatively high, yet coverage alone has not been effective supplementation. Fewer than 2% of adolescent girls take the tablets consistently each week, with most falling far short of the annual recommended dose (5).

This disparity between coverage and adherence points to a deeper implementation challenge. The adherence is shaped by a constellation of factors, including individual characteristics, knowledge, attitudes, drug-related factors such as organoleptic properties and side effects, and social influences including support from family, peers, and schools. Several studies suggest that respondent adherence to medication is significant linked to their level of knowledge and attitudes (13–17). While existing studies have documented associations between these variables and adherence, most have done so through bivariate or regression-based methods that treat each predictor independently. Few have attempted to model these determinants as an interconnected system, leaving the simultaneous direct and indirect pathways through which they influence adherence and hemoglobin levels largely uncharted. To address this gap, the present study applies Partial Least Square Structural Equation Modeling (PLS-SEM) through a structured pathway-based analytical framework that models interconnected influences rather than isolated associations.

The PLS-SEM approach offers the potential to analyze relationships among multiple contributing factors influencing both adherence and hemoglobin levels (18–20). By integrating individual, knowledge, attitude, drug-related factors and social factors into a unified pathway model, this study aims to provide a more comprehensive understanding of what drives iron supplementation adherence and its effect on hemoglobin levels among adolescent girls in Bali, Indonesia.

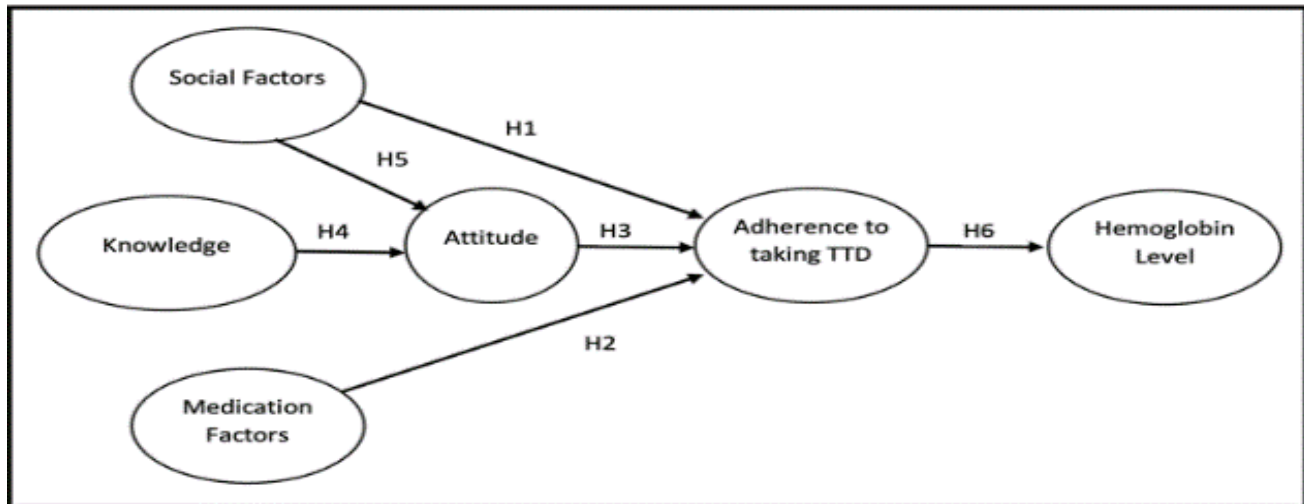
METHOD

Research Type

This study used a quantitative method with a one group pretest posttest design without control group to assess the impact of an educational intervention on adherence to iron supplement intake among adolescent girls. This design allows researchers to measure changes before and after the intervention, as well as to model the relationships between variables such as knowledge, attitude, drug-related factors (organoleptic properties and side effects), and social factors (support from family, school, and peers) that may influence adherence. The relationship between adherence and hemoglobin levels was analyzed using PLS-SEM to identify potential predictors.

The research hypotheses are as follows:

- H1:** Social factors influence adherence to iron supplement intake.
- H2:** Drug-related factors influence adherence to iron supplement intake.
- H3:** Attitude influences adherence to iron supplement intake.
- H4:** Knowledge affects adherence through attitude as a mediating variable.
- H5:** Social factors affect adherence through attitude as a mediating variable.
- H6:** Adherence influences hemoglobin levels.



Pic 1. Hypothesis

Population and Sample/Informants

The study population comprised 772 adolescent girls from four junior and senior high schools in the Bali region. Respondents were selected using a total sampling technique, whereby all adolescent girls meeting the inclusion criteria were enrolled. Inclusion criteria required active participation in school learning activities and receipt of iron supplement distribution. Exclusion criteria included lack of consent or withdrawal during the research process. For participations absent during data collection, contact was attempted through the homeroom teacher, with a maximum of three attempts. If there was no response or willingness to participate, the individual was excluded. No formal comparison was conducted between respondents and non-respondents, thus the potential for selection or non-response bias remains. Differences in motivation, health awareness, or absenteeism patterns between included and excluded participants may have affected the representativeness of the findings. Data collection commenced after obtaining permission from the school principal. All eligible students were assembled in a single room, where the researcher provided a detailed explanation of the research activities.

Research Location

This study was conducted in several schools in Bali, targeting adolescent girls.

Instrumentation

Data collection in this study employed a structured questionnaire that had undergone face validity testing by two expert panelists with experience and backgrounds in clinical and community pharmacy. The results of the validity test indicated that each statement or question in the questionnaire was comprehensible and easy for the respondents to understand. The questionnaire contents included:

Characteristics of adolescent girls, including age and parental income.

Knowledge regarding anemia and iron supplementation (20 items with yes/no answers using the Guttman scale).

Attitudes toward iron supplementation consumption (16 statements using a Likert scale: strongly agree, agree, disagree, strongly disagree).

Drug-related factors of iron supplementation (2 items: side effects such as nausea, vomiting, stomachache, diarrhea, constipation, black stool; and organoleptic properties such as taste, color, odor and all with yes/no options)

Social support from family, school, and peers. Family support (13 items using a Likert scale: always, often, sometimes, never); school support (10 items with yes/no responses); peer support (5 items with yes/no responses).

Adherence to iron supplementation (a question regarding the number of iron tablets consumed by the respondent in the past three months).

Hemoglobin levels were measured post-intervention using a hemoglobin testing device based on the reflective photometric method with capillary blood samples.

The study employed multiple measurement formats, including binary response items, Guttman scale indicators, and Likert scale statements, to operationalize the constructs examined. Given these differences in scale structure, variations in response distribution and indicator variance may occur within the structural equation modeling framework.

Data Analysis

Descriptive data analysis was using the Statistical Package for the Sosial Sciences (SPSS) version 26. Descriptive statistics were shown as frequencies (n) and percentages (%) to outline the characteristics of the respondents and the distribution of each study variable. A paired t-test or Wilcoxon signed-rank test assessed the pre and post intervention data, depending on whether the data was normal. We performed hypothesis testing using Partial Least Squares Structural Equation Modeling (PLS-SEM) with SmartPLS software version 4.1.1.2. PLS-SEM was selected based on the study's main objective to identify key predictors. The measurement model was evaluated through convergent validity (Average Variance Extracted > 0.5), discriminant validity (Heterotrait-Monotrait Ratio [HTMT]), and construct reliability (Cronbach's alpha and Composite Reliability > 0.7). The structural model was assessed using the coefficient of determination (R^2), path coefficients (β), t-statistics derived from bootstrapping (5,000 resamples), effect size (f^2), and variance inflation factor ($VIF < 5$). Model fit was determined using the Standardized Root Mean Square Residual (SRMR), with a threshold of < 0.08. A p-value of < 0.05 was considered statistically significant (18–20).

Ethical Approval

This study was approved by the Institutional Ethics Committee of University of Surabaya (Approval Number: 357/KE/III/2024).

RESULTS

This study involved 483 respondents, with a response rate of 62.6%. Responses from all participants were collected and analyzed collectively. The findings showed that the majority of respondents were aged 13 years (23.19%), followed by 14 years (20.08%) and 15 years (17.81%). Most of the participants came from families with a parental income at or below the regional minimum wage (53.62%). The detailed characteristics of the respondents are presented in Table 1.

Table 1. The characteristics of respondents

Characteristics	Description	Frequency	%
Age of Respondent	11 years	2	0.41
	12 years	52	10.77
	13 years	112	23.19
	14 years	97	20.08
	15 years	86	17.81
	16 years	83	17.18
	17 years	47	9.73
	18 years	3	0.62

Characteristics	Description	Frequency	%
Parent's income	19 years	1	0.21
	> RMW	259	46.38
	≤ RMW	224	53.62

Note: RMW: Regional Minimum Wage

The majority of respondents showed a significant improvement in knowledge after the intervention, with a pretest–posttest score increase ranging from 11.2% to 31.3% ($p = 0.000$). Respondents' positive attitudes also increased by 7.7% compared to the pretest scores, with statistical significance at $p = 0.019$. The adherence level after the intervention indicated that more than half of the respondents (51.6%) were classified as adherent with statistical significance ($p = 0.000$). Regarding medication-related factors, more than half of the respondents (62.94%) experienced side effects, primarily nausea (49.7%) and abdominal pain (19.9%). A total of 70.6% of respondents reported discomfort in consuming iron tablets, caused by sensory factors such as taste (47.2%) and smell (54.9%). In terms of social factors, less than half of the respondents received positive support from family (43.48%) and peers (46.17%). However, the majority of respondents reported receiving positive support from the school (64.18%). Complete data regarding factors influencing respondents' adherence are presented in Table 2.

Table 2. Data on Factors Influencing Adherence

Respondent data	Pre-test		Post-test		p-value
	n	%	n	%	
Knowledge level					
Less	133	27.5	33	6.8	0.000*
Enough	296	61.3	299	61.9	
Good	54	11.2	151	31.3	
Respondent's attitude					
Positive	228	47.2	265	54.9	0.019*
Negative	255	52.8	218	45.1	
Drug factor					
Side effects					
Yes	304	62.94	-	-	-
No	179	37.06	-	-	-
Nausea	240	49.7	-	-	-
Vomiting	57	11.8	-	-	-
Stomach pain	96	19.9	-	-	-
Diarrhea	19	3.9	-	-	-
Constipation	17	3.5	-	-	-
Black stool	47	9.7	-	-	-
Organoleptical					
Yes	142	29.4	-	-	-
No	341	70.6	-	-	-
Taste	228	47.2	-	-	-
Odor	265	54.9	-	-	-
Color	42	8.7	-	-	-
Social factors					
Family support					
Positive	210	43.48	-	-	-
Negative	273	56.52	-	-	-
School support					
Positive	310	64.18	-	-	-
Negative	173	35.82	-	-	-
Peer support					
Positive	223	46.17	-	-	-
Negative	260	53.83	-	-	-

Note: There was a significant change between pre-test and post-test: $p < 0.05$

The majority of respondents were non-adherent (64.2%) before the intervention, which decreased to 48.4% after the intervention. Conversely, the proportion of adherent respondents increased from 35.8% (pre-test) to 51.6% after the intervention (Table 3).

Table 3. Respondent Compliance Data

Respondent Data	Pre-test		Post-test		p-value
	n	%	n	%	
Compliance level					
Adherent	173	35.8	249	51.6	0.000*
Non-adherent	310	64.2	234	48.4	

Hemoglobin (Hb) levels of respondents were measured after the intervention (only at post-test), indicating that most respondents had normal Hb levels (≥ 12 g/dL). However, 21.1% of respondents were found to have mild anemia (Hb 11–11.9 g/dL), and 9.1% had moderate anemia (Hb 8–10.9 g/dL), as shown in Table 4.

Table 4. Respondent Hb Level Data (post-test)

Respondent data	n	%
Hb level		
Normal (≥ 12 g/dl)	337	69.8
Mild Anemia (11–11,9 g/dl)	102	21.1
Moderate Anemia (8–10,9 g/dl)	44	9.1
Severe Anemia (≤ 8 g/dl)	0	0.0

Several findings from the analysis (Table 5):

The model explains 4.6% of the variance in iron tablet adherence ($R^2 = 0.046$) and 38.4% of the variance in hemoglobin levels ($R^2 = 0.384$). This indicates a relatively limited proportion of variance explained by the proposed predictors.

Family support has a significant effect on iron tablet adherence ($\beta = 0.051$, $t = 2.044$, $p = 0.041$).

School support has a significant effect on iron tablet adherence ($\beta = 0.131$, $t = 2.539$, $p = 0.011$).

Attitude has a significant effect on iron tablet adherence ($\beta = -0.071$, $t = 3.006$, $p = 0.003$). Notably, the direction of this association was inverse and theoretically counterintuitive.

Iron tablet adherence has a significant effect on hemoglobin levels ($\beta = 0.570$, $t = 17.768$, $p = 0.000$).

Drug-related factors (side effects and organoleptic characteristics) and peer support do not significantly affect iron tablet adherence.

All indirect effects, including family support, school support, and peer support through attitude on adherence, were not significant.

Table 5. Respondent Compliance Data

Outcome	Predictor	Path/ hypothesis	Coefficient (β)	t statistic	p value	PCI	Sig/ supported	f ²	VIF
Adherence taking IFA ($R^2 = 0.046$)	Drug factor	-(H2) Drug factor: side effect → Adherence taking IFA	-0.025	0.496	0.620	[0.127-0.075]	No	0.001	1.179
		-(H2) Drug factor: organoleptic → Adherence taking IFA	0.027	0.495	0.620	[0.082-0.135]	No	0.001	1.178
	Social factor	-(H1) Social factor:	0.051	2.044	0.041	[0.001-0.099]	Yes	0.010	1.094

		family support → Adherence taking IFA							
		-(H1) Social factor: school support → Adherence taking IFA	0.131	2.539	0.011	[0.030-0.234]	Yes	0.014	1.076
		-(H1) Social factor: peer support→ Adherence taking IFA	0.006	0.114	0.909	[0.102-0.107]	No	0.000	1.100
	Attitude	-(H3) Attitude → Adherence taking IFA	-0.071	3.006	0.003	[0.115-0.023]	Yes	0.021	1.021
Hemoglobin level (R ² = 0.384)	Adherence taking IFA	Adherence taking IFA → Hemoglobin level	0.570	17.768	0.000	[0.506-0.631]	Yes	0.625	1.000
	Indirect effects	Social factor: family support → Attitude→ Adherence taking IFA	-0.006	1.063	0.288	[0.018-0.004]	No	0.007	1.077
		Social factor: school support → Attitude → Adherence taking IFA	-0.004	0.404	0.686	[0.022-0.014]	No	0.001	1.048
		Social factor: peer support → attitude → Adherence taking IFA	-0.005	0.984	0.325	[0.026-0.008]	No	0.003	1.095

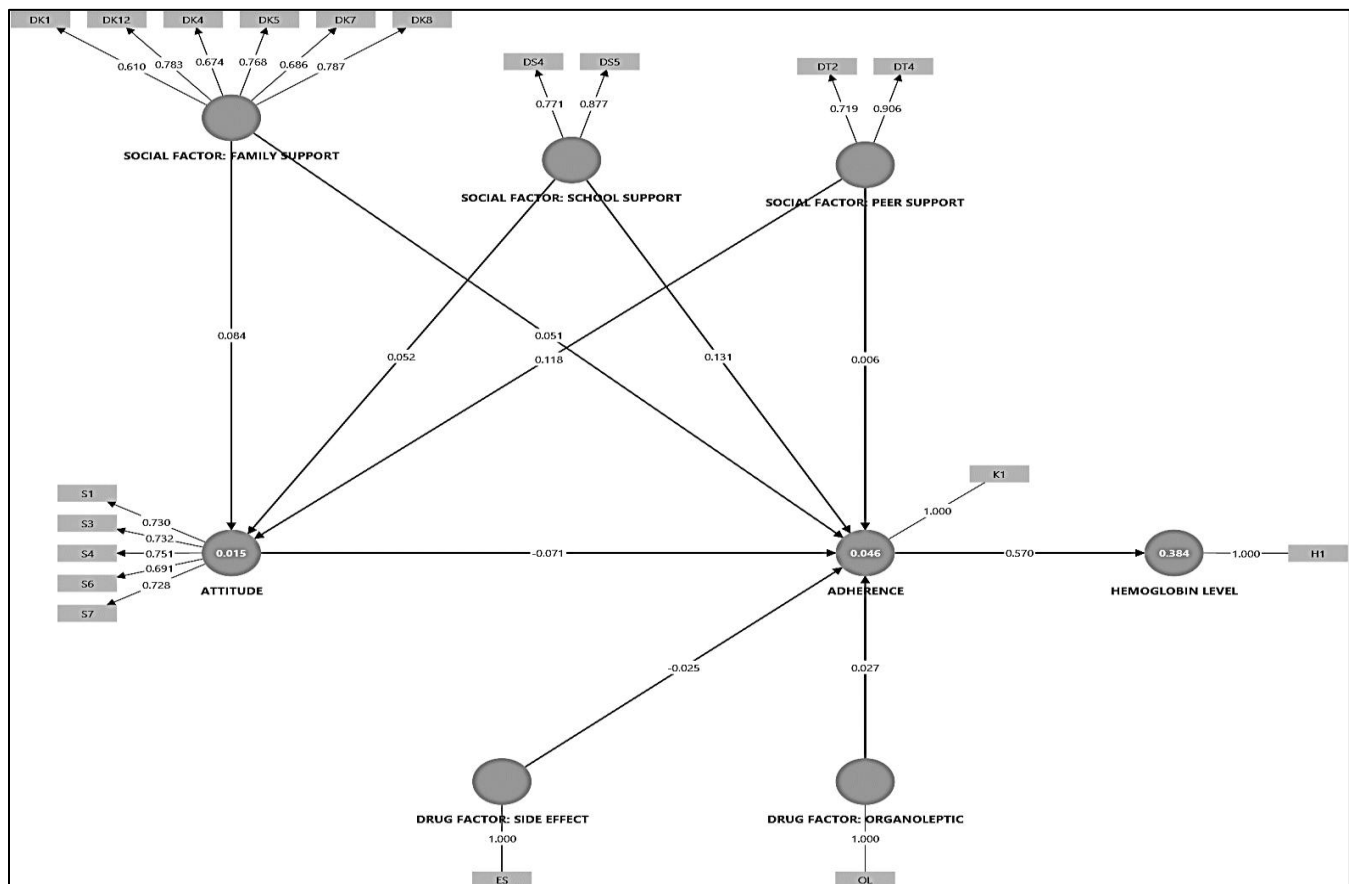
Note: Bootstrapping base on 5.000 samples. Effects of the covariates assessed by applying a two-tailed test at 5% of significance level [2.5%, 97.5%]. PCI = percentile confidence interval; VIF: variance inflation factor

Table 6. Evaluation of Structural Model Fit Based on SRMR Value

Indicator Model Fit	N	Criteria	Interpretation
SRMR	0.062	< 0.08	Suitable model (good model fit)

The knowledge predictor was excluded from the final model due to its outer loading value falling below the 0.5 threshold (20). A low loading value indicates that the knowledge indicators do not consistently and validly represent the construct (18,20). Several possible reasons for the low loading include: heterogeneity in the indicator

items, the use of the Guttman scale (yes/no), which may limit data variance, and weak statistical relevance of the knowledge construct to the main outcome (adherence), thus potentially rendering it undetectable as a significant factor in the structural model (Pic. 2).



Pic 2. Final Model PLS-SEM

DISCUSSION

Characteristics

A total of 483 respondents participated in this study, with ages between from 11 to 19 years. Most respondents were 12 to 16 age group, which 89.03% of total respondents. This show majority of respondents were in the early to middle adolescence stage, a period of physiological growth marked by increased iron requirements due to rapid growth and the onset of menstruation. These result highlight the relevance of selecting a target group aligned with the government's free iron supplementation program (6). There was a significant increase in respondents' knowledge after intervention ($p < 0.05$), where the proportion of respondents with good knowledge increased by 20.1%, while poor knowledge decreased by 20.7%. These findings indicate that the educational intervention successfully enhanced respondents' cognitive understanding regarding the importance of consuming iron supplements and the risks of anemia. These results are consistent with other studies reporting a significant improvement in adolescent girls' knowledge after receiving anemia and iron supplement-related interventions ($p < 0.05$) (21–23). Prior to the intervention, 52.8% of respondents had a negative attitude, which decreased to 45.1% after the intervention, while the proportion of positive attitudes increased to 54.9%, with a statistically significant change ($p = 0.019$). These findings are in line with other studies. Research by Abu-Baker et al. (2021) involving 363 adolescent girls showed a significant increase in positive attitudes ($p = 0.000$) regarding anemia following an educational intervention (21). Research by Fariba et al. (2021) on 120 adolescent girls also reported a significant change ($p = 0.009$) in attitudes

related to anemia and its prevention before and after the intervention (24). The increase in positive attitudes reflects not only a rational understanding of the importance of iron supplement consumption and anemia risk, but also the internalization of health values and emotional readiness to commit to preventive health behaviors. Adolescents with positive attitudes tend to demonstrate a greater ability to maintain their health (25).

The drug factor is primarily related to the side effects and organoleptic properties of iron tablets consumed by adolescent girls. The findings of this study indicated that 62.94% of respondents experienced side effects after consuming iron tablets, particularly nausea (49.7%), stomach pain (19.9%), and other digestive disorders. Most respondents also reported discomfort in consuming iron tablets due to their taste (47.2%) and odor (54.9%). This finding is indicated as one of the barriers for adolescent girls to consume iron tablets. This is supported by several findings reporting that side effects and discomfort caused by the smell or taste of the tablets may hinder adolescent girls from taking iron supplements (26–28). Positive school support as a social factor had the highest percentage (64.18%), followed by peer support (46.17%) and family support (43.48%). High school support reflects the role of institutions as educators and providers of population-based health education. Hemoglobin levels were measured only during the post-intervention phase, thus serving solely as an outcome that reflects the impact of educational exposure and iron tablet consumption behavior during the intervention period. The majority of respondents had normal hemoglobin levels (70.6%); however, some were found to have mild anemia (20.1%) with Hb levels of 11–11.9 g/dL and moderate anemia (9.3%) with Hb levels of 8–10.9 g/dL. This indicates that the educational intervention implemented has not fully contributed to the hemoglobin status of the respondents. The results of this study are consistent with those of Abu-Baker et al. (2021), which showed that most respondents had normal hemoglobin levels (45.5%), mild anemia (44.5%), and moderate anemia (10%) (21).

Factors Affecting Adherence

The analysis revealed that the factors influencing respondents' adherence to iron supplement intake included social factors such as family support, school support, and attitude. Family support and school support had a significant influence on respondents' adherence ($p < 0.05$). The modest R^2 value for adherence (0.046) indicates that the psychosocial predictors included in the model explain only a small portion of supplementation behavior. This underscores the multifactorial nature of adherence and suggests the likely influence of additional unmeasured determinants, such as menstrual characteristics, dietary iron intake, supervision intensity, or structural aspects of program delivery. Therefore, the identified predictors should be interpreted as context-specific correlates rather than comprehensive explanatory determinants. The social factor of family support showed a significant effect on adherence ($\beta = 0.051$; $t = 2.044$; $p = 0.041$). This finding indicates that the greater the family support given to respondents, the more likely adolescent girls are to adhere to regular iron tablet consumption. Several studies have reported a significant association between family support and adherence levels among adolescent girls in taking iron supplements regularly (29–31). This emphasizes the role of the family, especially parents, in shaping and supporting healthy behaviors among adolescents. Adolescence is a developmental stage characterized by instability and high susceptibility to environmental influences. A study by Haile et al. (2024) involving 506 adolescent girls in a weekly iron tablet supplementation program found that low adherence could be attributed to a non-supportive family environment (AOR=1.40; 0.97–2.03).

This underscores that parental monitoring and motivation are not merely supplementary elements but rather serve as effective reinforcements and primary drivers in sustaining long-term health behavior. In addition to family support, school support was also found to significantly influence adherence ($\beta = 0.131$; $t = 2.539$; $p = 0.011$). Schools function not only as formal educational institutions but also as strategic platforms for health promotion, behavior formation, and motivation to enhance adolescent girls' adherence to iron supplement consumption. This is reinforced by existing studies. Research by Gosdin et al. (2021) on 1,387 adolescent girls demonstrated that a school-based weekly iron supplement program effectively increased average iron tablet intake and reduced anemia prevalence over one academic year of intervention, from 25.1% to 19.6% ($p = 0.001$) (32). A cross-sectional study by Apriningsih et al. (2020) involving 274 adolescent girls also showed that school support significantly improved adherence through collective iron tablet consumption (OR=7.2; CI: 3.5–14.6; $p = 0.000$) and educational efforts from teachers (OR=2.3; CI: 1.2–4.6; $p = 0.013$) (33). Family and school support as information providers and reminders also play a crucial role. An observational study involving 202 adolescent girls reported that the involvement of social environments such as parents and teachers as sources of information ($r = 0.175$; $p = 0.013$) and reminders ($r = 0.158$; $p = 0.025$) could help

increase adherence to iron supplement intake among adolescent girls (29). The attitude factor in this study had a significant influence on respondents' adherence ($p < 0.05$). This illustrates that respondents have a positive attitude toward iron supplements and are more likely to consume them consistently. Individuals with a positive attitude tend to exhibit positive behavior (34,35).

Adolescent girls with a positive attitude are more likely to adhere to iron supplement intake consistently compared to those with a negative attitude (35). Several observational studies have shown a significant influence between attitude and adherence to iron supplement intake among adolescent girls ($p < 0.05$) (34–36). The findings on the attitude factor in this study showed significance but with a negative coefficient value ($\beta = -0.071$; $t = 3.006$; $p = 0.003$). This indicates a negative influence, where the more positive the respondents' attitude, the lower the adherence. Considering the direction of the relationship does not align with general theoretical expectations regarding the role of attitude, in which a more positive attitude is expected to lead to higher adherence, but the opposite occurs. This statistically significant but inverse association warrants cautious interpretation. Conceptually, positive attitudes are generally expected to increase adherence behavior. The unexpected negative direction may reflect a suppression effect within the multivariate structural model, potential construct misalignment, or residual confounding from unmeasured behavioral or contextual variables. Additionally, the finding may illustrate the presence of an attitude–behavior gap, in which favorable cognitive evaluations do not necessarily translate into consistent health behavior. However, no formal suppression diagnostics or alternative model specifications were conducted in the present analysis. Therefore, this pathway should be interpreted conservatively, and future studies employing robustness checks and longitudinal designs are needed to clarify the stability and directionality of this relationship. According to Hair et al. (2022), PLS-SEM analysis results should be interpreted not only based on statistical significance but also by considering the research context, the direction of the relationship, and the possibility of complex relationships among constructs (18). This negative result may reflect the existence of an attitude-behavior gap, where a positive attitude is not always translated into actual behavior. This assumption is supported by the theory of Myers and Twenge (2022), which states that attitude is not always a strong predictor of behavior, even if an individual has a positive attitude toward an action; various factors such as environmental barriers, social norms, and weak attitude intensity may hinder the application of a positive attitude in real behavior (37). This is likely to occur in the context of adolescent girls, where the attitude toward adherence to regular iron supplement intake is not fully internalized into consistent action. Therefore, this needs to be addressed systematically through experiential-based education, strengthening social support, and continuous monitoring in adolescent health programs.

Adherence to Hemoglobin Levels

The study results indicated a significant effect of respondents' adherence on hemoglobin levels ($\beta = 0.570$; $t = 17.768$; $p = 0.000$). This finding indicates a positive relationship between adherence and hemoglobin levels at the time of measurement. Because baseline hemoglobin levels were not assessed, the association between adherence and hemoglobin status should be interpreted as cross-sectional rather than indicative of change over time or intervention-induced improvement. Therefore, while the structural model suggests that higher reported adherence was correlated with higher hemoglobin levels, the present design does not permit conclusions regarding causal effects or physiological improvement attributable to the educational intervention. A randomized study by Handiso et al. (2021) involving 226 adolescent girls aged 10–19 years reported an increase of 1.2 g/dl in hemoglobin concentration in the intervention group receiving iron supplementation for three months compared to the control group ($p < 0.001$) (38). A meta-analysis by Kedir et al. (2024) also revealed that routine weekly consumption of iron tablets significantly increased hemoglobin levels in adolescents (Hedge's $g = 0.37$, 95% CI 0.01 to 0.73; heterogeneity $I^2 = 91.62\%$, $p < 0.001$) and reduced the risk of anemia by 20% (RR = 0.8, 95% CI 0.69 to 0.93; heterogeneity $I^2 = 28.12\%$, $p < 0.001$) (39). This affirms that adherence to iron tablet consumption is not merely a preventive measure but a critical component in supporting the body's physiological processes, particularly hemoglobin production. Hematopoiesis, the synthesis of red blood cells, is highly dependent on the body's iron availability. Iron deficiency impairs hemoglobin production, resulting in unmet physiological demands. This condition poses a high risk for adolescent girls who biologically experience blood loss due to menstruation and thus require more iron compared to non-menstruating groups. Non-adherence to iron tablet consumption can increase the risk of iron deficiency anemia, which may negatively affect productivity, cognitive ability, immune function, worsen pregnancy outcomes, increase birth-

related risks, contribute to the incidence of stunting in future generations, and impact long-term quality of life (2,6–10).

This study contributes to the existing literature by applying PLS-SEM to simultaneously examine psychosocial predictors of adherence and their association with hemoglobin status within a real-world school-based supplementation program in Indonesia. Unlike prior studies that primarily relied on bivariate or regression-based analyses, this study modeled interconnected pathways among social support, attitude, adherence behavior, and physiological outcomes. Additionally, the identification of a statistically significant yet inverse attitude–adherence relationship highlights a potential attitude–behavior gap within this population, offering a novel empirical insight that warrants further theoretical and methodological exploration.

Limitations

This study has several limitations that should be acknowledged. First, this study utilized a one-group pretest-posttest design without a control group, which limits the strength of causal inference from the findings. As a result, the observed associations should not be interpreted as causal relationships. Second, adherence data were collected through self-report, introducing the possibility of recall bias and social desirability bias, particularly given the school-based program context in which participants may feel inclined to respond favourably. Third, the structural model accounted for only a small portion of variance in adherence behaviour ($R^2 = 0.046$), indicating that additional determinants beyond those included in the current framework likely exist. Fourth, the simultaneous use of binary, Guttman, and Likert-type scales within the SEM framework may have affected construct validity and the comparability of indicators across constructs. Fifth, hemoglobin levels were measured solely at posttest, which precludes any assessment of change over time or evaluation of intervention-related improvement. Finally, findings derived from a specific regional context in Bali may not be directly transferable to other populations or sociocultural environments. Nonetheless, this study offers exploratory insights into the psychosocial pathways associated with iron supplementation adherence in a real-world school setting.

CONCLUSION

This study identified family support, school support, and attitude as factors statistically associated with iron supplement adherence among adolescent girls in Bali. However, given the exploratory design, absence of a control group, and limited explanatory power of the model for adherence behavior, these findings should be interpreted as hypothesis-generating rather than definitive predictors. Future studies employing controlled longitudinal designs, baseline hemoglobin assessment, and more comprehensive behavioral measurement are necessary to confirm the robustness and directionality of the proposed pathways.

AUTHOR'S CONTRIBUTION STATEMENT

Author 1: Conducted the research from start to finish, including designing the study, collecting and analyzing data, interpreting results, and preparing and finalizing the final report and manuscript.

Author 2: Assisted in designing the research concept, preparing the research proposal, supporting data management, and preparing the final report and manuscript.

Author 3: Assisted in designing the research concept, data interpretation and critically revised the final report and manuscript.

Author 4: Assisted in data interpretation and critically revised the final report and manuscript.

Author 5: Assisted in obtaining research approvals, facilitating the conduct of the study, supporting research documentation, and contributing to the preparation of the final report and manuscript.

CONFLICTS OF INTEREST

The author has no conflict of interest regarding this article.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

The authors declare that ChatGPT was used solely to improve text grammar, phrasing, and readability. All scientific concepts, study design, data collection and analysis, and interpretation of findings were developed and conducted entirely by the authors.

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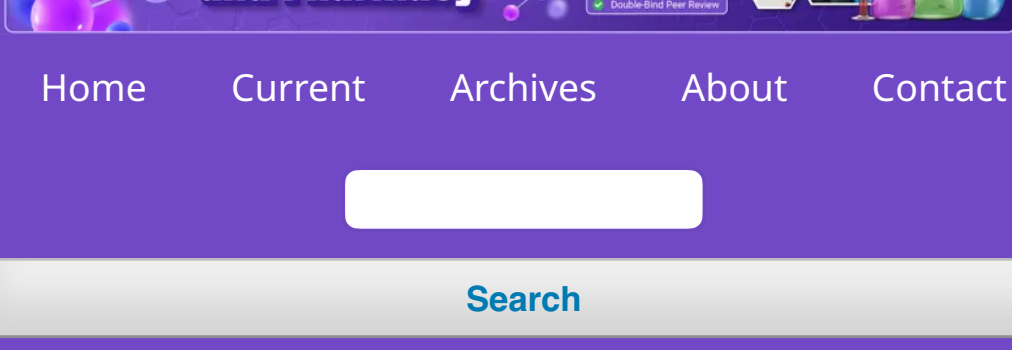
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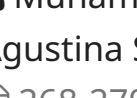
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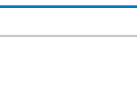
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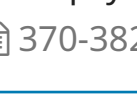
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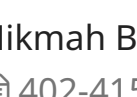
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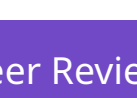
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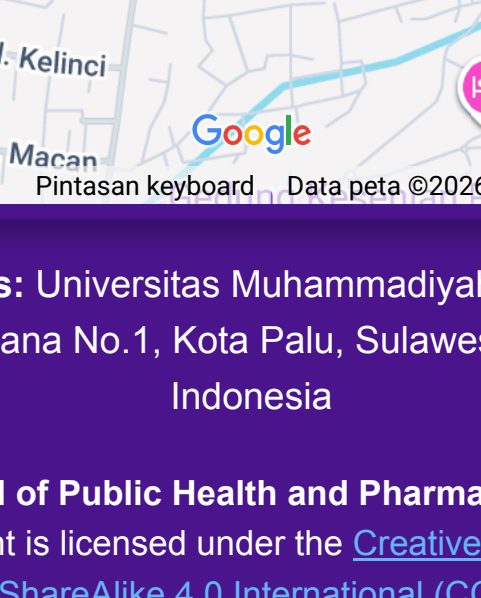
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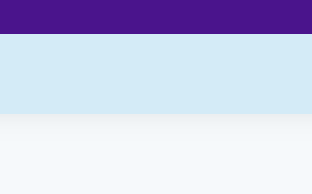
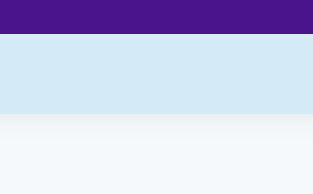
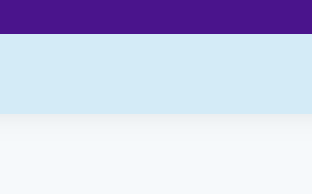
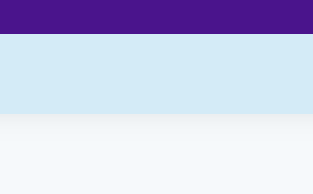
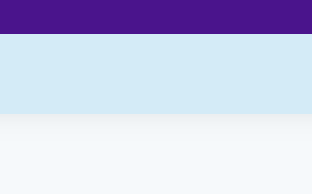
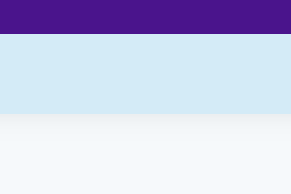


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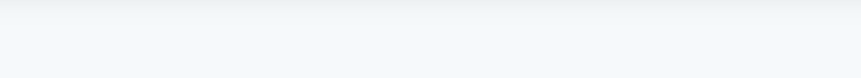
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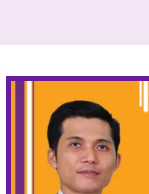
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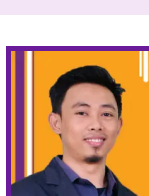
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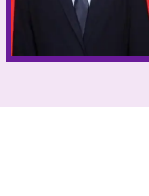
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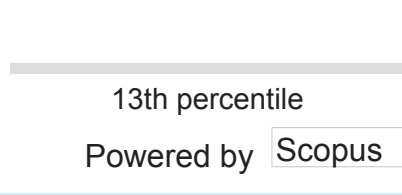
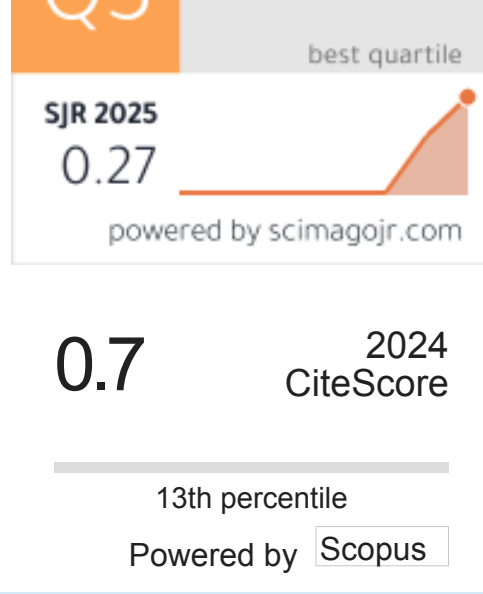
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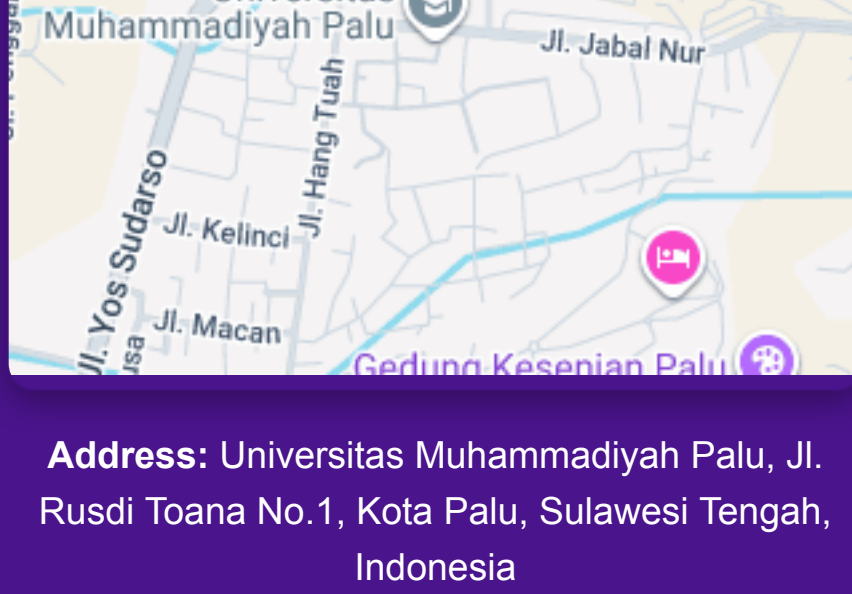
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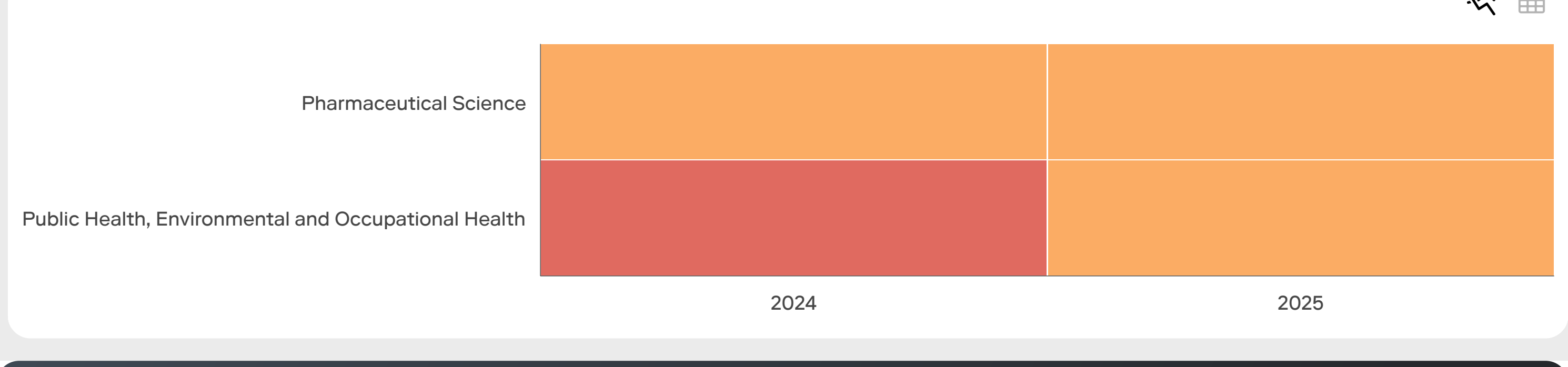
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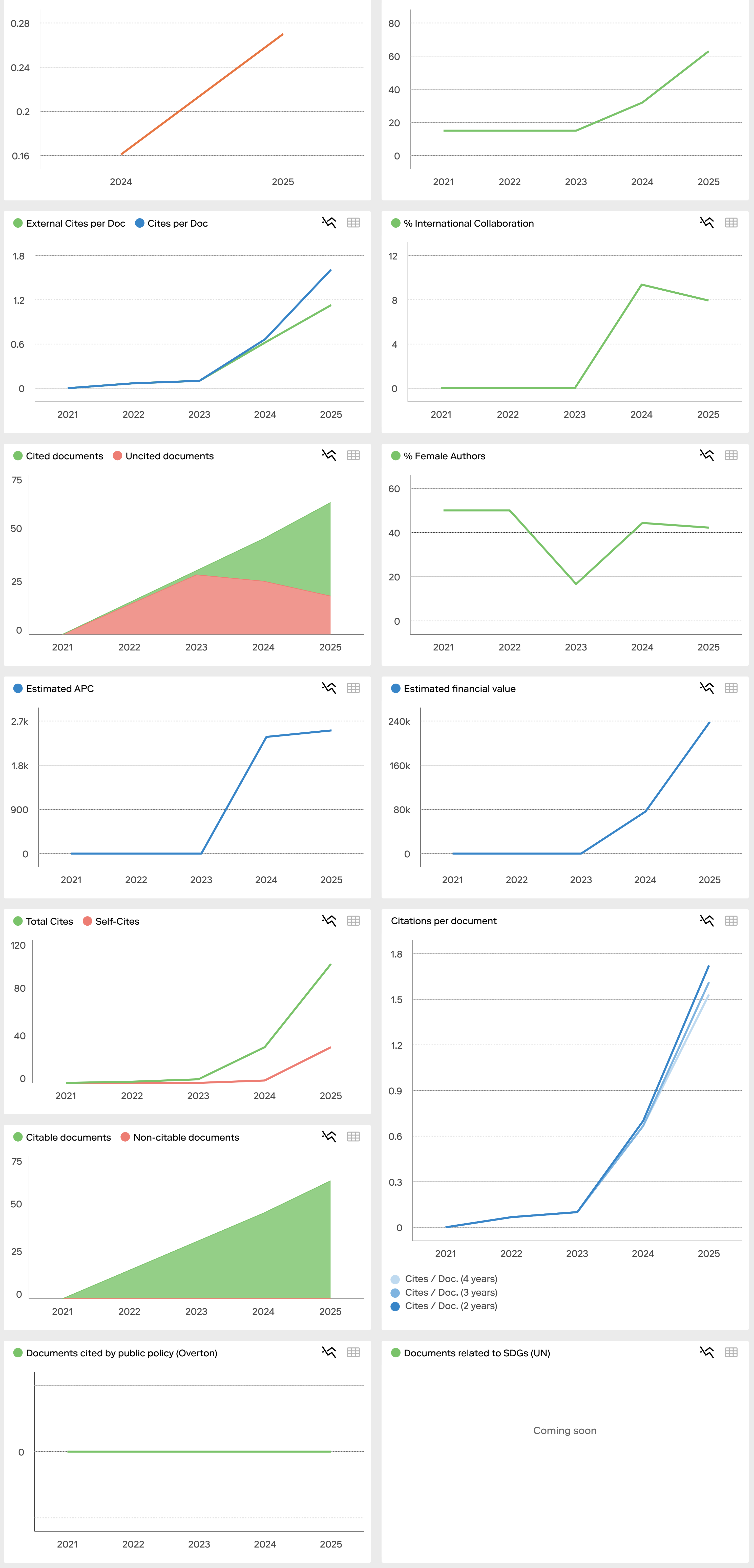


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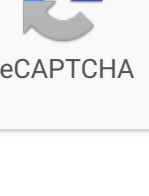
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