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RED-S Risk Assessment and Association Between Dietary Intake and Performance Among Athletes

Risikobewertung des RED-S und Zusammenhang zwischen Nahrungsaufnahme und Leistungsfähigkeit bei Athleten

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Summary

- **Introduction:** Relative Energy Deficiency in Sport (RED-S) results from low energy availability and negatively affects athlete health and performance. Data on RED-S prevalence among Indian athletes remain limited. This study aimed to quantify the prevalence of RED-S risk and examine whether lower energy intake is associated with impaired physical performance among young athletes.
- **Methods:** A total of 316 endurance state and national-level athletes (18-25 years) from Tamil Nadu, India, were recruited using purposive sampling. RED-S risk was assessed using the Relative Energy Deficiency in Sport Screening Tool (RST). Dietary intake was evaluated using a 24-hour dietary recall and food frequency questionnaire, and physical fitness performance was assessed using standardized tests of cardiovascular endurance, muscular endurance, muscular strength, and flexibility. Group differences were analysed using chi-square tests and ANOVA.
- **Results:** Moderate-to-high RED-S risk was observed in 73% of female and 51% of male athletes (χ^2=8.58, p<0.01). Mean energy and nutrient intakes were below ICMR-RDA 2024 recommendations in both sexes. Athletes classified as low RED-S risk demonstrated significantly superior cardiovascular endurance, muscular endurance, and flexibility compared to high-risk athletes (p<0.05). Associations between lower energy intake and poorer performance outcomes were more pronounced among females.
- **Conclusion:** This study provides first quantitative evidence of a high prevalence of RED-S risk among Indian athletes and demonstrates its association with inadequate dietary intake and reduced physical performance. Early screening and targeted nutrition interventions are essential to protect athlete health and optimize performance.

KEY WORDS:
Relative Energy Deficiency in Sport, Energy Intake, Physical Performance, Athletes, India

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Introduction

Relative Energy Deficiency in Sport (RED-S) is a clinical syndrome resulting from low energy availability (LEA), a state in which the dietary energy remaining after exercise energy expenditure is insufficient to support optimal physiological functions required for health and performance. Prolonged exposure to LEA can impair metabolic rate, menstrual function, bone health, immunity, and athletic performance (7, 8). Initially described as the Female Athlete Triad, the concept was expanded by the International Olympic Committee (IOC) to include both male and female athletes and a broader range of physiological and performance impairments (3, 11, 15).

RED-S affects multiple systems including metabolism, bone health, reproductive and cardiovascular function, immunity, and psychological well-being. Athletes in endurance and weight-sensitive sports are particularly vulnerable due to high energy expenditure and pressures related to body composition (1,3,5,16). The consequences range from fatigue, recurrent injuries, and poor recovery to long-term risks such as hormonal disturbances and osteoporosis.

Nutritional factors are central to RED-S. Insufficient caloric intake, whether intentional or unintentional, limits energy available for recovery and normal physiological processes, leading to impaired health and performance (12, 25). Carbohydrate deficiency reduces glycogen stores and accelerates fatigue, while inadequate protein compromises muscle repair and immune defence (32). Micronutrient deficiencies, especially calcium, vitamin D, and iron, are also prevalent, contributing to low bone mineral density, impaired oxygen transport, and reduced energy metabolism (33). Furthermore, restrictive eating practices and disordered eating behaviours frequently exacerbate LEA in sports emphasizing aesthetics or weight categories (35, 36).

Despite increasing global recognition, the identification of RED-S remains challenging, as dietary self-reports alone cannot be used to identify athletes at risk due to reporting bias and compliance limitations. Research on RED-S in the Indian sporting context is still limited, underscoring the need for region-specific studies.

The present study aims to assess the risk of RED-S among athletes and to examine the relationship between energy availability-related dietary intake indicators, RED-S risk, and physical performance. By evaluating energy availability, nutrient consumption, and performance outcomes, the study seeks to provide evidence-based insights for developing targeted nutritional strategies to optimize athlete health and performance.

Despite growing international evidence on Relative Energy Deficiency in Sport (RED-S), data on its prevalence and performance implications among Indian athletes are scarce. Most existing studies originate from Western populations, limiting their applicability to the Indian sporting and nutritional context. Therefore, the present study aims to assess the prevalence of RED-S risk among Indian athletes and to examine the relationship between energy availability-related dietary intake indicators, RED-S risk, and physical performance. By evaluating energy intake, nutrient consumption, and performance outcomes, this study seeks to provide first empirical evidence from India to inform context-specific screening, nutrition education, and targeted intervention strategies for optimizing athlete health and performance.

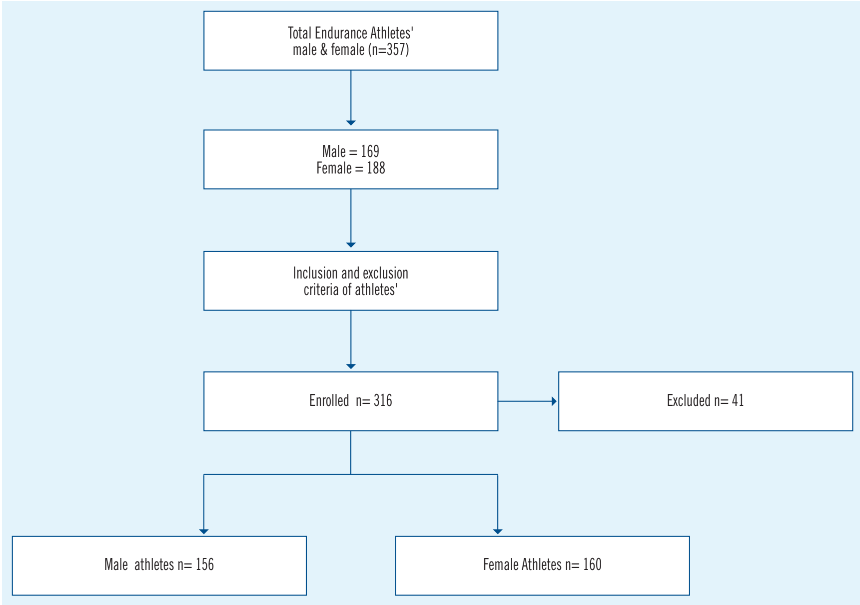

Figure 1
Selection and recruitment of study participants.

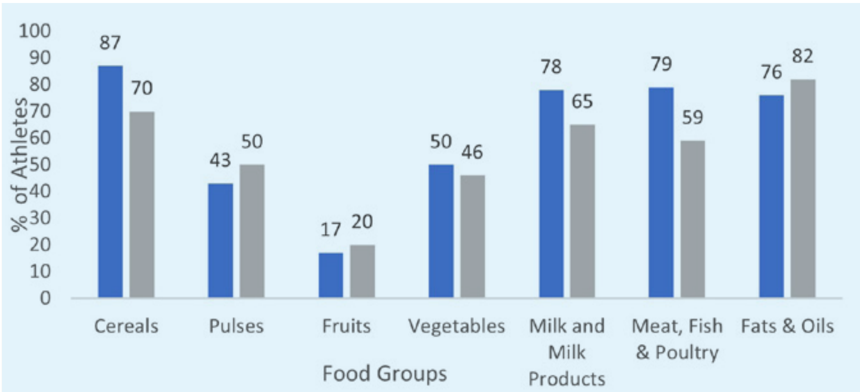

Figure 2
Daily mean consumption of food groups. Blue=Male, grey=female.

Methods

Athletes for this study were recruited from Tamil Nadu, India, using purposive sampling. A total of 316 endurance state and national level athletes (156 males and 160 females) were selected according to predefined inclusion and exclusion criteria. The selection process is shown in figure 1. Eligible participants were aged 18-25 years (The age range was restricted to 18-25 years to reduce age-related physiological heterogeneity that could influence energy availability, RED-S risk, and performance measures), actively engaged in structured sports training or competition for at least five days per week over the past three years, and had competed at state or national levels. Exclusion criteria included athletes aged 26 years or above, pregnant athletes, and those with recent or pre-existing injuries or medical conditions likely to impair performance. Individuals undergoing treatment for chronic illnesses such as diabetes, hypertension, or thyroid disorders were also excluded. Written consent from the study participants was received before the commencement of the study (figure 2). The study protocol was reviewed and approved by the Institutional Human Ethics Committee (Approval No: AUW/IHEC/FSMD/23-24/FHP-01, dated 12th April 2024).

Background information was obtained through a structured interview schedule. Age, sex, level of participation, major specialization, etc. were collected. Along with that, the socio-demographic profile was also collected based on the modified Kuppuswamy Scale (2023) (34) and anthropometric details of the athletes were assessed by the investigator using standard procedures, including measurement of BMI and waist-hip ratio. The risk of RED-S was evaluated using the RED-S Screening Tool (RST) developed by Foley et al. (2020) (9). The RST includes 30 items grouped into seven subsections.

The performance tests selected in this study are validated field-based assessments of general physical fitness components, including muscular strength, flexibility, muscular endurance, and cardiovascular endurance. These tests are widely used and appropriate for young adult athletes across multiple endurance sports disciplines and competitive levels. The study aimed to evaluate general fitness indicators associated with RED-S risk rather than sport-specific performance; therefore, standardized tests with demonstrated validity and feasibility in heterogeneous athletic populations were chosen. Muscular strength, defined as the capacity of muscles to exert maximum force in a single effort against resistance, was evaluated using the plank test (20). Flexibility, which indicates the range of motion at a joint or series of joints and the ability to move without discomfort or stiffness, was assessed through the sit-and-reach test (38). Muscular endurance, referring to a muscle or muscle group's ability to perform repeated contractions or maintain a static hold over time without excessive fatigue, was measured using the sit-up test (25). Cardiovascular endurance, the ›

Table 1
Distribution of RED-S screening tool scores by subsection among male and female athletes.

SUBSECTION OF RED-S SCREENING TOOL	TOTAL SCORE	
	FEMALE	MALE
1. Menstrual function	150	-
2. Activity levels	100	100
3. Nutrition/diet/weight	290	290
4. Injury	100	100
5. Factors that affect bone mineral density	50	50
6. Psychologic effects	75	75
7. Physiological effects	115	115
Total	880	730

Table 2
RED-S Scoring Classifications to determine the risk level

RISK LEVEL	SCORE	
	FEMALE	MALE
Low risk	<150	<100
Moderate risk	151-500	101-400
High risk	>500	>400
Maximum possible score	880	730

efficiency with which the heart, lungs, and circulatory system deliver oxygen to muscles during prolonged physical activity, was tested using the 12-minute Cooper test (2).

Dietary intake was assessed using a combination of repeated 24-hour dietary recalls and a semi-quantitative Food Frequency Questionnaire (FFQ) under the supervision of a trained sports nutritionist. Habitual dietary intake over the preceding six months was evaluated using the FFQ, while short-term intake variability was captured through repeated 24-hour dietary recalls collected over a two-week period. The 24-hour recall method involved detailed documentation of all foods and beverages consumed during the previous day, including portion sizes and preparation methods, using standardized household measures. Nutrient intake was estimated using standard Indian food composition tables. The combined use of these methods enabled assessment of both short-term intake and long-term dietary patterns, providing a comprehensive understanding of participants' nutritional practices in relation to dietary guidelines (13,18). Estimated dietary intake was compared with the Indian Recommended Dietary Allowances (RDA) issued by the ICMR-NIN (2020, 2024), which serve as nationally accepted reference standards for dietary assessment in India. Based on RDA classification, individuals are categorized into sedentary, moderate, and heavy activity levels; as the participants were competitive athletes, they were classified under the heavy activity category to reflect their higher energy and nutrient requirements. This classification provided a contextual reference for expected nutrient needs but did not permit direct measurement of actual energy expenditure or precise identification of dietary gaps (13, 17, 18).

Statistical analysis was carried out using IBM SPSS Statistics version 26.0. The normality of the data was evaluated using the Kolmogorov-Smirnov test. Descriptive statistics, chi-square tests, analysis of variance (ANOVA), and correlation analysis were employed. The association between RED-S and sex (male vs. female athletes) was examined using chi-square analysis. The relationship between relative energy deficiency and performance was assessed using correlation analysis. ANOVA was used to determine the significant differences between energy intake and physical fitness performance scores among the RED-S categories.

Results

Demographic profile of athletes

Among the 316 athletes, 66.7% of females and 71.2% of males were aged 18-21 years. Socio-economic status, according to the Modified Kuppuswamy Scale (2023), indicated that 34.4% of females and 45.6% of males belonged to the upper-lower class (low-middle socio-economic status). Additionally, 67.2% of females and 60.8% of males were hostlers.

Anthropometric details of athletes

Among the 316 athletes, Underweight prevalence was observed in 20% of males and 18% of females, whereas 10% of males and 14% of females were classified as overweight or obese. The predominance of normal BMI among the athletes may be attributed to their high physical activity levels inherent to physical education training, which reduces the likelihood of overweight and Obesity. A higher waist-hip ratio was noted in 17% of males and 26% of females, indicating central adiposity among obese athletes, while most athletes showed normal waist-hip ratios (83% males and 74% females).

In Table 3, 51% of male athletes and 73% of female athletes were in the medium RED-S category, while 7% of males and 11% of females were in the high RED-S category. The chi-square test indicated a significant association between RED-S category and gender (χ^2=8.58, p=0.04).

Table 4 presents the estimated average daily intake of macro- and micronutrients among 156 male and 160 female athletes in comparison with the 2024 RDA values. The estimated energy intake was lower than the recommended levels in both female and male athletes, indicating mean deficits of approximately 364 kcal and 210 kcal, respectively. Protein and carbohydrate intake were also below RDA in both groups. Micronutrient intake showed notable gaps, particularly for zinc, vitamin C, vitamin A, vitamin D, iron, magnesium, and calcium. Fat intake was relatively closer to recommended levels in both groups. These findings reflect estimated deviations from RDA and should be interpreted cautiously.

Figure 2 illustrates the daily mean consumption patterns of various food groups among male and female athletes.Cereals were the most consumed, with 87% of males and 80% of females reporting daily intake. Pulse consumption was higher among females (50%) than males (43%). Fruit intake was low in both groups (17% males, 20% females), and vegetable consumption was similarly inadequate (50% males, 46% females). Dairy intake was higher in males (78%) than females (65%). Meat, fish, and poultry were consumed daily by 79% of males and 59% of females. Fat and oil intake was slightly higher among females (82%) than males (76%).

Table 5 presents the correlation between energy intake and physical performance variables among athletes. Energy intake showed a moderate positive correlation with the Cooper test (r=0.765, p=0.03). Sit-up performance demonstrated a strong positive correlation (r=0.654, p=0.03). The sit-and-reach test showed the weaker correlation (r=0.265, p=0.03). A statistically significant correlation was noted with plank duration (r=0.534, p=0.01).

Table 3

Comparison of RED Scores among selected athletes

RED-S RISK CATEGORY	GENDER (N=316)				CHI SQUARE VALUE (χ^2)	P VALUE
	MALE(N=156)		FEMALE(N=160)			
	N	%	N	%		
Low RED-S	63	42	23	16		
Medium RED-S	80	51	118	73	8.58	0.04*
High RED-S	13	7	19	11		

Table 4

Estimated average daily nutrient intake of athletes derived from repeated 24-hour dietary recalls in comparison with RDA (2024). Values represent estimated average daily intake derived from repeated 24-hour dietary recalls collected over a two-week period and analysed using Indian Food Composition Tables (ICMR-NIN). Differences indicate deviation from RDA and should be interpreted as indicative estimates rather than precise habitual intake.

NUTRIENTS	REFERENCE -RDA FEMALE -2024	FEMALE (N=160)	THE ABSOLUTE DIFFERENCE OF INDIVIDUAL INTAKE – RDA	REFERENCE -RDA MALE -2024	MALE (N=156)	THE ABSOLUTE DIFFERENCE OF INDIVIDUAL INTAKE – RDA
PROXIMATE NUTRIENTS						
Energy	2720 Kcal	2356.70±332.05	-364	3470	3260±320.2	-210
Protein	46 g	37.24±4.6	-8,4	54	50.01±2.5	-4
Fat	30 g	29.69±4.11	-0,4	40	39.89±3.1	-0,2
CHO	280 g	243±31.23	-37	330	320±35.23	-10
MICRO NUTRIENTS						
Zinc	13.2 mg	10.90 ± 1.85	-2,3	17	13±2.5	-4
Vitamin C	65 mg	54.95±3.69	-10,1	80	65.09±3.4	-15
Vitamin A	840 µg	715.12±129.26	-125	1000	867.65±110.78	-133
Vitamin D	600 µg	553.64±28.90	-47	600	583±32.12	-17
Iron	29 mg	20.38±3.21	-8,62	19	13±1.23	-6
Magnesium	370 mg	290.26 ±43.17	-80	400	290±58.34	-110
Ca	1000 mg	927.96±34.65	-73	1000	912±54.34	-88

ANOVA was used to examine the differences in physical performance between athletes classified as low- and high-risk for RED-S based on their energy intake. Low-risk male athletes, who consumed more calories (as per RDA) (3210 kcal/day), performed significantly better in the Cooper test (2430±135m) plank (261±50s) and sit-ups (50±1) compared to high-risk athletes (2910 kcal/day), with an F-value of 7.24 and p=0.03. Similarly, low-risk female athletes (2232 kcal/day) demonstrated superior performance in the Cooper test (2110±113m), plank (160±55 s) and sit-ups (43±2) relative to high-risk females (1989 kcal/day), with an F-value of 7.45 and p=0.04. These findings indicate that recommended dietary intake is associated with better physical fitness performance and lower RED-S risk.

Discussion

The present study revealed a considerable prevalence of Relative Energy Deficiency in Sport (RED-S) among athletes, with female athletes more frequently categorized at moderate-to-high risk compared to males. This gender difference has also been reported in other populations, where female athletes in endurance and intermittent sports are shown to be particularly vulnerable to low energy availability (23, 35, 28). The higher risk among females in our study may be linked to factors such as greater dietary restraint, social pressures, and physiological demands, although these variables were not directly assessed here.

Nutrient intake analysis indicated that both male and female athletes consumed less energy and micronutrients than recommended levels. Importantly, deficits were calculated against the ICMR-NIN 2024 RDA values for heavy activity (athletes' category), ensuring that the comparison reflects the increased energy and nutrient demands of trained individuals rather than sedentary adults. This aligns with evidence that athletes often fail to match intake with expenditure, especially for micronutrients such as iron, calcium, vitamin D, and zinc (4, 6, 35, 36). In particular, the observed shortfalls in iron and calcium are concerning, as these nutrients are critical for oxygen transport, recovery, and bone health, and their inadequacy has been widely associated with RED-S symptoms (37, 41, 42). The insufficiency observed in this study parallels national trends, as highlighted by the Indian National Family Health Survey (NFHS-5) (29), which reported low daily fruit and vegetable intake among adolescents and young adults—further reinforcing that inadequate dietary quality contributes to both micronutrient deficiencies and elevated RED-S risk in athletes. And one more important factor observed meat consumption appears higher than traditionally expected in India. However, recent evidence suggests a nutrition transition, particularly among urban and athletic populations. Athletes often include animal-source foods to meet increased protein and micronutrient requirements (31, 32, 33, 37).

When compared internationally, the prevalence of RED-S risk (using RST tool) in our cohort (medium-to-high risk in ›

Table 5

Correlation between energy intake and the performance of athletes. *=significant at p<0.05.

PHYSICAL FITNESS/ PERFORMANCE VARIABLES	M±SD	PEARSON CORRELATION (R) VALUE	P VALUE
Cooper test (meter)	2620±154	0,765	0.03*
Plank (seconds)	255±65	0,534	0.01*
Sit Up (count)	52±3	0,654	0.03*
Sit and reach (centimeter)	23±6	0,265	0.03*

~83% of females and ~58% of males) appears similar to findings from European endurance athletes, where 60-80% of females and 40-60% of males were reported to experience low energy availability (10, 21, 24).These parallels suggest that RED-S is a global concern extending beyond Western contexts, with Indian athletes facing similar nutritional and performance-related challenges.

The correlation analysis revealed significant positive associations between energy intake and all assessed physical fitness variables, indicating that recommended dietary energy intake is related to better physical performance. Among the variables, aerobic endurance assessed by the Cooper test demonstrated the strongest correlation with energy intake (r=0.765, p<0.05), followed by sit-ups, plank performance, and sit-and-reach flexibility.

The strong association between energy intake and Cooper test performance can be attributed to the high dependence of aerobic endurance on adequate energy availability, particularly carbohydrate intake and glycogen stores. Insufficient energy intake can impair oxidative metabolism, reduce glycogen availability, and increase early fatigue, thereby negatively affecting sustained aerobic performance. Consequently, athletes with higher energy intake are better able to maintain cardiovascular endurance, resulting in superior Cooper test outcomes.

Moderate correlations observed for sit-ups and plank performance suggest that muscular endurance and core strength are also influenced by energy intake, although these components may be partially maintained through neuromuscular adaptations and technique. In contrast, sit-and-reach flexibility showed the weakest correlation, indicating that flexibility may be less directly dependent on short-term energy intake and more influenced by factors such as habitual stretching, joint structure, and muscle-tendon properties.

Our analysis further demonstrated that athletes classified as low risk for RED-S consistently performed better across endurance, strength, and flexibility tests compared to moderate- and high-risk groups. This pattern supports existing literature showing that inadequate energy availability compromises glycogen stores, muscle protein synthesis, and overall recovery, thereby reducing performance capacity (21, 22, 23). Although cause-effect relationships cannot be confirmed in this cross-sectional design, the consistent association highlights the critical role of adequate fueling in supporting athletic performance.

Furthermore, it is important to acknowledge the limitations of this study. An a priori sample size calculation based on power analysis was not performed. As this study was designed as an exploratory cross-sectional investigation to estimate RED-S risk prevalence among Indian athletes, a population for which no prior data were available to inform effect size assumptions. Dietary intake was assessed using self-reported 24-hour dietary recalls and a food frequency questionnaire, which are subject to recall bias and potential under- or over-reporting. Although data collection was conducted under the supervision of a trained sports nutritionist to improve accuracy, some degree of measurement error cannot be excluded. In addition, detailed documentation of training load (e.g., METs or PAL values) was not available, which may have limited precise estimation of energy availability. Physical fitness assessments were administered by a single assessor; however, standardized testing protocols were followed to minimize variability. Finally, the performance tests employed primarily assessed general physical fitness rather than sport-specific performance; nevertheless, standardized field-based tests such as the Cooper test were selected as practical and validated indicators of aerobic capacity in the absence of laboratory-based assessments.

Overall, these findings emphasize the urgent need for targeted nutritional strategies to address energy and micronutrient gaps among Indian athletes. Future research should include longitudinal monitoring of dietary behaviours, hormonal profiles, and psychological factors such as body image perceptions, which may help explain gender differences in RED-S vulnerability. Addressing these factors will be vital for optimizing both the health and performance of athletes.

Conclusions

In conclusion, the present study provides first insights into the prevalence of RED-S risk among Indian athletes, highlighting

Table 6

Analysis of variance between RED-S scores, energy consumption and physical fitness performance measures among male & female athletes.

RED IN MALE ATHLETES	ENERGY (KCAL)	PHYSICAL FITNESS PERFORMANCE OF ATHLETES (MEAN±STD. DEVIATION)				F VALUE	P VALUE
		COOPER TEST (METER)	PLANK (SECONDS)	SIT UP (COUNT)	SIT AND REACH (CENTIMETER)		
ANALYSIS OF VARIANCE BETWEEN RED-S SCORES, ENERGY CONSUMPTION AND PERFORMANCE MEASURES AMONG MALE ATHLETES							
Low risk (N=63)	3210	2430±135	261±50	50±1	22±4		
Moderate Risk (N=80)	3012	2313±125	264±25	42±5	19±5	7.24	0.03*
High risk (N=13)	2910	2131±130	198±12	40±2	19±2		
ANALYSIS OF VARIANCE BETWEEN RED-S SCORES, ENERGY CONSUMPTION AND PERFORMANCE MEASURES AMONG FEMALE ATHLETES							
Low risk (N=23)	223	2100±113	160±55	46±2	30±3		
Moderate Risk (N=118)	215	1730±120	132±25	42±8	26±4	7.45	0.04*
High risk (N=19)	1989	1700±105	124±12	37±3	27±5		

a high proportion of moderate- to high-risk individuals, particularly among females. The observed associations between RED-S risk, inadequate dietary intake, and reduced physical performance underscore the relevance of energy availability as a critical factor influencing athlete health and performance. These findings emphasize the need for early screening, structured nutrition education, and individualized sports nutrition interventions within the Indian sporting context. Given the limited RED-S data available from India, the present study contributes valuable baseline evidence and supports the integration of evidence-based nutrition strategies to protect athlete well-being, optimize performance, and promote long-term athletic sustainability.

Conflict of Interest

The authors have no conflict of interest.

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Ethical Approval

Approved by Institutional Human Ethical Committee , Avinashilingam Institute for Home Science and Higher Education for Women. Ethical Approval Number: AUW/IHEC/FSMD/23-24/FHP-01

Summary Box

What is already known about this topic?

- This study adds to the existing evidence on Relative Energy Deficiency in Sport (RED-S) by estimating its prevalence among athletes, with a higher risk observed among female athletes. The findings support earlier research by showing that RED-S risk is associated with inadequate energy and micronutrient intake, particularly iron, calcium, and vitamin D.

What does this study add?

- The study further demonstrates a significant association between RED-S risk and reduced physical performance parameters, including endurance, strength, and flexibility, using ANCOVA analysis. These results highlight low energy availability as a key factor influencing athletic performance. The findings emphasize the need for targeted nutrition strategies to reduce RED-S risk and improve performance, especially among female athletes.

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