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Training and Nutritional Specifics of Women Competing in Road Cycling - A Literature Review

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Abstract

Introduction: Women's road cycling is developing rapidly, yet scientific data on the training and nutritional specifics of female road cyclists remain scarce compared with the literature on male cyclists, and many practical recommendations are still extrapolated from male-based research.

Aim: To systematize current knowledge on training characteristics, nutrition, menstrual cycle effects, relative energy deficiency in sport (RED-S), iron deficiency, altitude training, pregnancy-related return to sport, and sex-specific supplementation responses in female road cyclists.

Material and methods: This descriptive literature review was based on searches in PubMed/MEDLINE and Google Scholar, covering systematic reviews, meta-analyses, official consensus statements, and original studies published mainly between 2015 and 2026.

Results: Female cyclists show lower training volume but relatively higher intensity than males. Race nutrition data in women remain limited, mostly based on single case studies. Menstrual cycle phase appears to affect recovery more than performance. RED-S, iron deficiency, and low bone mineral density are frequent, interrelated health concerns. Altitude training, postpartum return to competition, and sex-specific supplement efficacy remain markedly understudied areas.

Conclusions: Female road cyclists remain underrepresented in sports science research. Training and nutrition recommendations should not be simply extrapolated from male data. Further sex-specific research is needed to guide evidence-based practice in this rapidly growing discipline.

Keywords: female athletes; road cycling; sports nutrition; menstrual cycle; relative energy deficiency in sport; iron deficiency; altitude training; sex differences

1. Introduction

Women's road cycling has undergone rapid development in recent years, reflected in the growing number of professional women's teams and the inclusion of multi-stage Grand Tour races, such as the Tour de France Femmes, in the competition calendar [1]. Despite this progress, scientific research on the training and nutritional specifics of women competing in road cycling remains scarce compared with the extensive literature on male cyclists, and numerous authors emphasize a clear deficit of empirical data in this population [1-3].

Available comparative studies indicate that training characteristics differ substantially between men and women at the highest professional level. Van Erp et al. demonstrated that female cyclists exhibit lower training volume than males, in particular spending less time in low- and moderate-intensity zones, despite a comparable relative training load as measured by the Training Stress Score [2]. A similar direction of differences was confirmed in a more recent study comparing weekly training characteristics of WorldTour female and male athletes, which hypothesized lower training volume but higher relative training intensity in women, potentially reflecting the distinct demands of women's road racing [1]. Authors of a review summarizing the physiological determinants of success in professional cycling likewise noted that, with the ongoing professionalization of women's cycling and the increasing possibility of full-time training, the training characteristics of leading female athletes may continue to evolve [3].

In the area of sports nutrition, data on professional female cyclists are particularly limited. Authors of the most recent review on race nutrition in road cycling point directly to the paucity of published data in the population of professional female cyclists, citing as one of the few available examples a case study of a single athlete during the Tour de France Femmes, in which daily carbohydrate intake ranged between 9.7-15.9 g/kg body mass and on-bike carbohydrate intake ranged between 68-105 g/h [5,7]. These authors emphasize the need for further research addressing changes in energy stores and energy expenditure specifically in women competing in multi-stage races [5]. In parallel, the physiological literature underscores the importance of protein quality and quantity in the athlete's diet for maintaining muscle protein turnover, which is of particular relevance in the context of high-volume endurance training [8].

An important area distinguishing the training physiology of women from that of men is the influence of the menstrual cycle on exercise capacity and recovery. The scientific evidence in this regard remains inconclusive. On one hand, menstrual cycle phase has been shown to affect the subjective quality of post-training recovery more than exercise capacity itself during high-intensity interval training in trained female cyclists [9], and a clustering analysis of training sessions in elite French female cyclists conducted over 30 months suggests the possibility of adjusting training intensity according to menstrual cycle phase or the use of combined hormonal contraception [11]. On the other hand, studies of power output profiles during standardized submaximal rides have not revealed clear differences between the early and late follicular phases, with the authors cautioning that a larger sample size is required before formulating practical recommendations [10]. Similarly inconclusive results have been reported regarding strength-related responses - a systematic review found no significant effect of menstrual cycle phase on strength performance or adaptations to resistance training [13], whereas other studies indicate a differentiated cardiorespiratory response to endurance exercise depending on cycle phase and the use of hormonal contraception [12]. These discrepancies are partly attributed to methodological limitations of existing studies, as noted by the authors of an international methodological guide for research involving women in sport and exercise science [14].

A particularly important clinical issue is the phenomenon of relative energy deficiency in sport (RED-S), encompassing disturbances in energy availability, menstrual dysfunction, and reduced bone mineral density [15,16]. A study of competitive male and female cyclists with lower-than-expected bone mineral density demonstrated an association between this phenomenon and insufficient energy availability together with specific dietary patterns [18]. In one qualitative study, as many as 45% of surveyed female cyclists reported experiencing irregular menstrual cycles, either currently or in the past, which the authors link to possible low body weight and insufficient energy intake relative to training demands [24]. A related problem is iron deficiency, which affects up to 60% of women competing in sport and is associated with a 3-4% reduction in endurance capacity, whereas appropriate iron supplementation may improve endurance capacity by as much as 2-20% [19].

Female cyclists are also exposed to health problems specific to this discipline, such as saddle sores and chafing, which according to a systematic review represent a common yet insufficiently studied problem among competitive athletes [21]. It is also worth noting that research on strength training among professional UCI cyclists showed that women engage in regular strength training more often than men, both during the preparatory period (96.6% vs. 85.3%) and the competitive season (66.1% vs. 36.4%), with the main motivations cited being improved performance, injury prevention, and concern for bone health [22].

Given the above - both the physiological and training-related differences between sexes and the female-specific hormonal, nutritional, and health-related considerations - it appears warranted to systematize the current scientific knowledge regarding the training and nutritional specifics of women competing in road cycling, with particular attention to areas where the available data remain incomplete or inconclusive.

2. Material and Methods

This paper takes the form of a descriptive (narrative) literature review. The aim of the applied methodology was to collect and systematize currently available scientific data on the training and nutritional specifics of women competing in road cycling, without applying a formal systematic review protocol (e.g., PRISMA), owing to the heterogeneous nature of the topics analyzed, spanning exercise physiology, nutrition, sports endocrinology, and injury epidemiology.

The literature search was conducted in the PubMed/MEDLINE and Google Scholar databases, as well as through searches of the websites of scientific journal publishers (including the International Journal of Sport Nutrition and Exercise Metabolism, Journal of Sport and Health Science, British Journal of Sports Medicine, and PLOS ONE). The search covered publications mainly from 2015–2026, with particular emphasis on papers published between 2024–2026 owing to the rapid development of research on women's cycling during this period.

The following keywords and their combinations were applied: female road cyclists, women cycling training, menstrual cycle cycling performance, RED-S cycling, low energy availability female athletes, iron deficiency female athletes, bone mineral density cyclists, saddle sores female cyclists, strength training cyclists, UCI Sports Nutrition Project.

The review included: systematic reviews and meta-analyses, official consensus statements from sporting organizations (including the International Olympic Committee), and original studies (observational, cohort, case reports) concerning women competing in road cycling or - given the limited number of discipline-specific studies - women competing in other endurance disciplines, provided that the findings could be contextually relevant to road cycling. Only publications in English and Polish, available as full text or a detailed abstract, were included.

Works not subjected to scientific peer review (e.g., popular-science articles, blog posts), conference reports without full text, and publications whose reliability or complete bibliographic data could not be unambiguously verified during the search were excluded from the review.

It should be emphasized that, owing to the narrative rather than systematic nature of this review, the material presented does not constitute an exhaustive analysis of the entirety of available literature in this area, but rather a representative overview of key, current scientific reports illustrating the main research directions and existing research gaps regarding the training and nutritional specifics of women in road cycling.

3. Results

3.1. Training Characteristics of Professional Female Road Cyclists

Data on the training characteristics of professional female road cyclists remain scarce compared with the extensive literature on male cyclists. Authors of the most recent study comparing weekly training indicators of WorldTour female and male athletes noted that previously available data - derived mainly from the work of Van Erp et al. - comprised values averaged across the entire season, including the competitive period, which may have distorted the actual picture of training differences between sexes during the preparatory phase [1,2]. In a more recent study, comprising 16 women (26 ± 5 years) and 16 men (29 ± 6 years) at the WorldTour level, it was hypothesized that women would be characterized by lower training volume alongside higher relative intensity, potentially reflecting the distinct demands of women's road racing [1].

Van Erp et al., analyzing data from 20 men and 10 women at the Pro-Continental and WorldTour levels, collected over a period of one to four years, showed that female cyclists train with lower total weekly hours than men - in particular spending less time in low- and moderate-intensity zones - despite a comparable relative training load as measured by the Training Stress Score [2].

Further, albeit indirect, data are provided by a study on nighttime recovery during a Grand Tour, which compared 8 men (28.0 ± 2.5 years; body mass 70.3 ± 4.6 kg; height 181.6 ± 4.9 cm) from a single team competing in the 2022 Tour de France with 9 women (26.7 ± 3.1 years; body mass 58.0 ± 4.4 kg; height 169.8 ± 5.6 cm) from two teams competing in the 2022 Tour de France Femmes [4]. Although focused on sleep quality and autonomic activity, this study provides rare, directly comparable anthropometric data on professional female cyclists at the highest level.

It is also worth noting that the very model of training periodization and intensity/volume distribution in endurance cyclists remains a subject of scientific debate independent of sex, which further complicates the unambiguous isolation of sex-specific differences against the backdrop of general methodological variability in cycling periodization research [23].

Table 1. Comparison of the characteristics of studied groups of male and female cyclists in selected studies

Study	N (F/M)	Competitive level	Age (F)	Key finding regarding women
Mateo-March et al. 2026 [1]	16 / 16	WorldTour	26 ± 5 y	Hypothesis of lower volume, higher relative intensity (preparatory phase)
Van Erp et al. 2020 [2]	10 / 20	Pro-Continental/WorldTour	not reported in available abstract	Lower training volume, less time in low/moderate intensity
Sargent et al. 2024 [4]	9 / 8	Professional (Tour de France Femmes/TdF)	26.7 ± 3.1 y	Body mass 58.0 ± 4.4 kg; height 169.8 ± 5.6 cm

3.2. Nutrition and Nutritional Periodization

In the area of sports nutrition, data on professional female cyclists are particularly limited. Authors of a review on race nutrition in road cycling (UCI Sports Nutrition Project) point directly to the paucity of published literature in the population of professional female cyclists [5]. As one of the few available examples, they cite a case study of a single athlete during the Tour de France Femmes, in which daily carbohydrate intake ranged between 9.7-15.9 g per kilogram of body mass, and on-bike carbohydrate intake ranged between 68-105 g per hour [5,7]. For comparison, the same review indicates that in men, on-bike carbohydrate intake reaching as much as 120 g/h has been observed on the most demanding stage days, with these values having historically increased from a level of 30-60 g/h prior to 2010 [5]. The authors explicitly emphasize the need for further research addressing changes in energy stores and energy expenditure specifically in women competing in multi-stage races [5].

A separate review within the same project (UCI Sports Nutrition Project) was devoted specifically to issues of body composition, energy requirements, and energy availability in cycling [6]. At the time this review was prepared, that paper held the status of an advanced online publication, without an assigned final issue number, illustrating how current this area of research is.

In parallel, the physiological literature emphasizes the key role of adequate protein quality and quantity in the athlete's diet for maintaining proper muscle protein turnover, which is of particular importance in the context of high-volume endurance training typical of road cycling [8].

Table 2. Carbohydrate intake among professional cyclists - comparative data

Parameter	Women (case-study data)	Men (UCI Sports Nutrition Project observations)
Daily CHO intake (g/kg BM)	9.7–15.9	9.6–18.5 (individual peaks up to 22.2)
On-bike CHO intake (g/h)	68–105	10 (rest days) to 120 (most demanding stages)
Data source	1 athlete, Tour de France Femmes [7]	authors' own observations, 8 Grand Tour riders [5]

Note: data for women derive from a single case study, not a group study - they require cautious interpretation and should not be generalized to the entire population of female athletes.

3.3. Influence of the Menstrual Cycle on Training and Recovery

Scientific evidence regarding the influence of the menstrual cycle on the exercise capacity and recovery of female cyclists remains inconclusive, which is partly attributable to methodological limitations of existing studies [14].

Righi and Barroso, studying 10 eumenorrheic female cyclists across five laboratory visits (early follicular phase with bleeding, two subsequent visits in the late follicular phase, and two in the late luteal phase), demonstrated that menstrual cycle phase affects the subjective quality of post-training recovery more than exercise capacity itself during high-intensity interval training [9].

A clustering analysis of training sessions in thirteen elite French female cyclists, conducted over 30 months and comprising 5,190 training sessions and 81 complete menstrual or hormonal contraceptive cycles, suggests the possibility of adjusting training intensity according to cycle phase - the authors propose scheduling more intensive training sessions immediately after the menstrual phase, and lower-intensity sessions during menstruation itself, provided that an individual peak-intensity pattern has been identified for a given athlete [11].

Conversely, a study of power output profiles during a standardized submaximal training ride found no significant differences between the early and late follicular phases, with the authors explicitly cautioning that a larger sample size is required before formulating practical training recommendations [10]. Similarly, a systematic review found no significant effect of menstrual cycle phase on acute strength performance or on adaptations to resistance training [13], whereas other studies indicate a differentiated cardiorespiratory response to endurance exercise depending on both menstrual cycle phase and the use of combined hormonal contraception [12]. In a qualitative study involving 20 athletes at varying competitive levels (3 elite, 7 sub-elite, 10 club-level; age 35.1 ± 7.7 years; cycling experience 11.9 ± 7.4 years), as many as 45% of respondents reported experiencing irregular menstrual cycles, either currently or in the past, citing low body weight and insufficient energy intake relative to training demands as possible causes [24].

Table 3. Summary of studies on the influence of the menstrual cycle on training and recovery in female cyclists

Study	Method / sample size	Main conclusion
Righi & Barroso 2026 [9]	10 eumenorrheic cyclists, HIIT, 5 visits	Cycle phase affects recovery more than exercise capacity
Emslie et al. 2024 [10]	submaximal ride, small sample	No significant differences EF vs. LF; larger sample needed
Clustering analysis (Front Sports Act Living 2024) [11]	13 elite cyclists, 30 mo., 5,190 sessions	Potential for individualized periodization by cycle phase
Colenso-Semple et al. 2023 [13]	systematic review	No significant effect on strength performance
Barba-Moreno et al. 2022 [12]	cardiorespiratory response	Differentiated response depending on cycle phase and contraception
Qualitative study (PLOS ONE 2026) [24]	20 cyclists (interviews)	45% reported irregular menstrual cycles

3.4. Relative Energy Deficiency in Sport (RED-S) and Bone Health

The phenomenon of relative energy deficiency in sport (RED-S) encompasses disturbances in energy availability, menstrual dysfunction, and reduced bone mineral density, leading to the multisystem consequences illustrated in the diagram below [15,16]. According to the 2023 International Olympic Committee consensus statement, the consequences of RED-S extend beyond the originally described female athlete triad (disordered eating, amenorrhea, osteoporosis) and additionally include metabolic, cardiovascular, immunological, and

psychological disturbances [15]. In the practical nutritional management of RED-S, emphasis is placed on the need for a gradual increase in energy availability and the individualization of dietary intervention depending on the severity and duration of energy deficiency in a given athlete [17].
A study of competitive male and female cyclists with lower-than-expected bone mineral density demonstrated an association between this phenomenon and insufficient energy availability together with specific dietary patterns [18], indicating that this problem affects not only women but also men competing in road cycling - a phenomenon sometimes attributed to the non-weight-bearing nature of the discipline, in which the natural mechanical stimulus for bone formation, typical of running disciplines, is absent.

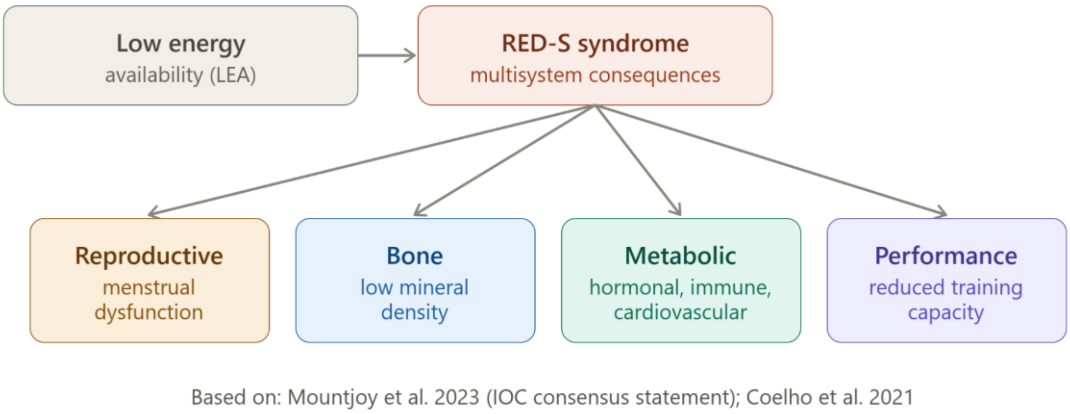

Figure 1. Conceptual overview of low energy availability and the multisystem consequences of relative energy deficiency in sport (RED-S).

3.5. Iron Deficiency

Iron deficiency remains a common problem among women competing in sport, affecting up to 60% of female athletes [19]. In a systematic review by Pengelly et al., comprising 23 studies and 669 female athletes aged 13-47 years from 16 sporting disciplines, iron deficiency was shown to reduce endurance capacity by 3-4%, whereas appropriate iron supplementation at a dose of 100 mg daily for up to 56 days may improve endurance capacity by 2-20% [19].
A study of elite young athletes showed that iron deficiency (serum ferritin concentration below 35 µg/L) occurred significantly more often in women than in men (57% vs. 31%, $p<0.001$), with lower ferritin concentrations in the female group additionally associated with a lower dietary iron density, suggesting different underlying mechanisms of iron deficiency in women and men competing in sport [20].

Table 4. Key data from the systematic review on iron deficiency in female athletes [19]

Parameter	Value
Number of studies included in the review	23
Number of female athletes studied	669 (age 13–47 years)
Number of sporting disciplines represented	16
Decrease in endurance capacity with iron deficiency	3-4%
Improvement in capacity after supplementation (100 mg Fe/day, up to 56 days)	2-20%

3.6. Discipline-Specific Health Issues and Strength Training in Female Cyclists

Women competing in road cycling are exposed to health problems specific to this discipline. A systematic (scoping) review devoted to saddle sores and chafing among female athletes showed that this is a common yet insufficiently studied health problem in this population [21].

Interesting data are provided by a study on strength training practices among 147 professional UCI cyclists (88 men and 59 women), which combined a quantitative questionnaire with 10 semi-structured interviews [22]. It showed that women engage in regular strength training significantly more often than men, both during the preparatory period and the competitive season.

Table 5. Prevalence of strength training among professional UCI cyclists by sex [22]

Season period	Women (n = 59)	Men (n = 88)
Preparatory period (pre-season)	96.6%	85.3%
Competitive season (race season)	66.1%	36.4%

Among the main motivations for undertaking strength training, respondents cited improved sports performance, injury prevention, and concern for bone health, whereas the most important barriers to its regular implementation included travel, fatigue, and competitive load [22].

3.7. Altitude (Hypoxic) Training and Sex Differences

The issue of sex-related differences in adaptation to altitude training remains one of the least studied areas of women's sports physiology. Authors of an extensive review devoted to women in mountain sports and hypoxic training emphasized that the scientific literature in this area is markedly scarce, with most existing studies having focused on men or not including direct comparisons between sexes [25]. These authors pointed to a potentially higher susceptibility of women to acute mountain sickness, the need for specific preparation of the respiratory system, and the influence of sex hormones on the body's response to hypoxia as important, though still largely speculative, issues requiring further research [25].

Separate physiological studies point to possible mechanistic underpinnings of these differences. Women, regardless of training status, may be more susceptible to pulmonary limitations during maximal-intensity exercise owing to smaller airways and a smaller gas-exchange surface area compared with men of similar height, which may be further exacerbated under hypoxic conditions [26]. In a study comparing the response of 26 elite American long-distance runners (17 men, 9 women) to moderate altitude, the authors emphasized the general paucity of literature data regarding erythropoietin (EPO) release at altitude in women [27].

The practical significance of altitude training is confirmed by a case report of 22 world-class female water polo players, in whom a 5.4 ± 5.1% increase in relative total hemoglobin mass (tHbmass) was observed during a 16-day "live high–train high" training camp at 2,320 m [28], suggesting that women may obtain favorable hematological adaptations from altitude training, even though the mechanisms underlying this response remain less well understood than in men.

3.8. Pregnancy and Return to Competitive Sport in Cycling

The growing number of female cyclists reaching the peak of their sporting careers during the period of optimal fertility means that an increasing number of athletes become pregnant during their competitive careers, a fact reflected in the official position of the Union Cycliste Internationale (UCI) on pregnancy and the postpartum period in cycling [29]. This document, developed with the involvement of elite female cyclists - including athletes who returned to competition after pregnancy - states that elite and competitive amateur female athletes can safely continue training and competing during pregnancy, without risk to themselves or their child [29]. At the same time, the authors of the position statement emphasize a clear lack of direct scientific evidence regarding the safe frequency, duration, and intensity of training and competition in this population, and note that the typical, voluntary reduction in training volume and intensity during pregnancy relies largely on clinical experience rather than robust research data [29]. The document also notes that the commonly assumed minimum period of six weeks before returning to activity may vary depending on the mode of delivery (cesarean section versus vaginal birth) and any peripartum complications, and that stationary cycling may serve as a safe first step in the return to riding outdoors [29].

Data from a broader population of elite female athletes confirm that returning to high-level competition after childbirth is possible. In a survey study of ten elite Canadian female athletes who became pregnant during their sporting careers, nine of ten reported resuming training after childbirth, and five returned to competitive-level competition, with four of those five reporting improved sporting performance compared with the pre-pregnancy period [30]. The study's authors also noted recurring difficulties reported by athletes, such as insufficient childcare support and difficulty reconciling breastfeeding with training demands [30]. Comprehensive recommendations on returning to competitive sport after childbirth emphasize the importance of an individualized, multidisciplinary approach, including pelvic floor physiotherapy, and identify cycling as one of the safe, non-impact forms of cross-training that can be implemented at an early stage of returning to activity [31].

3.9. Supplementation and Sex Differences

An important yet often overlooked issue is the inadequate representation of women in research on performance-enhancing supplements. A standardized literature audit covering five well-established supplements with confirmed ergogenic effects (β-alanine, caffeine, creatine, glycerol, nitrate/beetroot juice, and sodium bicarbonate) showed that, among 1,826 analyzed studies comprising a total of 34,889 participants, women constituted only 23%, and only 34% of studies included even a single woman [32]. Notably, depending on the type of supplement, only 0-8% of studies were conducted exclusively on women, and only 0-2% were specifically designed to compare responses between sexes [32].

This paucity of data has direct implications for uncertainty regarding the efficacy of nutritional recommendations for female cyclists. A review of β-alanine, caffeine, and nitrate in women indicates that, although β-alanine may reduce perceived exertion and prolong training session duration in women, and nitrates show variable effects depending on activity type and the primary muscle group involved, the available literature does not permit a clear consensus regarding dosing, timing, or efficacy of these supplements in women, and studies insufficiently account for athletes' hormonal status [33].

Regarding caffeine - one of the most widely used ergogenic aids in cycling - evidence suggests possible sex differences in effect magnitude. A systematic review of ten studies comparing caffeine's effect between sexes found no differences in aerobic capacity or fatigue index, whereas in four of seven studies (57.1%) analyzing anaerobic capacity, a stronger ergogenic effect of caffeine was observed in men than in women, particularly regarding generated power, total load lifted, and sprint speed [34]. A more recent randomized controlled trial evaluating the acute effect of caffeine on muscular strength, power, and endurance in resistance-trained individuals, however, found that caffeine's ergogenic effect at moderate and high loads (50-90% 1RM) in the lower body was evident regardless of sex, indicating a need for further research accounting for the specifics of different exercise types [35]. It is worth noting that women constitute only about 13% of all participants in studies on caffeine's ergogenic effects, further limiting the ability to formulate confident, evidence-based dosing recommendations specific to women competing in road cycling [36].

4. Discussion

This literature review aimed to systematize current knowledge on the training and nutritional specifics of women competing in road cycling. Analysis of the available sources confirms the initial premise formulated in the introduction - scientific data on this population remain markedly more limited than for male cyclists and many sports-medicine conclusions continue to be formulated on the basis of extrapolation from studies on men, single case reports, or studies involving other endurance disciplines.

4.1. Training and Nutritional Characteristics - Are Women “Smaller Men”?

The data collected suggest that differences in training characteristics between sexes in professional cycling are not reducible merely to proportional scaling of male parameters. The lower training volume combined with relatively higher intensity, observed both by Van Erp et al. [2] and in the more recent study by Mateo-March et al. [1], may reflect the genuine specifics of race demands in women's cycling rather than merely lower physiological capacities among female athletes. This observation carries important practical implications - coaches planning training periodization for women should not mechanically transfer volume-based models validated in men, but should instead account for the distinct structure of women's races.

A similar conclusion emerges in the area of nutrition. The fact that the only available reference point for daily carbohydrate intake in a professional female cyclist during a Grand Tour remains a single case report [7] is a telling illustration of the scale of the problem. Extrapolating male nutritional recommendations to women - despite the practical prevalence of such an approach within the sporting community 1- lacks solid grounding in population-based research and should be approached with caution, particularly given that women may differ from men in their use of energy substrates, insulin sensitivity, and the influence of hormonal fluctuations on carbohydrate and fat metabolism.

4.2. The Menstrual Cycle: A Promising Direction for Individualization, or Premature Conclusions?

The findings collected regarding the influence of the menstrual cycle on training and recovery reveal a clear discrepancy between studies focused on recovery and subjective well-being [9,11] and studies assessing objective performance indicators [10,13]. This can be interpreted in two ways. On one hand, the absence of significant differences in performance alongside an effect on recovery [9] suggests that cycle phase should not be treated as an absolute contraindication to intensive training, but rather as a factor modifying the subjective perception of exertion and the pace of return to full training readiness. On the other hand, the small sample sizes of the studies concerned (10 cyclists in the study by Righi and Barroso [9], a small sample in the study by Emslie et al. [10]) warrant caution before formulating universal recommendations for training periodization according to cycle phase.

It is worth emphasizing that the practical proposal emerging from the clustering analysis of elite French female cyclists [11] - scheduling more demanding sessions immediately after menstruation - concerned an individualized approach based on the recognition of an individual pattern in a specific athlete, rather than a rigid, universal scheme. This distinction carries key practical significance: the current data do not justify the implementation of uniform periodization protocols “for all women,” but rather support individualized monitoring of an athlete's response to specific cycle phases, in accordance with methodological recommendations for research involving women in sport science [14].

4.3. RED-S, Iron Deficiency, and Bone Health - A Common Denominator of a Neglected Area

Three seemingly distinct issues - relative energy deficiency in sport, iron deficiency, and reduced bone mineral density - emerge from this review as interrelated elements of one broader problem: insufficient energy and micronutrient intake relative to the training demands of road cycling. The fact that as many as 45% of surveyed female cyclists in one qualitative study reported irregular menstrual cycles [24], combined with data indicating iron deficiency in up to 60% of female athletes [19], suggests that this problem may affect a substantial proportion of women in this discipline, rather than only a narrow group of elite-level athletes.

An interesting, though still under-researched, observation in the literature is that reduced bone mineral density in cycling affects both women and men [18] - a feature that distinguishes this discipline from running sports, where the problem is concentrated almost exclusively among female athletes. This suggests that in road cycling, the non-weight-bearing nature of the discipline itself (the absence of a natural mechanical stimulus for bone formation) may be a more important risk factor than sex alone, which has implications for the design of preventive strategies - strength training incorporating axial loading may be equally important for both male and female cyclists.

4.4. Emerging Research Areas: Hypoxia, Pregnancy, and Supplementation

Extending the review to include altitude training, return to sport after pregnancy, and sex-specific supplementation revealed what may be the most striking pattern of the entire review: a systematic underrepresentation of women in basic research, alongside a growing practical demand from the sporting community for knowledge in these areas.

The contrast between the area of pregnancy and return to sport and the other topics analyzed is particularly telling. Whereas most of the areas discussed encountered a shortage of quantitative data, in the case of pregnancy we have access to something rarer - an official, practical position statement from a governing sporting organization (the UCI) [29], developed with the direct involvement of female cyclists who have experienced a return to competition after childbirth. At the same time, the authors of this position statement openly acknowledge that it relies largely on expert consensus and clinical experience rather than robust evidence from interventional studies [29] - an honest acknowledgment of the limits of current knowledge that is rarely encountered in guideline documents.

Data on caffeine, in turn, illustrate well the inconclusiveness of the conclusions that can currently be drawn. Whereas an older systematic review suggested a smaller ergogenic effect of caffeine in women during anaerobic tasks [34], a more recent randomized controlled trial found no sex difference in caffeine's effect at moderate and high loads [35]. This discrepancy may stem both from genuine methodological differences between studies and from the broader problem of insufficient sample size and study quality involving women, an issue repeatedly highlighted throughout this review.

An audit encompassing nearly 35,000 participants across studies on ergogenic supplements, in which women constituted only 23% of the sample and studies specifically designed to compare responses between sexes constituted only 0-2% [32], illustrates the scale of this problem more forcefully than any single clinical study.

4.5. Limitations of This Review

The analysis presented here has notable limitations that should be considered when interpreting its conclusions.

First, the narrative rather than systematic nature of this review means that the selection of analyzed sources, although based on a transparent search strategy, does not guarantee exhaustive coverage of the entirety of available literature. No formal protocol (e.g., PRISMA), dual independent study selection, or systematic assessment of risk of bias for individual studies was applied.

Second, a substantial proportion of the cited studies concern not road cycling itself but other endurance disciplines (running, water polo, rowing) or general athletic populations, which requires caution when transferring conclusions to the cycling context. This extrapolation was necessary owing to the paucity of studies specific to women's cycling, but it constitutes a significant interpretive limitation.

Third, many of the studies discussed are characterized by small sample sizes (in some instances single case reports, e.g., regarding race nutrition or hematological adaptations to altitude), which limits the generalizability of the findings to the entire population of professional female cyclists.

Fourth, the review covered mainly publications in English and Polish, which may have resulted in the omission of relevant studies published in other languages, particularly from French, Spanish, or Italian research centers with a strong cycling tradition.

Finally, the very fact that so many areas of this review conclude with an observation of insufficient data constitutes an important substantive finding of the review in itself, rather than merely a methodological limitation - it reflects the actual, documented state of scientific knowledge in this field, rather than the happenstance of the search conducted.

5. Conclusions

5.1. Women competing in road cycling remain a population significantly underrepresented in scientific research - in the areas of training physiology, nutrition, and supplementation alike - compared with male cyclists and with women competing in other endurance disciplines (e.g., running). Many of the practical recommendations currently applied to female cyclists are based on extrapolation of data obtained in men, which does not always find justification in the available scientific evidence.

5.2. The training characteristics of professional female cyclists differ from those of men not only quantitatively but likely also qualitatively - lower training volume combined with relatively higher intensity may reflect the distinct demands of women's racing rather than merely lower physiological capacities among female athletes. Planning training periodization for women should account for this specificity rather than rely on simple scaling of male models.

5.3. The influence of the menstrual cycle on training and recovery remains inconclusive, and the available data indicate that cycle phase may affect the subjective quality of post-training recovery more than objective exercise capacity. The current state of knowledge supports individualized monitoring of an athlete's response to specific cycle phases rather than the implementation of rigid, universal periodization schemes based on the menstrual cycle.

5.4. Relative energy deficiency in sport (RED-S), iron deficiency, and reduced bone mineral density constitute interrelated, significant health risks for women competing in road cycling, and these problems may affect a substantial proportion of athletes across different competitive levels rather than only a narrow elite group. Regular screening in this regard should constitute a standard element of medical care for female cyclists.

5.5. Reduced bone mineral density in road cycling affects both women and men, which distinguishes this discipline from running sports and suggests that the non-weight-bearing nature of cycling may be a more important risk factor than sex alone - with the practical implication that strength training incorporating axial loading is warranted for both male and female cyclists.

5.6. Altitude training, return to sport after pregnancy, and ergogenic supplementation are areas particularly affected by a lack of sex-specific research. In the case of pregnancy and the postpartum period, practical industry guidelines are available (the UCI position statement), but these rely largely on expert consensus rather than robust evidence from interventional studies. Data on caffeine supplementation point to possible, though still inconclusive, sex differences in the magnitude of the ergogenic effect.

5.7. Further research specific to women's road cycling is essential, encompassing larger study populations, longer observation periods, and direct comparisons between sexes, particularly in the areas of race nutrition, altitude training, and the efficacy of ergogenic supplements. The growing professionalization of women's cycling simultaneously creates increasingly favorable conditions for conducting such research in the population of world-class female athletes.

5.8. The recurring conclusion throughout this review regarding insufficient data constitutes an important substantive finding in itself, pointing to an urgent need for systemic changes in the research priorities of sport science, so that they may keep pace with the dynamic development of women's road cycling at the competitive level.

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Supplementary Materials

Not applicable.

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During the preparation of this work, the authors used ChatGPT for the purpose of language editing and stylistic refinement to improve clarity and readability of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the accuracy, integrity and conclusions of the publication

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