

Reducing Iron-Deficiency Anemia Among Adolescent Girls in Kazakhstan: A Multi-Criteria Decision Analysis of Intervention Strategies

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ABSTRACT

Iron-deficiency anemia (IDA) remains a significant public health concern among adolescent girls in Kazakhstan, driven by increased physiological iron demands during puberty, menstrual iron losses, and unequal access to nutritious food. While national anemia rates have declined over the past decade, the burden remains elevated among specific subgroups, including rural adolescents and those from households with lower food expenditure and maternal education. Existing research on adolescent anemia in Kazakhstan has largely documented prevalence and its correlates rather than evaluating which interventions are best suited to the country's existing healthcare and educational infrastructure. This literature review addresses that gap by examining the causes of adolescent IDA, reviewing international guidelines, and evaluating the evidence for four interventions, iron supplementation, food fortification, nutrition education, and a combined approach, using a Multi-Criteria Decision Analysis (MCDA) weighted across six criteria: clinical effectiveness, feasibility, cost, scalability, sustainability, and acceptability. The analysis finds that iron supplementation has the strongest direct clinical evidence, but food fortification and nutrition education score highest overall once feasibility, cost, and sustainability are considered, largely because Kazakhstan already has mandatory wheat flour fortification (since 2004) and an established school health network. The findings support a layered strategy: fortification as a population-wide foundation, nutrition education to reinforce dietary practices and supplementation adherence, and targeted iron supplementation reserved for high-risk subgroups, such as girls with heavy menstrual losses or limited access to fortified foods. Rather than proposing new delivery systems, this approach builds on infrastructure Kazakhstan already operates, offering a realistic, actionable framework for policymakers.

Keywords: iron-deficiency anemia; adolescent girls; Kazakhstan; iron supplementation; food fortification; nutrition education; multi-criteria decision analysis; public health.

INTRODUCTION

Anemia is a substantial global public health concern. In 2019, anemia affected approximately 24.8% of the global population, corresponding to nearly 1.8 billion individuals. It disproportionately affects women and children, roughly 4 in 10 children and 3 in 10 women are affected, especially in poorer countries [1]. Most of the time, anemia comes from not getting enough iron, though infections, long-term illness, and heavy periods can cause it too.

Teenage years are an especially risky time for girls to develop iron-deficiency anemia. Iron deficiency in this age group has both physiologic origins, driven by the high iron demands of rapid pubertal growth, and pathologic origins, driven by iron losses through menstruation, which can average around 20 mg per month and reach as high as 58 mg in some individuals [2]. Because adolescent girls often face both higher iron demands and repeated iron losses, they are more likely than boys to develop iron deficiency anemia, especially around the time of their first menstruation [3]. Beyond its immediate symptoms, IDA carries a range of longer-term consequences. Iron deficiency has been associated with impaired physical growth and development, weakened immune function, reduced physical work capacity, and diminished cognitive performance in both children and adolescents [2].

Although national epidemiological data from 2013 to 2023 indicate a significant decline in anemia prevalence among adolescents aged 15–17, a trend statistically correlated with increased household food expenditure, the burden remains clinically meaningful [4]. Despite improvements in national anemia rates, certain groups of adolescents in Kazakhstan continue to face a higher risk. For example, school-based studies have reported that approximately 13% of rural schoolchildren have anemia, while a regional analysis of surveys from Eastern Europe and Central Asia found that lower maternal education is associated with a higher prevalence of anemia in Kazakhstan and neighboring countries [5]. These findings suggest that anemia remains an important public health issue for vulnerable adolescent populations, despite overall national progress.

Existing research on adolescent anemia in Kazakhstan has focused mainly on documenting prevalence and identifying broad correlates, such as household food spending and maternal education [4] [5], rather than evaluating which specific interventions are best suited to the country's own healthcare and educational systems. This paper addresses that gap by identifying the most effective and actionable interventions for reducing anemia among adolescent girls in Kazakhstan.

Kazakhstan is a particularly instructive case study for this question because it already has much of the infrastructure that intervention strategies depend on: mandatory wheat flour fortification since 2004, an established school-based health promotion network, and comparable regional precedents in Uzbekistan and Kyrgyzstan. Few studies have used this existing infrastructure as a starting point for evaluating which interventions are realistically implementable, not just biologically effective, in this setting.

To answer this question, the paper examines the causes of iron-deficiency anemia in adolescent girls, reviews recommendations from international health organizations, evaluates evidence on existing interventions, and uses a multi-criteria decision analysis to compare their real-world feasibility and potential impact in the Kazakhstani context. Based on this analysis, the paper argues that food fortification and school-based nutrition education are the most feasible near-term strategies for Kazakhstan, with targeted iron supplementation layered on top for the highest-risk groups rather than used as a stand-alone intervention.

Causes And Risk Factors Of Anemia Among Adolescent Girls

Anemia is a multifactorial condition influenced by biological, nutritional, and socioeconomic factors. Among adolescents, iron deficiency anemia (IDA) is the most common form of anemia worldwide and remains a major public health concern because of its negative effects on physical growth, cognitive development, academic performance, and overall well-being [1]. Teenage girls are especially vulnerable because their biological need for iron increases significantly during puberty due to rapid growth and the start of menstruation [2] [3].

One of the primary causes of IDA is an inadequate intake of dietary iron. During adolescence, the body's demand for iron increases, yet many teenagers do not consume enough iron-rich foods like red meat, fish, beans, and leafy green vegetables. Additionally, daily eating habits affect how well the body absorbs the iron it receives. For example, Vitamin C increases iron absorption, while drinking tea or coffee with meals can inhibit it. As a result, diets that lack variety or do not include enough iron-rich foods significantly increase the risk of developing anemia [1].

Menstruation is another major biological risk factor. Monthly blood loss increases the amount of iron a girl needs, and those who experience heavy periods face an even higher risk. If these regular iron losses are not replaced through a healthy diet or supplements, the body's iron stores gradually deplete, eventually causing anemia. This makes adolescence a critical time for identifying iron deficiency before it develops into a more severe health issue [1].

Socioeconomic conditions also heavily impact anemia risk. Families with limited financial resources often struggle to afford nutritious foods, while teenagers living in lower-income or remote areas usually have less access to healthcare and nutrition education. A recent study in urban Kazakhstan highlighted this financial link, finding that every 1,000 KZT increase in household food spending was associated with a reduction of approximately 203 to 216 IDA cases per 100,000 children [4]. These findings demonstrate that making nutritious food more affordable could significantly lower anemia rates, showing that public health strategies must consider economic factors.

Recent research shows that IDA remains an ongoing problem in Kazakhstan, even though numbers have slowly improved over the years. The same Kazakhstan study noted that while the country's overall anemia rates have dropped over the last thirty years, unequal access to good nutrition is still the main driver of

IDA in children and teens. This remains true even as the country's health challenges shift due to rapid urbanization and changing lifestyles [4].

Studies outside of Kazakhstan support these conclusions. For instance, a 2026 study of ethnic Kazakh children living in Barkol County, China, found an IDA rate of 15.7%, which is higher than China's national average [6]. The researchers confirmed that a lack of dietary iron was the main cause of these high rates. Even though this study took place outside of Kazakhstan, it indicates that diet-related iron deficiency is an ongoing issue for Kazakh communities, even when living in different economic environments.

Ultimately, the existing literature shows that anemia in adolescent girls is caused by a combination of increased biological requirements, low dietary iron intake, menstrual blood loss, and social inequalities. Understanding these root causes is an essential first step. Before evaluating intervention strategies, it is necessary to recognize that effective programs must treat more than just the physical iron deficiency, they need to target the broader lifestyle and economic factors that cause it to develop

Existing Guidelines And Global Recommendations

The World Health Organization (WHO) does not use a single strategy for anemia prevention. Instead, it bases its guidelines on how severe anemia is in a specific population. In areas where anemia prevalence reaches 40% or higher, the WHO recommends daily oral iron supplementation for all children. In malaria-endemic regions, this intervention should be combined with measures to prevent, diagnose, and treat malaria to ensure safe and effective implementation [7].

The approach changes when it comes to menstruating adolescent girls. Instead of daily pills, the WHO recommends WIFAS for two overlapping target groups: adolescent girls aged 10-19, defined by age, and women of reproductive age (15-49), defined by fertility status, girls aged 15-19 fall under both categories. WIFAS is recommended specifically in areas where more than 20% of reproductive-age women are anemic [8]. Taking a supplement once a week is highly effective and much less demanding than a daily routine, making it a lot easier for busy teenagers to stick with the program. Because of its success, the WHO named WIFAS one of its eight priority actions for adolescent nutrition [9].

To build on this, Nutrition International has been working with the WHO Department of Nutrition and Food Safety since 2022 to get WIFAS added to the WHO Model Essential Medicines List [10]. If this gets approved, it will be much easier for governments to buy and distribute these weekly supplements for their national health programs.

Alongside supplements, the WHO views food fortification as a massive tool for helping entire populations at once. The WHO strongly recommends fortifying wheat flour with highly bioavailable iron, meaning iron that the body can easily absorb, to raise hemoglobin levels and lower anemia rates [11]. This recommendation fits Kazakhstan perfectly, since wheat products are a staple of the daily diet here. The

WHO also supports fortifying other common foods, allowing countries to adapt the strategy to whatever their citizens eat most [11].

The WHO brought all of these strategies together in its Comprehensive Framework for Integrated Action on the Prevention, Diagnosis, and Management of Anemia. This document outlines evidence-based steps to protect the groups most at risk, including young children, pregnant women, and menstruating teenage girls [11].

Finally, schools are one of the best places to reach teenagers because they offer regular access to students and allow health workers to provide multiple services at the same time. WHO/Europe defines a "health-promoting school" as one that actively builds an environment for healthy learning and living. In Kazakhstan, the WHO Health-Promoting Schools initiative started in the Mangystau, Kyzylorda, Almaty, and Astana regions before expanding nationwide, and it now includes over 500 school leaders and health professionals [12].

This existing school-based infrastructure creates an opportunity to integrate interventions such as iron and folic acid supplementation and nutrition education. Together, supplements, fortified foods, and school programs are the main global methods to prevent anemia, and they can be used as a model for Kazakhstan.

Evidence-Based Interventions to Reduce Anemia

School-based screening. A 2024 study of 405 school-going teenage girls in Dhankuta, Nepal, found that about 18% of them were anemic [13]. The researchers found that a lack of knowledge about anemia, skipping iron supplements, and eating a limited variety of foods were the main reasons why girls became anemic. In fact, girls who took their iron and folic acid supplements for less than 26 weeks were nearly 27 times more likely to develop anemia than those who stayed on track. To fix this, the study suggested a combined approach using school health programs, iron supplements, and deworming treatments together [13].

These findings show that screening works best as a starting point to find out who is sick, rather than as a standalone treatment. The main benefit of school screening is that it lets health officials spot local risk patterns early and at a low cost by using existing school buildings and staff. The downside is that, because this was a cross-sectional study. It looked at a single snapshot in time, and it cannot prove that just screening students is enough to improve their health over the long run.

Iron supplementation. The strongest evidence base among the four interventions comes from a 2023 meta-analysis of 129 randomized trials covering more than 34,000 children and adolescents. Supplementation reduced overall anemia by 39%, iron deficiency by 70%, and iron deficiency anemia by 80%, with hemoglobin rising by an average of 6.3 g/L [14].

Frequent (three to seven times weekly) and intermittent (one to two times weekly) schedules were similarly effective at reducing anemia, though frequent dosing produced larger ferritin gains [14]. These findings validate weekly iron and folic acid supplementation (WIFAS) protocols as an effective alternative to daily administration regimens, which frequently suffer from poor adherence during adolescence. The analysis also showed that moderate and high doses of iron improved hemoglobin levels more than lower doses, though even small amounts helped. The supplements did not cause any major side effects regarding growth or infections, and they even improved brain function and thinking skills for kids who started out anemic [14]. The only real limitation of this study is the age of the participants: only about 12% of the people in these trials were teenagers between 12 and 19, meaning the data is slightly less precise for adolescents than it is for younger children [14].

Food fortification. A 2023 WHO review found that adding iron to wheat flour cut the risk of anemia by 27% for everyone over the age of two, though its exact impact on pure iron deficiency was a bit less certain. Fortifying staple foods with multiple vitamins and minerals at the same time worked even better, cutting anemia risk by 32%, iron deficiency anemia by 72%, and general iron deficiency by 56% [11]. The data also showed that fortifying corn flour or rice is far less reliable than fortifying wheat flour [11]. This distinction is highly important for Kazakhstan, where wheat flour is the primary staple food and mandatory fortification is already a national law.

The biggest strength of fortification is that it automatically protects an entire population without requiring individuals to change their daily habits or remember to take pills. Its main drawback is that it has a milder overall impact compared to direct supplements, and it can miss teenagers who live in rural areas and eat locally milled, unfortified flour.

Ultimately, the data shows that oral iron supplements have the fastest, most powerful impact on reducing anemia. Food fortification also offers massive long-term benefits, especially in a country like Kazakhstan where wheat is eaten daily. Screening in schools is not very effective on its own, but it is incredibly useful for finding at-risk students and connecting them to real healthcare services. When comparing these options in a Multi-Criteria Decision Analysis (MCDA), biological effectiveness alone will not separate them. Instead, final decisions will likely depend on real-world factors like cost, feasibility, and how well each option fits into Kazakhstan's current wheat fortification infrastructure.

METHODOLOGY

Adolescent anemia cannot be addressed through a single intervention, as different approaches have different strengths and limitations. While some interventions may provide strong clinical benefits, others may be more affordable, easier to implement, or more acceptable within the local context of Kazakhstan. Therefore, MCDA was selected to compare these interventions across multiple dimensions and identify which approach offers the most balanced and practical solution for reducing anemia among adolescent girls.

Multi-criteria decision analysis (MCDA) is a systematic way to compare different options using several objectives at once, instead of focusing on just one measure like clinical benefit or cost [15]. In healthcare, this approach is useful because decisions often involve trade-offs between factors such as effectiveness, affordability, and practicality, none of which can be fully captured by a single metric [16]. MCDA works by first defining the criteria that matter, then assigning weights to show how important each criterion is. Each option is scored against these criteria, and the scores are combined into a weighted total that allows direct comparison [17]. A key strength of MCDA is its transparency. Since all criteria, weights, and scores are clearly stated, the reasoning behind the final ranking can be examined and debated, rather than hidden in one overall judgment [15]. Because of this, public health authorities increasingly use MCDA to set priorities when resources are limited [16]. In this study, MCDA is applied to compare four interventions for adolescent anemia, involving iron supplementation, food fortification, nutrition education, and a combined approach, across six criteria: clinical effectiveness, feasibility, cost, scalability, sustainability, and acceptability.

Criterion	Weight	Why it matters
Clinical effectiveness	30%	Does anemia/Hb actually improve?
Feasibility	25%	Can Kazakhstani schools/clinics deliver it?
Cost	15%	Affordable at scale?
Scalability	10%	Can it go national?
Sustainability	10%	Survives after donor/pilot funding ends?
Acceptability	10%	Will adolescents actually participate/adhere?

Figure 1. MCDA criteria and assigned weights.

The weighting of the MCDA criteria was determined based on the primary objective of this study: identifying interventions that are not only effective in reducing iron-deficiency anemia among adolescent girls, but also realistically implementable in Kazakhstan's healthcare and educational systems. Greater weight was therefore assigned to clinical effectiveness and feasibility, while economic and implementation factors received moderate weights. (see Figure 1).

Clinical effectiveness

Clinical effectiveness received the highest weight (30%) because improving hemoglobin concentration and reducing anemia prevalence represent the primary outcomes of interest. Regardless of cost or practicality, interventions that fail to produce meaningful health improvements cannot be recommended.

Feasibility

Feasibility was assigned the second highest weight (25%) because even highly effective interventions have limited public health value if they cannot be realistically implemented within Kazakhstan. Considered factors include existing healthcare infrastructure, school systems, and governmental capacity.

Cost

Cost was weighted at 15% because financial sustainability influences long-term implementation. However, cost alone should not outweigh intervention effectiveness, particularly when addressing a widespread public health issue such as adolescent anemia.

Scalability

Scalability received a weight of 10% since successful pilot interventions should ideally be expanded nationally. This criterion considers whether implementation can be extended across urban and rural regions without any structural barriers.

Sustainability

Sustainability was weighted at 10% because interventions requiring continuous support or temporary funding may not maintain their impact over time. Long-term integration into existing health and education systems was therefore considered important.

Acceptability

Acceptability received 10% because intervention success depends on adolescent participation and adherence. Even clinically effective programs may have limited impact if students, parents, or schools are unwilling to participate consistently.

Since there is no standard system for weighting criteria when evaluating anemia interventions in Kazakhstan, the weights in this study were set using expert judgment informed by existing literature. More importance was given to intervention effectiveness and feasibility of implementation, reflecting priorities commonly highlighted in public health and implementation science research.

Scoring

Each score (1–5) was based on evidence from peer-reviewed studies or WHO/UNICEF program evaluations, rather than being chosen by judgment alone. When findings were mixed or varied by context, the score represents the overall balance of evidence, and this is stated clearly. The weights follow the MCDA framework already defined in the paper: Clinical effectiveness (0.30), Feasibility (0.25), Cost (0.15), Scalability (0.10), Sustainability (0.10), and Acceptability (0.10).

Because translating evidence into a 1-5 scale always involves some interpretation, the justification for each score is written out in detail.

RESULTS

1. Iron Supplementation (weekly iron-folic acid supplementation, WIFAS)

Criterion	Weight	Score	Weighted Score
Clinical effectiveness	0.30	5	1.50
Feasibility	0.25	3	0.75
Cost	0.15	3	0.45
Scalability	0.10	4	0.40
Sustainability	0.10	2	0.20
Acceptability	0.10	3	0.30
Total			3.60

Figure 2. Scoring breakdown for iron supplementation across MCDA criteria.

Clinical effectiveness = 5. A prospective cohort evaluation of Ghana's school-based WIFAS program found that each additional tablet consumed over the school year significantly reduced the odds of anemia [18]. A 2025 network meta-analysis of 61 randomized controlled trials further confirmed that iron supplementation significantly improves hemoglobin concentration among adolescents [19], while Roche et al. (2021) concluded that the evidence supporting weekly IFA supplementation is now well established across multiple settings [20].

Feasibility = 3. Delivery is straightforward through schools, but the same Ghana cohort found most girls consumed fewer than the minimum number of tablets needed for a measurable effect [18]. A school-based study in northwest Ethiopia similarly found 47.9% of girls had poor compliance, driven mainly by absenteeism on distribution days [21].

Cost = 3. A comparative cost-effectiveness analysis in the Philippines found iron supplementation cost USD 179 per DALY averted, versus USD 66 for food fortification and USD 103 for dietary diversification within the same population [22]. This places supplementation in a moderate cost-efficiency band relative to the other single-component options evaluated here.

Scalability = 4. UNICEF's 2022 launch of the IFA supplementation program in Karakalpakstan, Uzbekistan, reached 131,938 adolescent girls in a single regional rollout, demonstrating that WIFAS can be scaled rapidly across a Central Asian population comparable in context to Kazakhstan [23].

Sustainability = 2. Roche et al. (2021) frame their case for adding WIFAS to the Essential Medicines List explicitly around the need to secure more reliable, continuous procurement and supply, which implies the intervention's ongoing dependence on functioning commodity logistics is a structural weakness relative to interventions that do not require repeat distribution [20].

Acceptability = 3. A mixed-methods adherence study among adolescent girls found that fear of side effects and unpleasant effects experienced during IFA intake, combined with inadequate counseling, were primary reasons for non-adherence [24]. This indicates acceptability is meaningfully constrained by tolerability rather than simple availability.

Overall, WIFAS appears to be a clinically strong intervention, with clear evidence that regular supplementation can reduce anemia among adolescent girls. However, its relatively lower scores for sustainability and moderate scores for feasibility and acceptability show that its effectiveness depends heavily on whether girls consistently take the tablets and whether a reliable supply can be maintained. This creates an important gap between the intervention's potential effectiveness and its effectiveness in real-world implementation. Therefore, WIFAS is a strong option for achieving direct health benefits, but its success may be limited by adherence and long-term delivery challenges.

2. Food Fortification (iron-fortified wheat flour / staple foods)

Criterion	Weight	Score	Weighted Score
Clinical effectiveness	0.30	3	0.90
Feasibility	0.25	5	1.25
Cost	0.15	5	0.75
Scalability	0.10	5	0.50
Sustainability	0.10	5	0.50
Acceptability	0.10	4	0.40
Total			4.30

Figure 3. Scoring breakdown for food fortification across MCDA criteria.

Clinical effectiveness = 3. A systematic review of flour fortification trials worldwide classified the trials conducted in Kazakhstan as only "moderately efficacious", meaning some iron-status indicators (such as ferritin or hemoglobin) improved significantly after fortification while others did not, in contrast to a smaller set of countries where fortification produced significant improvement across all measured indicators. [25]. This mixed, indicator-specific pattern in Kazakhstan's own program evidence is the basis for a moderate rather than high score.

Feasibility = 5. In an earlier evaluation of the same Uzbekistan program, fortified flour or bread was present in 71.3% of households three years after program launch, without requiring any individual enrollment, counseling, or repeat contact [26]. This reflects fortification's core structural advantage: population reach through the existing food supply rather than through individual compliance.

Cost = 5. In the same Philippines comparison cited above, fortification cost USD 66 per DALY averted, the lowest of the three interventions evaluated in that study (fortification, supplementation, dietary diversification) [22].

Scalability = 5. Pachón et al. (2015) reviewed evidence from 13 large-scale national flour fortification programs, confirming that fortification operates at full national scale once mandated, rather than requiring site-by-site rollout [27].

Sustainability = 5. A 2025/2026 systematic review of fortification cost-effectiveness across 63 countries found the large majority of evaluated programs had favorable, durable cost-effectiveness ratios once embedded in national food production systems, consistent with fortification requiring no repeated individual-level intervention to remain active [28].

Acceptability = 4. In the Uzbekistan program evaluation, only 32.1% of women were aware fortification was occurring, yet fortified flour was present in the large majority of households, indicating passive acceptance through normal dietary habits even where active awareness was low [26]. The score is not a 5 because this same low-awareness finding suggests the public has limited engagement with or understanding of the intervention.

Food fortification demonstrates the most balanced performance across the six criteria, receiving high scores for feasibility, cost, scalability, sustainability, and acceptability. Its main limitation is its moderate clinical effectiveness, particularly because evidence from Kazakhstan has shown mixed improvements across different measures of iron status. Nevertheless, fortification has a major practical advantage because it reaches people through commonly consumed foods without requiring individuals to actively participate in the intervention. Overall, its combination of broad population reach, low cost, and long-term sustainability makes it a particularly promising strategy for population-level anemia prevention.

3. Nutrition Education (school-based nutrition/anemia education)

Criterion	Weight	Score	Weighted Score
Clinical effectiveness	0.30	2	0.60
Feasibility	0.25	5	1.25
Cost	0.15	5	0.75
Scalability	0.10	5	0.50
Sustainability	0.10	4	0.40
Acceptability	0.10	5	0.50
Total			4.00

Figure 4. Scoring breakdown for nutrition education across MCDA criteria.

Clinical effectiveness = 2. A school-based nutrition education RCT among female adolescents with iron-deficiency anemia in Jordan found significant improvements in knowledge, attitudes, and reported iron-intake practices, but the study was not designed to demonstrate a corresponding change in hemoglobin or anemia status [29]. Because the strongest and most consistently reported outcome across this literature is behavioral/knowledge change rather than a direct biomarker effect, this criterion is scored below supplementation and the combined intervention.

Feasibility = 5. The same Jordan trial was delivered entirely through the existing school system without requiring a commodity supply chain, clinical staff, or laboratory equipment [29], illustrating the low operational barrier to implementation relative to interventions dependent on procurement.

Cost = 5. A 2025 systematic review of 16 educational intervention studies for anemic adolescents in low- and middle-income countries found the interventions were delivered primarily through low-cost modalities, printed materials, videos, and packaging modifications, rather than ongoing commodity distribution [30].

Scalability = 5. A teacher-delivered dietary-behavior education trial in Rajasthan, India, was implemented across 16 schools and reached 1,224 students using a standardized short teacher-training protocol, demonstrating that a single training model can be replicated across many sites.

Sustainability = 4. The same Rajasthan trial's teacher-delivered model is designed to persist through the existing curriculum structure rather than an external delivery team, though the trial itself notes this depends on sustained teacher training investment [31], which keeps the score below fortification's structural durability.

Acceptability = 5. The Rajasthan trial reported significant improvements in students' attitudes, subjective norms, and behavioral intentions toward healthy eating following the teacher-delivered curriculum, with no reported resistance to the intervention itself [31].

Nutrition education performs particularly well in terms of implementation, receiving high scores across feasibility, cost, scalability, and acceptability. Its main weakness is clinical effectiveness, as improving knowledge and dietary behaviors does not necessarily translate directly into a substantial reduction in anemia. This suggests that education is more effective as a way of supporting healthier behaviors than as a standalone solution to iron deficiency. Therefore, although it is relatively easy and inexpensive to implement, its limited direct clinical impact may reduce its overall ability to address adolescent anemia on its own.

4. Combined Intervention (weekly IFA supplementation + school-based nutrition education + routine anemia screening)

Criterion	Weight	Score	Weighted Score
Clinical effectiveness	0.30	5	1.50
Feasibility	0.25	3	0.75
Cost	0.15	2	0.30
Scalability	0.10	3	0.30
Sustainability	0.10	4	0.40
Acceptability	0.10	4	0.40
Total			3.65

Figure 5. Scoring breakdown for the combined intervention across MCDA criteria.

Clinical effectiveness = 5. A systematic review of integrated anemia strategies (diet, education, and supplementation combined) concluded that integrated interventions are more effective at raising hemoglobin than single-component approaches [32]. A quasi-experimental controlled study comparing an integrated iron-rich-diet, supplementation, and education package against single-component strategies found the combined approach produced larger hemoglobin gains among adolescent girls [32].

Feasibility = 3. A 2025 study on school-based WIFAS programs in Ethiopia notes that schools function as a strategic platform for delivering integrated health and nutrition interventions, supplementation, screening, and education together, but this coordination across three simultaneous components raises implementation complexity relative to a single-component program [33].

Cost = 2. No cost-effectiveness study identified in this review reported a combined multi-component package to be more cost-effective than fortification or other single-component interventions. Although programs such as the Uttar Pradesh WIFAS-plus-counseling initiative were described as cost-effective in absolute terms [34], they were not shown to be more cost-efficient than simpler alternatives. Because combined programs require supplementation, education, and screening simultaneously, they are expected to incur the highest implementation costs.

Scalability = 3. The same Ethiopian school-platform study supports combined interventions being deliverable at scale through existing school systems, but scored below single-channel interventions because replicating three coordinated delivery components (commodities, curriculum, screening) uniformly across many sites is harder than replicating one [33].

Sustainability = 4. By addressing both the supply of iron and the behavioral and detection drivers of anemia at once, and by using an institutionally durable school platform, combined programs have a plausible sustainability advantage over single-mechanism programs, though this still depends on continuous coordination between health and education systems [34].

Acceptability = 4. A 2025/2026 study of a digital education companion ("Jaga Diri") added to routine school-based IFA supplementation in Indonesia found the combined app-plus-supplementation intervention significantly improved both knowledge and adherence to IFA tablets compared with routine supplementation alone [35]. This indicates that adding an education/counseling component measurably improves acceptance of the supplementation component itself.

MCDA Calculation

A weighted total score was calculated for each intervention using the formula
 $S = \sum (\text{weight} \times \text{score})$.

The total score was obtained by multiplying the weight assigned to each criterion by the intervention's score for that criterion and summing the six resulting values. For example, food fortification received a total score of 4.30: $(0.30 \times 3) + (0.25 \times 5) + (0.15 \times 5) + (0.10 \times 5) + (0.10 \times 5) + (0.10 \times 4) = 4.30$.

Overall MCDA interpretation

The comparison shows that no single intervention performs best across every criterion. Iron supplementation and the combined approach offer stronger direct clinical benefits, while food fortification performs particularly well in terms of cost, scalability, and sustainability. Nutrition education is highly feasible and acceptable but has weaker evidence for directly reducing anemia. Taken together, these findings suggest that the most effective intervention is not necessarily the one with the highest clinical impact, but the one that provides the best balance between health outcomes and the practical realities of implementation.

Summary Table

Intervention	Total Weighted Score
Food fortification	4.30
Nutritional education	4.00
Combined intervention	3.65
Iron supplementation	3.60

Table 1. Weighted MCDA scores by intervention.

Highest score: Food fortification (4.30), driven primarily by its structural advantages in feasibility, cost, scalability, and sustainability, which together carry 0.60 of the total weight, even though its clinical-effectiveness evidence is more mixed than supplementation's.

Table 1 summarizes the weighted MCDA scores across all six criteria. This ranking is sensitive to two choices worth stating explicitly in the methodology section:

Weighting: because feasibility, cost, scalability, and sustainability together are weighted 0.60 versus 0.30 for clinical effectiveness, interventions with strong delivery-system properties (fortification, education) outrank interventions with strong biological effect but weaker logistics (supplementation). If the paper's argument is that adolescent-specific clinical impact should dominate, a re-weighting toward clinical effectiveness would shift the ranking toward the combined intervention and supplementation.

Fortification's clinical effectiveness score (3) reflects genuinely mixed programmatic evidence, not weak efficacy evidence, the underlying biological mechanism is well established, but national-level program impact on children specifically (as opposed to women) is inconsistent across the countries reviewed. [27] This is worth flagging in the discussion section since a reviewer could reasonably ask why fortification ranks highest overall despite a below-average clinical score.

Comparative Evaluation of Intervention Strategies

Relying solely on hemoglobin concentration as a primary outcome measure provides an incomplete evaluation of anemia interventions among adolescent populations. Although a given therapeutic strategy may demonstrate high efficacy within controlled clinical trial settings, its real-world effectiveness can be severely compromised by economic constraints, logistical delivery bottlenecks, and poor long-term sustainability [11]. To compare interventions more fairly, a Multi-Criteria Decision Analysis was used (MCDA). This method scored four strategies, iron supplementation, food fortification, nutrition education, and a combined approach, across six criteria: clinical effectiveness, feasibility, cost, scalability, sustainability, and acceptability.

Food fortification scored the highest overall (4.30). It works through the existing food supply, so people do not need to remember to take anything, and it needs almost no behavior change from individuals. This makes it easy to scale and easy to sustain over time. Still, the actual evidence that fortification lowers anemia rates is mixed. A large review of fortification programs found only limited proof that fortified flour reduces anemia, even though it does raise iron levels in some groups [27].

Nutrition education came in second (4.00). It is low-cost and well accepted by communities, which raises its score on those criteria. Education also targets a real problem: research on adolescent girls found that

poor knowledge about anemia was strongly linked to higher anemia rates [13]. But education alone usually cannot reverse anemia that has already developed, since it does not add iron to the body directly.

The combined intervention placed third (3.65). Mixing strategies together should, in theory, produce the best real-world results, since it covers the weaknesses of any single approach. However, combining programs also raises cost and coordination demands, which pulled its total score down compared to the simpler single interventions.

Iron supplementation scored lowest of the four (3.60), even though it had the strongest clinical evidence. Large trials show that oral iron reliably improves hemoglobin and iron levels in children and teens [14]. Its low overall score comes from sustainability and acceptability problems: people often stop taking the pills because of side effects or simply forgetting, which drags down its real-world value even though it works well biologically.

School-based screening was not included with a numeric score in this table, since screening identifies anemia rather than treating it directly. This is a limitation of the MCDA method itself, not proof that screening lacks value.

Taken together, these results suggest food fortification and nutrition education are Kazakhstan's strongest starting points, since they scored highest on real-world feasibility. But the clinical strength of iron supplementation means it still deserves a role, ideally paired with fortification and education rather than used alone.

Applicability of Evidence-Based Interventions in Kazakhstan

Kazakhstan already has helpful infrastructure for these programs. The country has required wheat flour fortification since 2004, and a systematic review of fortification programs specifically included Kazakhstani data, showing the country already has the industrial and legal systems needed to keep such a program running [27].

Neighboring countries show these approaches can work in similar settings. In Uzbekistan's Karakalpakstan region, UNICEF and the Ministry of Health gave out 50,000 iron and folic acid supplement packs to 131,938 adolescent girls aged 10 to 17, in an area where anemia rates were 40–50% above the national average [23]. This shows that large teenager-focused supplement programs can be delivered within a Central Asian health system similar to Kazakhstan's.

Kyrgyzstan's National Integrated Micronutrient and Anthropometric Survey also shows what regional data collection can look like. Researchers surveyed 3,062 households and tested blood samples to map out micronutrient deficiencies by age and region [36]. A similar survey in Kazakhstan could help identify exactly which regions and age groups need the most support.

Kazakhstan's schools are already a trusted channel for health programs. Since 2019, the WHO Health Promoting Schools initiative has trained hundreds of school leaders and health professionals across Kazakhstan's regions to run health and nutrition programs [12]. This shows that schools are a realistic, already-tested place to deliver nutrition education or iron supplements to teenagers.

Altogether, this evidence suggests Kazakhstan already has both the systems and the experience needed to adapt these interventions, especially a model that leans on its strongest-scoring strategies, fortification and education, while still using targeted supplementation where it is needed most.

DISCUSSION

The MCDA results raise an interpretive question that the numeric ranking alone cannot answer: why food fortification, an intervention with only a moderate clinical-effectiveness score, outranked iron supplementation, the intervention with the strongest direct evidence of biological effect. The answer lies in a distinction between biological efficacy and population-level programmatic effectiveness. Fortification's underlying mechanism is well established, but its measured impact on anemia prevalence varies across national programs, including within Kazakhstan's own fortification data, where flour fortification trials were classified as only moderately efficacious rather than uniformly effective [27] [25]. What separates fortification from supplementation is not superior biology but superior delivery. Because it reaches the population passively through the existing food supply, fortification removes the two structural weaknesses that most limit supplementation's real-world value: dependence on individual adherence and dependence on continuous commodity distribution [26] [22].

This is consistent with a broader principle in health-intervention design, that an intervention's real-world value depends as much on how reliably it reaches its target population as on how well it performs under controlled trial conditions [16].

This same logic explains why implementation-related criteria carried more weight than clinical effectiveness in determining the final ranking. Cost, scalability, sustainability, and feasibility together accounted for 0.60 of the total score, compared to 0.30 for clinical effectiveness, so an intervention with only moderate biological impact but strong delivery properties could still outrank one with stronger biological impact but weaker logistics. This weighting choice reflects a recognized rationale for using MCDA in public health policy: decision-makers operate under constrained budgets and existing infrastructure, so an intervention that performs only moderately in a clinical trial but can be sustained indefinitely at low marginal cost may deliver more population-level benefit over time than one with a larger effect size but a fragile delivery system [16] [15]. Fortification's cost advantage illustrates this directly: at USD 66 per DALY averted, compared with USD 179 for supplementation, most of its cost is a one-time regulatory and industrial investment rather than a recurring per-person expense [22].

Iron supplementation's low overall rank, despite its clinical strength, illustrates the opposite side of this trade-off. Meta-analytic evidence shows that supplementation reduces overall anemia by 39% and iron-deficiency anemia by 80%, with no major adverse effects [14]. Yet program-level data from Ghana, Ethiopia, and India consistently show that supplementation's field effectiveness depends on adherence that is difficult to sustain in practice, with dropout linked to side effects, forgetfulness, and irregular distribution schedules [18] [21] [24]. This gap between demonstrated clinical efficacy and demonstrated field effectiveness is precisely what an MCDA is designed to surface: efficacy answers whether an intervention works under ideal conditions, while feasibility and sustainability answer whether it will keep working once handed to a resource-constrained health system [20].

None of this suggests supplementation should be abandoned. WHO guidance is itself risk-stratified: daily supplementation is recommended where anemia prevalence exceeds 40%, and weekly supplementation is recommended specifically for adolescent girls because menstrual iron losses place them at elevated risk regardless of dietary intake [7] [8]. Because fortification delivers a fixed and modest iron increment through ordinary food consumption, it is unlikely on its own to close the gap for girls who are already iron-deficient, and it may under-reach rural adolescents who consume locally milled, unfortified flour rather than commercially fortified products. The regional precedent from Karakalpakstan, where supplementation was deliberately targeted at a subregion with anemia prevalence 40–50% above the national average rather than distributed nationally, is instructive for Kazakhstan: it suggests supplementation is most defensible not as a national default but as a targeted layer for adolescent subgroups whose risk a population-wide strategy like fortification cannot fully address [23].

Nutrition education's position in the ranking follows a related pattern. It scored well largely because of its low cost, high scalability, and strong acceptability, not because it directly corrects iron status. A school-based trial in Jordan found significant improvement in knowledge and reported dietary practices but did not demonstrate a corresponding change in hemoglobin [29], while a teacher-delivered trial in Rajasthan showed that a brief curriculum can shift attitudes and behavioral intentions across many schools at once [31]. At the same time, evidence from Nepal found that low anemia knowledge was itself associated with which girls became anemic, and that girls with poor supplementation adherence were nearly 27 times more likely to develop anemia [13]. Taken together, these findings suggest that education's primary value lies less in treating anemia directly and more in improving the performance of other interventions: a digital education companion added to routine supplementation in Indonesia measurably improved adherence to iron and folic acid tablets compared with supplementation alone [35]. This helps explain why the combined intervention, which layers supplementation, education, and screening together, achieved the highest clinical-effectiveness score of any strategy in this analysis, even though the added coordination and cost of running three components simultaneously pulled its composite ranking below fortification and education alone [33] [32].

These findings should be interpreted alongside the limitations of the MCDA itself. The criterion weights were set using expert judgment informed by the literature rather than a structured elicitation involving Kazakhstani policymakers, clinicians, or adolescents, so decision-makers who prioritized

adolescent-specific clinical outcomes more heavily could reasonably arrive at a different ranking, one favoring the combined intervention or supplementation over fortification [15]. School-based screening could not be scored on the same numeric scale as the other three interventions because it identifies anemia rather than treating it directly, which means this analysis likely understates its practical value as a low-cost referral mechanism that connects at-risk adolescents to fortification, supplementation, or education programs.

Much of the evidence used to score feasibility, cost, scalability, and sustainability was drawn from neighboring countries or other low- and middle-income settings rather than from Kazakhstan-specific program data, which limits how precisely the scores generalize to the Kazakhstani context. Several of the underlying studies, including the school-based screening evidence, were cross-sectional, which restricts causal interpretation.

Read as a whole, the results support a layered rather than single-intervention strategy: fortification as the population-wide foundation, education as a low-cost reinforcing mechanism, and targeted supplementation reserved for adolescents whose risk the first two cannot fully address.

Based on these findings, a realistic near-term policy priority for Kazakhstan would treat food fortification, the addition of micronutrients such as iron to widely consumed staple foods (in Kazakhstan's case, wheat flour) during industrial processing, as the population-wide foundation of anemia prevention, since it is already mandated and requires no new individual-level compliance, while using school-based nutrition education to reinforce dietary practices and strengthen adherence to any supplementation adolescents do receive. Iron supplementation should be preserved as a targeted layer for adolescent subgroups at elevated risk, including girls with heavy menstrual losses, rural adolescents who may rely on unfortified flour, and those identified through school-based screening, rather than promoted as a universal, stand-alone program. This layered structure follows directly from where each intervention scored strongest in the MCDA, rather than treating the single highest-ranked option as a substitute for the others.

CONCLUSION

This paper set out to identify which anemia interventions are most effective and realistically implementable for adolescent girls in Kazakhstan. The evidence reviewed confirms that iron-deficiency anemia in this population arises from a convergence of increased physiological demand, menstrual iron loss, and unequal access to nutritious food, and that this burden persists in specific subgroups even as national rates have improved [4] [5]. Applying multi-criteria decision analysis showed that food fortification offers the strongest overall balance of clinical benefit and real-world feasibility, with nutrition education and targeted iron supplementation playing complementary roles rather than standing alone.

As outlined above, Kazakhstan is well positioned to act on these findings without building new delivery systems: fortification should serve as the population-wide foundation, nutrition education should reinforce

dietary practices and supplementation adherence, and targeted iron supplementation should be reserved for adolescent subgroups at elevated risk.

Future research should prioritize a Kazakhstan-specific evaluation of this layered fortification-plus-targeted-supplementation model, paired with a formal stakeholder weighting exercise to test the ranking's sensitivity to different value judgments.

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