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EFFECTIVENESS OF COMPREHENSIVE LIFESTYLE INTERVENTIONS (DIET, EXERCISE, SLEEP, AND STRESS MODIFICATION) IN THE TREATMENT OF POLYCYSTIC OVARY SYNDROME: A SYSTEMATIC REVIEW AND META-ANALYSIS

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ABSTRACT

Background: Polycystic ovary syndrome (PCOS) is a common endocrine-metabolic disorder affecting women of reproductive age and is characterized by hyperandrogenism, ovulatory dysfunction, insulin resistance, obesity, and psychological distress. Lifestyle modification is recommended as first-line therapy; however, the comparative effectiveness of multidomain interventions integrating diet, exercise, sleep optimization, and supplementation remains unclear. This systematic review and meta-analysis evaluated the impact of comprehensive lifestyle interventions on metabolic, hormonal, reproductive, inflammatory, and psychosocial outcomes in women with PCOS.

Methods: A systematic literature search of PubMed/MEDLINE was conducted according to PRISMA 2020 guidelines. Randomized controlled trials published in English within the previous 10 years were included if they enrolled reproductive-aged women with confirmed PCOS and evaluated at least one lifestyle intervention: dietary modification, supplementation, structured exercise, sleep-related therapy, or combined programs. Outcomes included anthropometric indices, insulin resistance markers, lipid profile, reproductive and hormonal parameters, inflammatory biomarkers, sleep quality, and mental health. Where sufficient homogeneity existed, pooled quantitative analyses were planned; otherwise, narrative synthesis was performed.

Results: Comprehensive lifestyle interventions demonstrated significant benefits across multiple domains. Dietary strategies, particularly calorie-restricted, low-glycemic-load, Mediterranean-style, and ketogenic diets, improved body weight, body mass index, waist circumference, insulin resistance, lipid profile, and androgen excess. Structured exercise, including aerobic training and high-intensity interval training, improved body composition, insulin sensitivity, menstrual cyclicity, ovarian morphology, cardiovascular fitness, and psychological well-being, while reducing inflammatory markers (CRP, IL-6, TNF-α). Adjunctive supplementation (probiotics, synbiotics, coenzyme Q10, omega-3 fatty acids, vitamin D, magnesium, flaxseed, and melatonin) showed additional improvements in metabolic, hormonal, oxidative stress, and menstrual outcomes. Sleep-focused interventions, particularly melatonin supplementation and behavioral modification, improved sleep quality, anxiety, depression, insulin resistance, and lipid parameters.

Conclusions: Comprehensive lifestyle intervention is an effective evidence-based strategy for PCOS management. Combined approaches targeting nutrition, exercise, sleep, and selected supplementation improve metabolic, endocrine, reproductive, and psychological outcomes. Given the heterogeneity of PCOS, individualized multidisciplinary lifestyle treatment should be considered a central component of long-term care and may complement pharmacological therapy.

KEYWORDS

PCOS, Diet, Exercise, Sleep, Systematic Review, Women

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1. Introduction

1.1. PCOS Overview: Definition, Diagnostic Criteria, and Epidemiology

Polycystic ovary syndrome (PCOS) is one of the most common endocrine disorders affecting women of reproductive age and is recognized as a heterogeneous condition involving reproductive, metabolic, and psychological dysfunction **(**Orio, F, et al., 2016). It is primarily characterized by hyperandrogenism, ovulatory dysfunction, and polycystic ovarian morphology, although the phenotype may vary substantially among individuals. In addition to gynecological manifestations, PCOS is strongly associated with insulin resistance, obesity, dyslipidaemia, chronic low-grade inflammation, infertility, and impaired quality of life.

The diagnosis of PCOS is most commonly based on the revised Rotterdam criteria, which require the presence of at least two of the following three features after exclusion of alternative etiologies: (1) oligo-ovulation or anovulation, (2) clinical and/or biochemical hyperandrogenism, and (3) polycystic ovarian morphology on ultrasound. Other diagnostic frameworks, including the National Institutes of Health (NIH) criteria and the Androgen Excess and PCOS Society criteria, place greater emphasis on androgen excess. Diagnostic evaluation generally includes menstrual history, anthropometric measurements, hormonal laboratory assessment, metabolic screening, and pelvic ultrasonography.

The global prevalence of PCOS is estimated to range from approximately 6% to 20%, depending on diagnostic criteria, ethnicity, and study population. Increasing prevalence has been linked to rising obesity rates, sedentary behavior, and worsening metabolic health. Women with PCOS frequently present with overweight or obesity, central adiposity, menstrual irregularity, infertility, hirsutism, acne, and insulin resistance. Psychological comorbidities are also common, including anxiety, depression, body image dissatisfaction, and reduced health-related quality of life (Eisenberg, E., et al., 2021; Patten, R. K., et al., 2023; Lopes, I. P., et al., 2018). Furthermore, poor sleep quality has been associated with less favorable anthropometric and cardiometabolic markers in affected women (Benham, J. L., et al., 2023).

Insulin resistance is considered a central pathophysiological mechanism in many PCOS phenotypes. Compensatory hyperinsulinaemia enhances ovarian androgen production, contributes to impaired folliculogenesis, and exacerbates both metabolic and reproductive dysfunction. As a result, interventions targeting metabolic regulation often improve endocrine and reproductive outcomes simultaneously.

1.2. Aim of the Study

The aim of this study was to evaluate the effectiveness of comprehensive lifestyle interventions, including different dietary strategies, supplementation, physical exercise, and sleep-related approaches, on metabolic, hormonal, reproductive, inflammatory, and psychosocial outcomes in women with polycystic ovary syndrome.

By synthesizing evidence derived from randomized controlled trials, this review also aimed to identify which non-pharmacological interventions appear most clinically beneficial and whether multidimensional lifestyle treatment may enhance long-term management of PCOS.

1.3. Lifestyle Interventions and the Role of Lifestyle Management in PCOS

Lifestyle modification is currently regarded as first-line therapy in women with PCOS, particularly in the presence of overweight, obesity, insulin resistance, or increased cardiometabolic risk. Since the syndrome involves multiple interconnected metabolic and endocrine pathways, lifestyle treatment may address underlying mechanisms rather than isolated symptoms.

1.3.1. Dietary Management

Nutritional intervention plays a key therapeutic role in PCOS. Various dietary approaches—including caloric restriction, low-glycemic-load diets, Mediterranean-style diets, ketogenic diets, and high-protein regimens—have demonstrated beneficial effects on body weight, insulin resistance, oxidative stress, lipid profile, and androgen excess (Deshmukh, et al., 2023; Sharifi, Saber, Moludi, Salimi & Jahan-Mihan, 2024; Dou, et al. 2024; Bozbulut, Döğer, Çamurdan, & Bideci, 2024; Khalid, et al. 2023). In some randomized trials, intensive caloric restriction resulted in greater reductions in body weight and hyperandrogenaemia than conventional energy-deficit approaches (Deshmukh, et al., 2023).

1.3.2. Supplementation

Adjunctive supplementation may further support metabolic and reproductive outcomes. Randomized trials have reported favorable effects of probiotics, synbiotics, coenzyme Q10, omega-3 fatty acids, magnesium, vitamin D, flaxseed, green cardamom, and dietary fiber on menstrual regularity, inflammatory markers, insulin resistance, lipid metabolism, and androgen profile. However, findings remain heterogeneous, and not all supplements demonstrate consistent benefit.

1.3.3. Exercise Interventions

Regular physical activity is another cornerstone of PCOS management. Aerobic exercise, interval training, and resistance-based programs improve body composition, insulin sensitivity, lipid profile, inflammatory status, menstrual function, and psychological well-being (Benham, et al., 2021; Patten, et al., 2023; Patten, et al., 2022). High-intensity interval training (HIIT) may be particularly effective for improving insulin sensitivity, menstrual cycles, and anxiety symptoms (Patten, et al., 2022).

1.3.4. Sleep Optimization

Sleep health has recently emerged as an important but often overlooked component of PCOS treatment. Women with PCOS more frequently report sleep disturbances than control populations (Eisenberg, et al., 2021). Poor sleep quality has been associated with adverse anthropometric and cardiometabolic outcomes (Benham, et al., 2023). Behavioral sleep modification and melatonin supplementation have demonstrated beneficial effects on sleep quality, mental health, insulin resistance, and lipid parameters (Oberg, Blomberg, Åkerstedt, & Hirschberg, 2023; Shabani, et al. 2019).

Collectively, these findings support the concept that lifestyle medicine should be considered a multidimensional treatment strategy in PCOS, integrating diet, exercise, sleep, and targeted supplementation according to individual clinical phenotype.

1.4. Research Problem

Despite growing recognition of lifestyle management in PCOS, important clinical uncertainties remain. Lifestyle interventions differ considerably in intensity, composition, duration, and patient adherence. Furthermore, PCOS itself is highly heterogeneous, with some women presenting predominantly reproductive dysfunction, whereas others exhibit marked obesity, insulin resistance, inflammation, or psychological distress.

As a result, no single lifestyle strategy can currently be considered universally optimal. It remains unclear which interventions are most effective for specific outcomes such as weight reduction, ovulatory restoration, androgen reduction, insulin sensitivity, lipid improvement, sleep quality, or mental health. The comparative effectiveness of isolated versus combined interventions also requires further clarification.

Therefore, the principal research problem addressed in this review is whether integrated lifestyle interventions can significantly modify the core pathophysiological mechanisms of PCOS and improve clinically meaningful outcomes beyond conventional symptom-focused pharmacotherapy. This study further seeks to determine which domains of lifestyle treatment - nutrition, supplementation, exercise, and sleep optimization - provide the greatest therapeutic benefit and how these strategies may be incorporated into individualized long-term management plans for women with PCOS.

2. Methodology

2.1. Study design

This study was conducted as a **systematic review with meta-analysis** to evaluate the effectiveness of comprehensive lifestyle interventions in women with polycystic ovary syndrome (PCOS). The review focused on non-pharmacological strategies including dietary interventions, supplementation, physical exercise, and sleep-related approaches. A systematic review design was considered the most appropriate methodology because it allows structured identification, critical appraisal, and synthesis of available randomized controlled trial (RCT) evidence addressing multiple therapeutic modalities within the same clinical condition.

Where sufficient numerical data were available, quantitative synthesis through meta-analysis was planned to estimate pooled effects of selected interventions on metabolic, hormonal, anthropometric, and reproductive outcomes. The methodology and reporting framework were developed in accordance with the **Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020)** guidelines to ensure transparency, reproducibility, and methodological rigor.

2.2. Search Strategy

A structured literature search was performed using the **PubMed/MEDLINE** electronic database. PubMed was selected because of its comprehensive coverage of biomedical and clinical literature, particularly randomized trials relevant to endocrinology, gynecology, reproductive medicine, and lifestyle interventions in my search group.

The search included studies published within the **last 10 years** to capture contemporary evidence reflecting current diagnostic criteria, intervention strategies, and clinical management of PCOS. Only articles published in English were considered.

Search terms were developed using combinations of Medical Subject Headings terms and free-text keywords related to PCOS and lifestyle management. The principal keywords included:

- "PCOS"
- "polycystic ovary syndrome"
- "diet"
- "exercise"
- "physical activity"
- "sleep"
- "supplementation"
- "randomized controlled trial"
- "RCT"

Boolean operators (AND/OR) were used to refine searches. Examples of search combinations included:

- "PCOS AND diet AND randomized controlled trial"
- "polycystic ovary syndrome AND exercise AND RCT"
- "PCOS AND sleep AND RCT"
- "PCOS AND supplements AND RCT"

The search strategy specifically aimed to identify **randomized controlled trials only**, as RCTs provide the highest level of evidence for assessing intervention effectiveness in my search area.

2.3. Data Collection

All records retrieved from the database search were screened in a stepwise process. Firstly, titles and abstracts were reviewed to exclude clearly irrelevant publications, duplicates, narrative reviews, case reports, and non-human studies. Secondly, potentially eligible articles underwent **full-text assessment** to determine final inclusion.

Data was extracted systematically from each included study using a standardized collection framework. The following variables were recorded:

- First author and year of publication
- Study design and randomization method
- Number of participants and group allocation
- Participant characteristics (age, BMI, confirmed PCOS diagnosis)
- Type of intervention (diet, exercise, sleep intervention, supplementation, combined lifestyle strategy)
- Duration of intervention and follow-up period
- Comparator group (placebo, control, standard care, alternative intervention)
- Primary and secondary outcomes

Special attention was given to clinically relevant endpoints frequently reported across the included studies, such as:

- **Anthropometric outcomes:** body weight, body mass index (BMI), waist circumference, waist-to-hip ratio
- **Metabolic outcomes:** fasting glucose, fasting insulin, HOMA-IR, lipid profile (HDL, LDL, triglycerides, total cholesterol)
- **Hormonal outcomes:** total testosterone, free androgen index (FAI), sex hormone-binding globulin (SHBG), LH/FSH ratio
- **Reproductive outcomes:** menstrual regularity, ovulatory function, fertility-related parameters
- **Inflammatory/oxidative markers:** CRP, TNF-α, IL-6, malondialdehyde (MDA), total antioxidant capacity
- **Psychological and sleep outcomes:** quality of life, depression, anxiety, sleep quality scores

2.4. Analysis Technique

2.4.1. Inclusion Criteria

Studies were included if they met all of the following criteria:

I. **Randomized controlled trials (RCTs)** or randomized comparative intervention studies.

II. Adult women of reproductive age with a confirmed diagnosis of **PCOS** based on recognized diagnostic criteria (Rotterdam, NIH, or equivalent).

III. Evaluation of at least one **lifestyle intervention**, including:

- dietary modification
- supplementation
- structured exercise or physical activity
- sleep-related intervention
- combined lifestyle programs

IV. Reported measurable clinical outcomes relevant to PCOS management (metabolic, hormonal, reproductive, anthropometric, psychological, or sleep-related outcomes).

V. Published in English within the previous 10 years.

2.4.2. Exclusion Criteria

Studies were excluded if they met any of the following criteria:

- Animal or in vitro studies.
- Observational studies, case reports, narrative reviews, editorials, or conference abstracts without full data.
- Studies involving participants without confirmed PCOS diagnosis.
- Interventions based solely on pharmacological treatment without lifestyle components.
- Articles lacking extractable numerical data or clearly reported outcome measures.
- Duplicate publications or overlapping datasets.

2.4.3. Statistical Synthesis

Where at least two studies reported sufficiently comparable numerical outcomes, pooled meta-analysis was considered. Continuous variables such as BMI, HOMA-IR, testosterone, or lipid parameters were planned to be analyzed using mean differences or standardized mean differences with 95% confidence intervals. Clinical and methodological heterogeneity between studies was considered during interpretation of pooled estimates. Where meta-analysis was not feasible because of heterogeneity in interventions or reporting methods, a structured narrative synthesis was performed.

3. Results:

4. Dietary Strategies:

4.1. Caloric Restriction and Weight Reduction-Based Dietary Interventions

Dietary intervention remains a cornerstone of first-line management for women with polycystic ovary syndrome (PCOS), particularly in those presenting with obesity, insulin resistance, dyslipidaemia, and hyperandrogenism. As PCOS is increasingly recognized as a multisystem metabolic disorder, nutritional strategies may exert clinically meaningful effects on anthropometric, endocrine, reproductive, hepatic, and cardiometabolic outcomes. Evidence derived from randomized controlled trials (RCTs) suggests that both energy restriction and dietary composition are relevant determinants of treatment response (Kazemi, et al., 202; Bozbulut, et al., 2024; Khalid, et al., 2023).

Caloric reduction remains one of the most consistently effective strategies for improving metabolic dysfunction in PCOS. In a 2023 RCT, a very-low-calorie diet (VLCD) resulted in significantly greater weight reduction than a conventional energy-deficit approach in obese women with PCOS and was accompanied by more pronounced improvements in hyperandrogenaemia, body composition, and several metabolic parameters (Deshmukh, et al., 2023). These findings support the concept that more intensive short-term dietary restriction may accelerate clinical improvement in selected patients.

More recent evidence indicates that several calorie-restricted dietary models may achieve clinically relevant short-term weight loss. A 2024 RCT demonstrated that three distinct diets reduced body weight by more than 5% within eight weeks in overweight or obese women with PCOS, while simultaneously improving insulin resistance and oxidative stress markers (Dou, et al., 2024). Importantly, high-protein dietary strategies were superior in preserving lean body mass and improving oxidative stress damage (Dou, et al., 2024).

4.2. Dietary Composition, Macronutrient Quality, and Phenotype-Specific Interventions

Beyond caloric restriction, dietary composition appears to play a critical role in metabolic and endocrine outcomes. In a 2024 randomized trial, two structured dietary patterns significantly improved anthropometric parameters; however, the RESMENA diet demonstrated additional beneficial effects on insulin resistance and androgen levels (Bozbulut, et al., 2024). This suggests that hypocaloric diets may differ substantially in their metabolic effects depending on macronutrient distribution and dietary pattern composition.

Earlier RCT evidence similarly emphasizes the importance of diet quality. In a study comparing diet-only, diet-plus-exercise, and exercise-only interventions, reductions in BMI, waist circumference, and total cholesterol were observed in diet-based groups, while insulin resistance (HOMA index) improved particularly in the diet-only group (Nybacka, Hellström & Hirschberg, 2017). Increased fibre intake was identified as the strongest predictor of BMI reduction, whereas reduced trans fatty acid intake predicted improvements in insulinogenic index (Nybacka, et al., 2017).

From a mechanistic perspective, fibre-rich diets may improve satiety, glycaemic control, and gut microbiota composition, while reducing postprandial insulin excursions. Conversely, trans fatty acids may contribute to chronic low-grade inflammation and impaired insulin signalling. Accordingly, dietary counselling in PCOS should emphasize whole grains, legumes, fruits, vegetables, and unsaturated fats, while minimizing ultra-processed foods and industrial trans fats (Nybacka, et al., 2017).

Phenotype-specific dietary strategies may further optimize treatment response. A 2024 RCT demonstrated that two dietary approaches both improved PCOS manifestations, although the PMCD dietary model appeared particularly beneficial in women with dyslipidaemia (Sharifi, et al., 2024). These findings support an individualized nutritional approach based on metabolic phenotype, including lipid profile, insulin resistance status, and reproductive dysfunction.

4.3. Hormonal Regulation, Appetite Control, and Metabolic Comorbidities

Beyond weight reduction and macronutrient composition, dietary interventions may influence hormonal signalling pathways involved in appetite regulation and metabolic comorbidities.

A 2021 randomized trial demonstrated that after habituation to a low glycaemic load (GL) diet, consumption of a low-GL meal significantly reduced ghrelin concentrations (Kazemi, et al., 2021). Ghrelin is a key orexigenic hormone involved in hunger regulation, and its suppression may improve satiety and support long-term dietary adherence in PCOS.

Emerging evidence also supports ketogenic dietary strategies in selected patients with metabolic complications. In a 2021 RCT, a ketogenic diet significantly reduced liver function markers and improved hepatic steatosis compared with control treatment. Fatty liver resolution occurred in most participants in the ketogenic group after 12 weeks, alongside improvements in glycaemic control, body weight, and reproductive hormone profiles (Khalid, et al., 2023). These findings are particularly relevant given the high prevalence of non-alcoholic fatty liver disease in PCOS and its strong association with insulin resistance.

5. Dietary Supplements and Metabolic–Hormonal Outcomes

5.1. Microbiota-Targeted Supplements

Randomized controlled trials suggest that microbiota-targeted supplementation may influence both metabolic and reproductive features of polycystic ovary syndrome (PCOS), particularly when combined with lifestyle modification.

Probiotic supplementation alongside dietary and lifestyle interventions has been shown to significantly improve menstrual cycle regularity, reduce total testosterone levels, and decrease central adiposity (waist circumference and waist-to-hip ratio), while also improving quality-of-life domains related to menstruation (Kaur, et al., 2022). These findings suggest potential interactions between gut microbiota modulation and hypothalamic–pituitary–ovarian axis regulation.

Similarly, synbiotic supplementation has demonstrated improvements in hyperandrogenism, lipid profile, and endotoxemia markers, indicating potential effects on gut barrier integrity and systemic inflammatory load (Chudzicka-Strugała, et al., 2025). The reduction in endotoxemia suggests a possible mechanism linking intestinal permeability with insulin resistance and androgen excess in PCOS.

Dietary fiber supplementation has also shown significant metabolic effects, including reductions in body weight, BMI, fasting glucose, insulin levels, lipid profile, and testosterone, alongside an increase in HDL cholesterol (Manzoor, et al., 2022). These effects are consistent with improved glycaemic control and lipid metabolism, likely mediated by delayed carbohydrate absorption and modulation of gut microbial composition.

5.2. Mechanistic pathways

Across studies, microbiota-targeted interventions appear to act through multiple pathways:

- modulation of gut-derived endotoxins and inflammation (Chudzicka-Strugała, et al., 2025)
- improvement of insulin sensitivity via short-chain fatty acid production (Manzoor, et al., 2022)
- regulation of androgen levels possibly through insulin-mediated ovarian steroidogenesis (Kaur, et al., 2022)
- enhanced satiety and energy regulation via dietary fiber fermentation products (Manzoor, et al., 2022)

However, a 20-week RCT reported no additional benefit of probiotic supplementation beyond an energy-restricted diet on gut microbiota composition, short-chain fatty acids, or lipid profile (Łagowska, & Drzymała-Czyż, 2022), suggesting that dietary intervention alone may already exert significant microbiome-related effects.

5.3. Antioxidant and Metabolic-Modulating Supplements (CoQ10, Vitamin E, Omega-3, Magnesium)

Coenzyme Q10 (CoQ10), alone or combined with vitamin E, has demonstrated consistent improvements in insulin sensitivity and hormonal profiles. RCT evidence shows reductions in fasting blood glucose, insulin levels, HOMA-IR, and total testosterone following supplementation (Samimi, et al., 2017). Additionally, co-supplementation has been associated with changes in sex hormone-binding globulin (SHBG), suggesting altered bioavailability of androgens.

In another trial, CoQ10 and vitamin E supplementation resulted in improvements in serum triglycerides, total cholesterol, LDL-cholesterol, and visceral adiposity index, with additional reductions in diastolic blood pressure observed in combined supplementation groups (Izadi, Shirazi, Taghizadeh, & Gargari, 2019).

Omega-3 fatty acids combined with vitamin E significantly improved oxidative stress biomarkers, including increased total antioxidant capacity, glutathione levels, and catalase activity, alongside reductions in malondialdehyde concentrations (Sadeghi, Alavi-Naeini, Mardanian, Ghazvini, & Mahaki, 2020). These findings indicate reduced lipid peroxidation and enhanced antioxidant defense systems.

Magnesium combined with vitamin E supplementation also reduced inflammatory markers such as high-sensitivity C-reactive protein (hs-CRP), while improving nitric oxide bioavailability and total antioxidant capacity (Shokrpour, & Asemi, 2019). Clinical improvement in hirsutism was additionally observed, suggesting a potential link between inflammatory reduction and androgen-related symptoms.

Collectively, antioxidant-based supplementation appears to act through:

- improvement of insulin sensitivity (CoQ10, vitamin E) (Samimi, et al., 2017; Izadi, et al., 2019)
- reduction of systemic oxidative stress (omega-3, vitamin E, magnesium) (Sadeghi, et al., 2020; Shokrpour, et al., 2019)
- improvement of lipid metabolism and visceral adiposity (Izadi, et al., 2019)
- modulation of inflammatory pathways (hs-CRP reduction) (Shokrpour, et al., 2019)

5.4. Hormonal and Endocrine-Modulating Supplements (Plant-Based and Micronutrient Interventions)

Several nutraceuticals have demonstrated direct effects on reproductive hormone profiles in women with PCOS.

Flaxseed supplementation has been associated with increased follicle-stimulating hormone (FSH) levels and a reduced luteinizing hormone (LH)/FSH ratio, indicating partial normalization of gonadotropin imbalance (Najdgholami, Sedgi, Ghalishourani, Feyzpour, & Rahimlou, 2025). This hormonal shift may support improved ovulatory function.

Vitamin D supplementation (50,000 IU weekly) significantly improved menstrual cycle regularity in women with vitamin D insufficiency compared with placebo (Jafari-Sfidvajani, et al. (2018), suggesting a role in reproductive axis regulation.

Green cardamom supplementation resulted in reductions in luteinizing hormone, androstenedione, and dehydroepiandrosterone, alongside increased FSH levels (Cheshmeh, et al., 2022), indicating multi-level modulation of ovarian androgen production.

Probiotic and synbiotic interventions have also demonstrated reductions in total testosterone and improvements in menstrual regularity (Kaur, et al., 2022; Chudzicka-Strugała, et al., 2025), suggesting microbiota–endocrine axis interaction.

5.5. Metabolic and Multisystem Bioactive Supplements (Licorice, Fiber, and Combined Nutraceuticals)

Licorice supplementation has been associated with improvements in obesity indices, glucose homeostasis, and lipid profiles compared with placebo (Hooshmandi, et al., 2024), indicating potential multi-target metabolic effects.

Dietary fiber supplementation similarly improved glucose levels, insulin sensitivity, lipid profile, and testosterone concentrations, while increasing HDL cholesterol (Manzoor, et al., 2022), highlighting its central role in metabolic regulation.

Some interventions do not appear to provide additional benefit when combined with structured dietary interventions. Fennel supplementation added to a hypocaloric high-protein diet did not further improve anthropometric or androgen indices in women with PCOS (Nadjarzadeh, et al., 2021), suggesting a ceiling effect of dietary intervention alone.

6. Exercise Interventions

Physical exercise is a central non-pharmacological intervention in the management of polycystic ovary syndrome (PCOS), a complex endocrine–metabolic disorder characterized by hyperandrogenism, ovulatory dysfunction, insulin resistance, and increased cardiometabolic risk. Evidence from randomized controlled trials (RCTs) indicates that structured exercise training improves anthropometric outcomes, cardiometabolic parameters, reproductive hormone profiles, inflammatory markers, psychological health, and quality of life. Different exercise modalities—including high-intensity interval training (HIIT), moderate-intensity continuous training (MICT), continuous aerobic training (CAT), and intermittent aerobic training (IAT)—appear to produce overlapping but partially distinct physiological effects (Benham, et al., 2021; Patten, et al., 2023).

6.1. Aerobic Training and High-Intensity Exercise: Effects on Body Composition and Metabolic Risk

Aerobic exercise interventions consistently demonstrate beneficial effects on body composition and metabolic health in women with PCOS. In a randomized controlled trial comparing high-intensity interval training (HIIT), continuous aerobic exercise training (CAET), and a non-exercise control group, both exercise modalities significantly improved anthropometric parameters and cardiometabolic markers (Benham, et al., 2021). Body mass index (BMI) decreased significantly in the CAET group compared with control and HIIT, whereas HIIT produced more favorable lipid changes, including greater reductions in LDL-cholesterol and increases in HDL-cholesterol (Benham, et al., 2021).

Progressive aerobic exercise training has also been shown to significantly improve cardiorespiratory fitness, cardiometabolic profiles, and health-related quality of life (HRQoL) in overweight and obese women with PCOS (Costa, et al., 2018). Similar findings were observed in additional RCTs, where reductions in waist circumference, hip circumference, total cholesterol, and LDL-cholesterol were consistently reported following structured aerobic interventions (Ribeiro,et al., 2020, 2021). These findings suggest that aerobic exercise exerts clinically relevant effects on both central adiposity and lipid metabolism.

Comparative trials indicate that both continuous aerobic training (CAT) and intermittent aerobic training (IAT) reduce anthropometric indices and hyperandrogenism, although their metabolic profiles may differ. CAT appears more effective in improving lipid parameters, whereas IAT may have stronger effects on free androgen index (FAI) reduction (Ribeiro, et al.,2020). Both modalities have demonstrated reductions in testosterone levels and waist-to-hip ratio, suggesting improvements in central adiposity and endocrine balance (Philbois, et al., 2022).

6.2. HIIT Versus Moderate-Intensity Continuous Training

High-intensity interval training (HIIT) has emerged as a particularly effective modality in PCOS, with multiple studies comparing its effects to moderate-intensity continuous training (MICT). HIIT significantly improves insulin sensitivity and increases sex hormone-binding globulin (SHBG) levels to a greater extent than MICT (Patten, et al., 2022). Furthermore, participants undergoing HIIT were substantially more likely to report improved menstrual cyclicity compared with those undergoing MICT, suggesting a potential reproductive advantage (Patten, et al., 2022).

Both HIIT and MICT improve VO_2peak and reduce resting heart rate, indicating enhanced cardiovascular efficiency (Philbois, et al., 2022). In addition, both modalities reduce testosterone levels and

improve metabolic markers, although HIIT may confer additional benefits in insulin sensitivity and androgen binding capacity (Philbois, et al., 2022). These findings suggest that while both training types are effective, HIIT may induce more pronounced endocrine and metabolic adaptations in shorter timeframes.

Importantly, HIIT has also been associated with superior lipid outcomes compared with continuous training, including greater reductions in LDL-cholesterol and improved HDL responses (Benham, et al., 2021). These lipid changes are particularly relevant given the increased cardiovascular risk profile in women with PCOS.

6.3. Reproductive and Endocrine Outcomes: Ovulatory Function and Androgen Regulation

Exercise interventions consistently improve reproductive and endocrine outcomes in PCOS. Both HIIT and aerobic training improve menstrual cyclicity, reduce ovulatory dysfunction, and improve ovarian morphology (Ribeiro, et al., 2020). Specifically, reductions in follicle number per ovary, ovarian volume, and free androgen index (FAI) have been observed following structured exercise interventions (Ribeiro, et al., 2020).

Both continuous and intermittent aerobic training significantly reduce testosterone levels and improve SHBG concentrations, reflecting reduced bioavailable androgen levels (Patten, et al., 2023; Lopes, et al., 2018). In comparative analyses, IAT has been particularly effective in reducing FAI, while CAT demonstrates broader metabolic improvements (Ribeiro, et al., 2020). These endocrine changes suggest that exercise may directly influence ovarian steroidogenesis and hypothalamic–pituitary–ovarian axis regulation.

Additionally, exercise interventions improve menstrual regularity and reproductive function, with some evidence suggesting normalization of ovulatory patterns following sustained training programs (Patten, et al., 2022; Kazemi, et al., 2020). These findings highlight the role of exercise as a potential modulator of reproductive dysfunction in PCOS.

6.4. Psychological Outcomes and Quality of Life Improvements

Psychological dysfunction, including anxiety, depression, and stress, is highly prevalent in women with PCOS. Exercise interventions demonstrate consistent benefits across mental health outcomes. HIIT significantly reduces depression, anxiety, and stress scores, with greater reductions in anxiety compared with MICT (Patten, et al., 2023). MICT also reduces stress levels, although its effects on depression and anxiety are less pronounced than HIIT (Patten, et al., 2023).

Aerobic and interval training also improve health-related quality of life (HRQoL), including sexual function. Continuous aerobic training has been associated with significant improvements in Female Sexual Function Index (FSFI) scores, particularly in domains of sexual satisfaction and pain reduction (Lopes, et al., 2018). Both CAT and IAT also reduce anxiety and depressive symptoms, indicating broad psychosocial benefits of structured exercise interventions (Lopes, et al., 2018).

Furthermore, HIIT is associated with more positive affective responses and higher exercise enjoyment compared with MICT, suggesting improved long-term adherence potential (Patten, et al., 2023). This is clinically relevant, as sustainability is a key determinant of long-term metabolic and endocrine benefits in PCOS.

6.5. Inflammatory and Oxidative Stress Pathways

Chronic low-grade inflammation is a key pathophysiological feature of PCOS, contributing to insulin resistance and hyperandrogenism. Exercise has been shown to significantly reduce inflammatory markers, including interleukin-6 (IL-6), tumor necrosis factor-alpha (TNF-α), and C-reactive protein (CRP) (Elbandrawy, et al., 2022). These reductions indicate attenuation of systemic inflammatory activity following regular aerobic exercise.

In addition, exercise reduces oxidative stress markers such as malondialdehyde (MDA), while improving antioxidant capacity (Nasiri, Monazzami, Alavimilani, & Asemi, 2025). These changes suggest reduced lipid peroxidation and improved redox balance. The combined reduction in inflammatory and oxidative stress markers supports a mechanistic role for exercise in modulating systemic metabolic dysfunction in PCOS.

6.6. Cardiometabolic Function and Integrated Physiological Adaptations

Exercise interventions consistently improve cardiometabolic risk factors in PCOS. Reductions in BMI, waist circumference, hip circumference, total cholesterol, LDL-cholesterol, and insulin resistance indices have been observed across multiple RCTs (Benham, et al., 2021; Ribeiro, et al., 2021; Costa, et al., 2018). Improvements in VO_2peak and aerobic capacity further reflect enhanced cardiovascular fitness (Patten, et al., 2022; Philbois, et al., 2022).

HIIT and MICT both improve insulin sensitivity, although HIIT may exert stronger effects on insulin dynamics and SHBG regulation (Patten, et al., 2022; Philbois, et al., 2022). Additionally, exercise reduces heart rate and improves autonomic regulation, contributing to improved cardiovascular efficiency (Philbois, et al., 2022). These metabolic adaptations occur alongside endocrine and inflammatory improvements, suggesting integrated systemic effects of structured exercise interventions.

Furthermore, combined improvements in metabolic, reproductive, and psychological domains indicate that exercise exerts multi-system effects in PCOS rather than isolated organ-specific benefits. This includes simultaneous modulation of insulin sensitivity, androgen excess, inflammatory activity, and neuropsychological functioning.

7. Sleep

7.1. Sleep Disturbances and Sleep-Targeted Interventions

Sleep dysfunction has emerged as an important but frequently underrecognized component of polycystic ovary syndrome (PCOS). Beyond reproductive and metabolic abnormalities, women with PCOS appear to experience impaired sleep quality, altered sleep architecture, and higher rates of sleep disturbances, which may further aggravate insulin resistance, obesity, mood disorders, and infertility. Current evidence suggests a bidirectional relationship in which hormonal and metabolic dysregulation contribute to poor sleep, while sleep impairment may worsen core manifestations of PCOS.

7.2. Sleep Quality, Obesity, and Cardiometabolic Risk

Observational evidence indicates that poor sleep quality is highly prevalent among women with PCOS. In a 2023 study, most participants demonstrated suboptimal sleep quality, which was associated with less favorable anthropometric and cardiometabolic health markers (Benham, et al., 2023). These findings are clinically relevant because central obesity, dyslipidaemia, and insulin resistance are common in PCOS and may be exacerbated by chronic sleep disruption.

Another 2023 study reported that overweight and obese women with PCOS had normal total sleep duration but significantly poorer sleep efficiency than controls (Oberg, et al., 2023). This distinction is important, as sleep quantity alone may fail to capture clinically meaningful sleep impairment. Reduced sleep efficiency may reflect fragmented sleep, difficulty maintaining sleep, or altered circadian regulation, all of which may adversely influence glucose metabolism and appetite control. Behavioral modification intervention in this cohort reduced daytime sleep, suggesting that structured lifestyle strategies may improve sleep behavior even when nocturnal sleep duration remains unchanged (Oberg, et al., 2023).

Taken together, these findings indicate that women with PCOS may present with qualitative rather than purely quantitative sleep abnormalities, and that sleep efficiency may represent a clinically relevant therapeutic target.

7.3. Sleep Disturbances, Reproductive Function, and Neuroendocrine Regulation

Sleep impairment may also interact with reproductive dysfunction in PCOS. In a 2021 study, infertile women with PCOS reported sleep disturbances more frequently than women with unexplained infertility, suggesting that sleep problems may be particularly relevant in the PCOS infertility phenotype (Eisenberg, et al., 2021). Given the central role of ovulatory dysfunction in infertility, sleep-related endocrine disruption may represent a clinically meaningful cofactor.

Mechanistic evidence supports this hypothesis. A 2018 physiological study demonstrated abnormalities in luteinizing hormone (LH) pulse regulation during sleep in women with PCOS (Lu, et al., 2018). Normally, rapid eye movement (REM) sleep suppresses LH pulse initiation, whereas brief awakenings weaken this inhibitory effect. In women with PCOS, LH pulse initiation was not appropriately suppressed during REM sleep and may even have been facilitated during slow-wave sleep. These abnormalities may contribute to the elevated nocturnal LH pulse frequency commonly observed in PCOS (Lu, et al., 2018).

Because increased LH pulsatility promotes ovarian androgen production, disturbed sleep architecture may directly contribute to hyperandrogenism and ovulatory dysfunction. This highlights a potential neuroendocrine pathway linking sleep disturbance with reproductive abnormalities in PCOS.

7.4. Sleep-Targeted Supplementation: Melatonin and Magnesium

Interventions targeting sleep physiology may also improve metabolic and psychological outcomes. In a randomized controlled trial, 12 weeks of melatonin supplementation significantly improved Pittsburgh Sleep Quality Index scores and reduced depression and anxiety symptom scores compared with placebo (Shabani, et al., 2019). In parallel, melatonin reduced serum insulin, HOMA-IR, total cholesterol, and LDL-cholesterol, while improving insulin sensitivity as assessed by QUICKI (Shabani, et al., 2019). Molecular analyses additionally demonstrated upregulation of peroxisome proliferator-activated receptor gamma (PPAR-γ) and LDL receptor (LDLR) gene expression, suggesting potential metabolic regulatory effects.

Another trial found that co-supplementation with melatonin and magnesium for eight weeks reduced body weight, BMI, waist circumference, hirsutism, and serum TNF-α levels, while increasing total antioxidant capacity (Mousavi, et al., 2022). Melatonin alone also contributed to lower TNF-α concentrations, indicating anti-inflammatory potential (Mousavi, et al., 2022).

These findings suggest that melatonin-based interventions may offer multimodal benefits in PCOS by simultaneously targeting sleep quality, mood symptoms, inflammation, and insulin resistance.

8. Discussion

The present systematic review and meta-analysis indicates that comprehensive lifestyle interventions represent an effective and clinically relevant therapeutic strategy in women with polycystic ovary syndrome (PCOS). Across the included randomized controlled trials, interventions targeting diet, supplementation, physical exercise, and sleep demonstrated favorable effects on multiple domains of the syndrome, including anthropometric status, insulin resistance, lipid metabolism, androgen excess, menstrual dysfunction, psychological well-being, and quality of life. These findings reinforce the concept that PCOS should be approached not only as a reproductive disorder, but as a chronic multisystem metabolic condition requiring multidimensional management.

One of the most consistent observations across studies was the improvement in metabolic health. Weight reduction, lower body mass index, decreased waist circumference, and improved insulin sensitivity were reported after several dietary and exercise interventions. This is clinically important because insulin resistance is a central pathophysiological driver of many PCOS manifestations. Hyperinsulinaemia contributes to ovarian androgen production, ovulatory dysfunction, and progression of cardiometabolic risk. Therefore, interventions capable of reducing insulin resistance may exert benefits that extend beyond simple weight reduction. In this review, calorie-restricted diets, low-glycaemic-load patterns, ketogenic approaches, and structured aerobic or interval exercise frequently improved fasting insulin and HOMA-IR values, supporting their role as first-line therapeutic tools.

The review also highlights that dietary composition may be as important as caloric reduction alone. While energy deficit remains fundamental for weight management, several studies suggested that higher-protein diets, Mediterranean-style patterns, increased fiber intake, and lower glycaemic load may produce additional improvements in body composition, satiety, oxidative stress, and endocrine parameters. This finding supports a move away from a “one-size-fits-all” nutritional prescription toward phenotype-specific dietary planning based on obesity status, dyslipidaemia, insulin resistance, or reproductive priorities.

Exercise interventions similarly demonstrated broad therapeutic value. Both moderate-intensity continuous training and high-intensity interval training improved anthropometric and cardiometabolic outcomes. However, HIIT appeared particularly promising for enhancing insulin sensitivity, menstrual cyclicity, exercise enjoyment, and mental health outcomes in selected studies. Because adherence is critical in long-term lifestyle therapy, interventions associated with greater enjoyment and patient acceptability may have superior real-world effectiveness. Exercise additionally reduced inflammatory markers such as CRP, IL-6, and TNF-α, which may be relevant given the chronic low-grade inflammatory state frequently observed in PCOS.

Another important finding is the potential role of adjunctive supplementation. Probiotics, synbiotics, coenzyme Q10, omega-3 fatty acids, vitamin D, magnesium, flaxseed, melatonin, and antioxidant combinations demonstrated varying degrees of benefit on metabolic, hormonal, and inflammatory markers. Although results were heterogeneous, these interventions may provide additional support in selected patients, particularly when nutritional

deficiencies, oxidative stress, gut dysbiosis, or sleep disturbance coexist. However, supplementation should be viewed as complementary rather than a substitute for core lifestyle therapy.

Sleep emerged as an increasingly relevant yet historically under-recognized component of PCOS care. Included studies suggested that women with PCOS frequently experience poor sleep quality, altered sleep efficiency, and increased sleep disturbances. Sleep dysfunction may worsen insulin resistance, appetite regulation, mood disorders, and cardiometabolic health. Interventions such as sleep hygiene modification and melatonin supplementation may therefore represent useful adjunctive strategies within a broader lifestyle medicine model.

Collectively, the reviewed evidence supports individualized, multidisciplinary management of PCOS. Because phenotypes differ considerably between patients, treatment plans should be tailored according to BMI, insulin resistance, hyperandrogenism severity, fertility goals, psychological burden, and personal preference. Rather than focusing solely on symptom suppression through pharmacotherapy, clinicians should consider comprehensive lifestyle optimization as a core therapeutic framework.

9. Limitations

Several limitations should be acknowledged. Most randomized clinical trials included women with overweight or obesity, which may limit generalizability to lean women with PCOS. In addition, intervention duration was frequently short, and long-term adherence, relapse prevention, and sustainability remain insufficiently studied.

10. Future Directions

Future research should prioritize longer-duration randomized trials comparing combined multidomain lifestyle strategies with isolated interventions. Studies involving lean PCOS phenotypes and fertility-related outcomes such as ovulation, pregnancy, and live birth are particularly needed.

11. Conclusions

Comprehensive lifestyle interventions appear to be an effective evidence-based approach for managing of polycystic ovary syndrome. Across randomized controlled trials, dietary modification, structured exercise, selected supplementation, and sleep-focused strategies improved key metabolic, hormonal, reproductive, and psychological outcomes. Weight reduction and improved insulin sensitivity were strongly associated with reductions in androgen excess and menstrual dysfunction, highlighting the interconnected nature of PCOS pathophysiology. Exercise contributed additional cardiometabolic, anti-inflammatory, and mental health benefits, while sleep optimization and adjunctive supplementation may further enhance treatment response in selected patients. Given the heterogeneity of PCOS, no single intervention is universally optimal. Instead, individualized and multidisciplinary lifestyle management should be considered a central component of long-term PCOS care, with potential to complement pharmacological treatment and improve overall health outcomes.

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