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Diet and Physical Activity as a Cornerstone in Polycystic Ovary Syndrome: A Critical Review

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Abstract

Polycystic ovary syndrome (PCOS) is a common and complex endocrine disorder that affects the reproductive, metabolic, and psychological health of women of reproductive age. Characterised by irregular menstrual cycles, hyperandrogenism, ovulatory dysfunction, and metabolic disturbances like insulin resistance and obesity, PCOS has a multifactorial aetiology influenced by genetic, environmental, and lifestyle factors. Poor diet, sedentary behaviour, delayed diagnosis, and inadequate healthcare contribute to its rising prevalence and exacerbate long-term risks such as type 2 diabetes, cardiovascular disease, and infertility. Early diagnosis and intervention are essential for improving outcomes. This review highlights the emerging roles of lifestyle modifications, probiotics, and herbal therapies in managing PCOS. Lifestyle changes, including dietary improvements and regular exercise, remain the cornerstone of treatment, improving metabolic health, hormonal balance, and fertility. Probiotics and synbiotics offer promise by modulating gut microbiota, reducing inflammation, and enhancing insulin sensitivity, complementing conventional treatments. Herbal remedies show potential but require further research to confirm their efficacy and safety. In conclusion, a personalised, multi-pronged treatment approach combining lifestyle interventions, probiotics, and herbal therapies holds promise for improving the health and quality of life of women with PCOS. Continued research is needed to refine these strategies and ensure their safe and effective integration into clinical practice.

Major Finding: Lifestyle modifications serve as the foundational, first-line intervention with the highest efficacy in optimising PCOS metabolic and reproductive outcomes.

Keywords: Health Education, Health Issues, Nutrition, Public Health, Reproductive Health, Well Being

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1. Introduction

PCOS stands as a major stumbling block worldwide. PCOS is a prevalent endocrine disorder affecting women of reproductive age[1].PCOS is acknowledged as a significant reproductive and metabolic disorder, primarily impacting ovarian function, and its global prevalence is estimated to range between 4% and 20%, reflecting its widespread impact across diverse populations[2]. Nationally, the prevalence of PCOS is reported to vary widely, ranging from 3.7% to 22.5%[3]. Polycystic ovaries on ultrasound are usually defined by the detection of 12 or more small follicles, with individual follicle sizes ranging from 2 to 9 millimetres, within each ovary. Additionally, a notable feature of PCOS is an increase in ovarian volume, typically exceeding 10 milliliters[4].PCOS is most often diagnosed using the Rotterdam criteria, which stipulate that at least two of three defining features must be present: irregular or infrequent menstrual cycles. elevated androgen levels, and the presence of multiple ovarian cysts[5].The clinical manifestations of PCOS are diverse, and they include irregular or absent menstrual cycles, chronic pelvic pain and signs of hyperandrogenism

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such as hirsutism and alopecia[6]. Additionally, many individuals with PCOS experience dermatological issues, including acne, acanthosis nigricans and the presence of skin tags[7].These symptoms not only vary in severity but also contribute to the overall burden of the condition. The exact aetiology of PCOS remains incompletely understood; however, it is widely regarded as a multifactorial disorder influenced by a complex interplay of genetic, metabolic, endocrine, and environmental factors. Emerging research suggests that a genetic tendency is believed to contribute substantially to the development of PCOS, as evidenced by its frequent occurrence within families and the identification of specific gene variants pointing to hereditary contributions[8]. Although the precise genetic basis of PCOS remains unidentified, it is well established that a family history of the disorder is frequently observed. Despite this association, the exact nature of the hereditary patterns or familial transmission of PCOS is yet to be clearly understood[9]. Scientific evidence indicates that exposure to the environmental pollutants, including pharmaceuticals and personal care products, microplastics, endocrine disruptors and nanoparticles contribute to the manifestation of PCOS symptoms and related complications[10]. Certain environmental pollutants, including endocrine-disrupting chemicals (EDCs), have been shown to interfere with normal hormonal regulation, potentially worsening the hyperandrogenism, insulin resistance, and ovarian dysfunction characteristic of PCOS[11]. Lifestyle modification is widely recommended as the cornerstone of therapeutic interventions for weight management in individuals with PCOS[12]. It is considered the primary approach in the management of PCOS, particularly in terms of improving metabolic and reproductive outcomes. This includes interventions such as dietary changes, regular physical activity, and weight management, all of which have been shown to positively influence insulin sensitivity, hormonal balance, and menstrual regularity in women with PCOS[13]. Figure 3 illustrates the integrative mechanisms of multifaceted interventions in alleviating PCOS.

The present review intentionally encompasses a broad spectrum of interventions, including physical activity, synbiotics, functional foods, nutraceuticals, and commonly used herbs and spices, as these approaches have recently gained considerable scientific and public attention for promoting a healthier lifestyle and managing disease conditions through non-invasive strategies. In recent years, there has been a growing preference among individuals toward preventive and lifestyle-based therapeutic

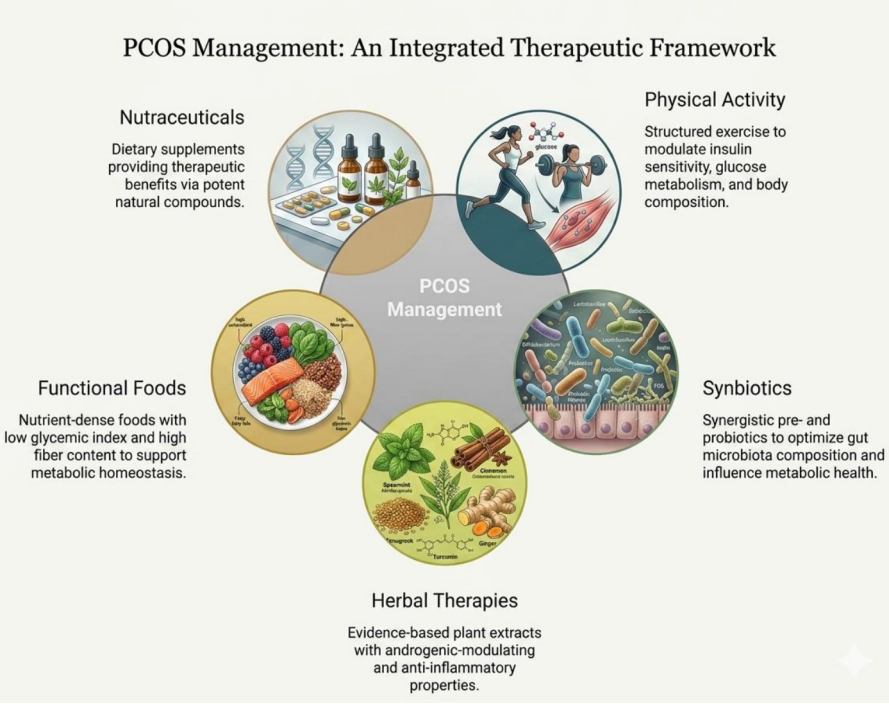


Figure 1. An integrative therapeutic framework for PCOS management.

approaches rather than invasive treatment modalities. Consequently, interventions such as regular physical activity, synbiotics, and functional foods have emerged as important areas of research owing to their potential health-promoting and disease-modulating effects. Simultaneously, traditionally used household herbs and spices are also receiving increased recognition because of their accessibility, natural origin, therapeutic potential, and long-standing use in complementary healthcare practices. Figure 1 explicates an integrative therapeutic framework for PCOS management.

2. Materials and Methods

2.1 Eligibility Criteria

The selected studies fulfilled predefined eligibility criteria, comprising randomised clinical trials and interventional studies focused on the management

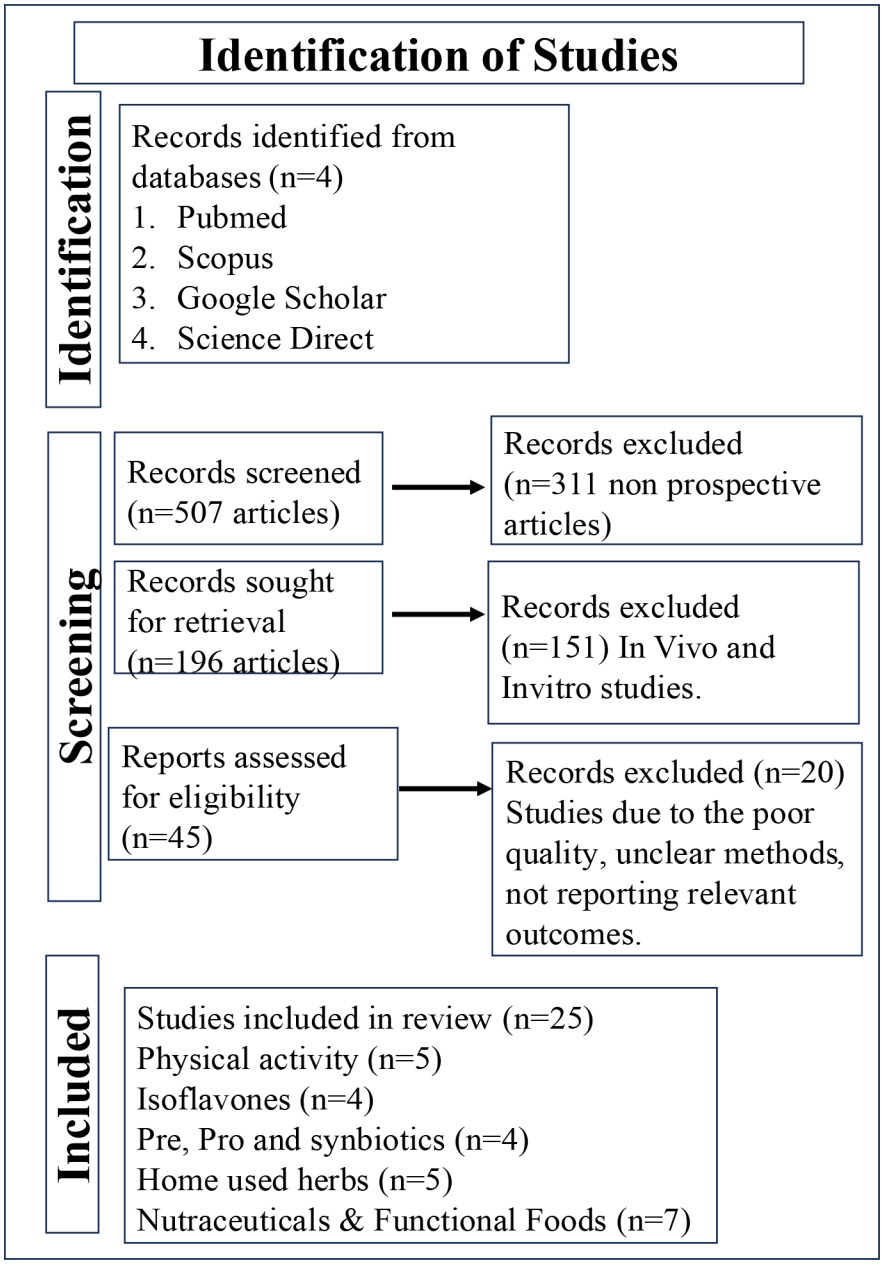


Figure 2. Illustrates the flowchart that outlines the procedure for selecting articles in accordance with PRISMA guidelines.

of PCOS. The interventions investigated included physical activity, isoflavone supplementation, prebiotic and probiotic supplementation, commonly used herbs and spices, nutraceuticals, and functional foods among women with PCOS. To ensure comprehensive coverage of the research area, randomised controlled trial designs were primarily considered. Study participants included women diagnosed with PCOS based on the Rotterdam criteria, along with healthy control subjects where applicable. The included studies evaluated various clinical outcomes related to PCOS management using validated questionnaires, assessment scales, and biological sample analyses.

2.2 Search Strategy and Study Selection

An extensive investigation was conducted utilising PubMed, Scopus, Google Scholar and ScienceDirect as a primary medical database source. The literature search was narrowed down to include studies published within the time frame of 2019–2023. The terms used were: "polycystic ovarian syndrome", "endocrine", "nutrition", "dietary supplements", "isoflavones", "physical activity", "herbs", "spices", "probiotics", "prebiotics", "functional foods", "nutraceuticals", "phytoestrogen", "aerobic exercise" "synbiotics", "omega 3 fatty acids", "curcumin" "berberine" "fructooligosaccharides" and "inulin". Following the literature search, data extraction was carried out, and selected articles were thoroughly reviewed to exclude studies that were irrelevant to the topic and animal studies. Figure 2 illustrates the flow chart of how the articles are selected.

3. Physical Activity and PCOS

Physical activity can be broadly defined as any movement of the body that is initiated by skeletal muscles, leading to an increase in energy expenditure[14]. Exercise has been shown to reduce oxidative stress and inflammation, strengthen the body's natural antioxidant defences, and support the healthy functioning of multiple organs and tissues. Regular physical activity induces a series of adaptive responses that help to counteract the damaging effects of free radicals and reactive oxygen species (ROS), which are known to contribute to cellular damage and the pathogenesis of numerous chronic diseases[15]. Studies have shown that regular physical activity improves insulin sensitivity, enhances skeletal muscle glucose uptake, reduces hyperinsulinemia, and lowers androgen excess in women with PCOS, thereby contributing to improved ovulatory and metabolic outcomes. Exercise-induced improvements are mediated through enhanced GLUT-4 activity, mitochondrial function, reduced visceral adiposity, and attenuation of chronic inflammation[16].

Aerobic exercise training regimens, especially those that incorporate higher-intensity activities, greater frequency of sessions per week, and/or longer durations of exercise, have been shown to enhance various markers of insulin metabolism and improve insulin sensitivity. These training protocols, by engaging the cardiovascular system more intensely and consistently, promote a more efficient use of insulin by muscle cells, thereby improving the body's overall insulin responsiveness[17]. Table 1explicates the physical activity interventions in PCOS.

4. Effects of Isoflavones Supplementation in PCOS

Isoflavones, primarily derived from soy and other leguminous sources, have gained considerable attention as potential therapeutic agents in the management of PCOS due to their multifaceted endocrine and metabolic effects.Phytoestrogens are compounds that possess estrogenic activity due to their structural similarity to the endogenous hormone 17β-estradiol[23]. Phytoestrogens are widely incorporated into various dietary supplements and have gained prominence as a natural alternative in hormone replacement therapy (HRT), offering a plant-based option to synthetic hormonal treatments[24].Novel dietary supplements, particularly those enriched with phytoestrogens, have emerged as a promising alternative strategy for managing the symptoms of PCOS. These supplements have demonstrated potential in improving ovulatory function, lowering blood glucose levels, reducing stress, and promoting weight reduction, thus offering a multifaceted approach to alleviating the adverse effects associated with PCOS[25].

Structurally similar to endogenous estrogens, isoflavones such as genistein and daidzein exert phytoestrogenic activity by selectively binding to estrogen receptors, particularly estrogenreceptor-β (ER-β). This receptor modulation contributes to the

Table 1. Physical activity intervention in PCOS

Subjects	Study Design, Aim	Dosage and Duration	Outcomes Measured	Findings	References
Sixty-six women with PCOS	A randomised, double-blind, placebo-controlled trial was conducted to evaluate the effectiveness of exercise in improving clinical manifestations, anthropometric measures, glucose tolerance, and biochemical parameters in women with PCOS. The study also aimed to assess the added benefits of combining exercise with metformin on these outcomes in women affected by the condition.	Participants were assigned to a six-month intervention in which women in Group A followed a structured exercise regimen combined with an oral placebo, while those in Group B undertook the same exercise program alongside oral metformin therapy.	The assessed parameters included menstrual cycle regularity, degree of hirsutism, body weight, body mass index, waist circumference, waist-to-hip ratio, serum testosterone levels, and results of the Oral Glucose Tolerance Test (OGTT).	Consistent physical activity should be encouraged for women with PCOS, as it leads to significant improvements in menstrual cycle regularity, hirsutism, body weight, body mass index, waist circumference, and waist-to-hip ratio.	18
Forty-seven women with PCOS	A pilot randomised controlled trial was carried out to evaluate and compare the impacts of high-intensity interval training (HIIT), continuous aerobic exercise training (CAET), and a no-exercise control on reproductive, anthropometric, and cardiometabolic parameters in women with PCOS.	Forty-seven women were randomised to no-exercise control (n = 17), high-intensity interval training (n = 16), or continuous aerobic exercise training (n = 14).	Outcomes included reproductive, anthropometric and cardiometabolic health markers.	Continuous aerobic exercise training and high-intensity interval training were both effective at improving anthropometrics and some cardiometabolic health markers.	19
36 women with PCOS	A randomised controlled trial was performed to investigate the feasibility of 2 Physical Activity interventions to decrease cardiovascular disease risk among PCOS women.	Participants were randomly assigned to one of three groups for 12 weeks: a supervised exercise intervention (n = 12), a lifestyle physical activity program focused on decreasing sedentary behaviour (n = 12), or a control group (n = 12).	The primary outcomes focused on evaluating the practicality and participant acceptability of the interventions and study procedures.	The study achieved a recruitment rate of 56%. Adherence to the interventions was 53% for the exercise group and 100% for the lifestyle physical activity group. Secondary outcome analysis revealed a decrease in oxidised low-density lipoprotein levels in the exercise group, while both intervention groups experienced reductions in body weight.	20

Table 1. Continued...

Subjects	Study Design, Aim	Dosage and Duration	Outcomes Measured	Findings	References
40 females aged 25-35 years diagnosed with PCOS participated in the study.	The investigation explored the potential impact of aerobic exercise on interleukin-6 (IL-6), tumour necrosis factor (TNF), and C-reactive protein (CRP) levels in women with PCOS, using a randomised controlled trial design.	Participants were evenly allocated into two groups: an aerobic exercise group and a metformin-only group. Those in the aerobic exercise group engaged in aerobic training three times per week for 12 weeks alongside metformin therapy, while the comparison group received metformin treatment alone.	The outcomes measured were interleukin-6 (IL6), tumour necrosis factor (TNF), and C-reactive protein (CRP)	Aerobic physical activity has been shown to effectively reduce levels of IL-6, TNF-α, and C-reactive protein in women with polycystic ovary syndrome.	21
36 participants with PCOS participated in the study.	A randomised controlled trial was conducted to study the impact of vigorous *vs.* moderate exercise on metabolic parameters in polycystic ovary syndrome	Participants were assigned through block randomisation to a home-based exercise regimen consisting of either 75 minutes of vigorous-intensity activity or 150 minutes of moderate-intensity activity per week, continued over eight weeks.	Changes in glucose, insulin, and insulin resistance are the outcomes measured.	Unsupervised exercise interventions may fail to produce meaningful metabolic benefits in individuals with PCOS, irrespective of whether the activity is performed at moderate or high intensity.	22

regulation of steroidogenesis, restoration of hormonal balance, and reduction of ovarian androgen synthesis, thereby alleviating hyperandrogenic manifestations commonly observed in women with PCOS[26]. In addition to their hormonal effects, isoflavones play a significant role in improving insulin sensitivity and glucose metabolism. They influence key insulin signalling pathways through activation of peroxisome proliferator-activated receptors (PPARs), enhancement of glucose transporter-4 (GLUT-4) activity, and modulation of pancreatic β-cell function. These mechanisms contribute to reduced insulin resistance and compensatory hyperinsulinemia, which are central pathophysiological features of PCOS. Improved insulin regulation may subsequently support ovulatory function and reproductive health[27]. Isoflavonesalso possess potent antioxidant and anti-inflammatory properties that may further contribute to their therapeutic efficacy. By reducing reactive oxygen species generation and suppressing pro-inflammatory mediators such as nuclear factor-kappa B (NF-κB), tumour necrosis factor-α (TNF-α), and interleukin-6 (IL-6), isoflavones help mitigate chronic low-grade inflammation and oxidative stress associated with PCOS. Furthermore, several clinical and experimental studies have demonstrated improvements in lipid metabolism, ovarian morphology, menstrual regularity, and reproductive hormone profiles following isoflavone supplementation. Collectively, these findings suggest that isoflavones may serve as promising adjunctive interventions for improving both metabolic and reproductive outcomes in women with PCOS[28]. Table 2explicates the isoflavones intervention in PCOS.

5. Effect of Prebiotics and Probiotics Supplementation in PCOS

Probiotic supplementation has emerged as a promising adjunctive strategy for the management of PCOS in adolescents with obesity. The existing body of literature indicates that probiotic and symbiotic supplementation holds potential in improving several

Table 2. Isoflavones supplementation in PCOS

Subjects	Study Design, Aim	Dosage and Duration	Outcomes Measured	Findings	References
146 subjects with PCOS	This study aimed to evaluate the effects of soy-derived phytoestrogens on reproductive hormone concentrations and lipid profiles in women with polycystic ovary syndrome (PCOS), using a quasi-experimental study design.	The experimental group was administered 18 mg of Genistein orally, twice daily, while the control group received identical capsules containing cellulose, over a duration of three months.	Hormonal parameters and lipid profiles were assessed both prior to and following three months of supplementation.	After 3 months of supplementation, no significant changes were observed in HDL and FSH levels between the Genistein and placebo groups. However, the Genistein group showed significant reductions in LH, triglycerides, LDL, DHEAS, and testosterone levels.	29
A total of 70 women, aged between 18 and 40 years, who were diagnosed with polycystic ovary syndrome (PCOS) based on the Rotterdam criteria, were included in the study.	The current investigation sought to assess the effects of soy isoflavones on metabolic parameters in women with polycystic ovary syndrome (PCOS). A randomised, double-blind, placebo-controlled trial was carried out to determine the effectiveness of soy isoflavones in influencing key aspects of metabolic health in this population.	Participants were randomly assigned to one of two groups: one receiving 50 mg/day of soy isoflavones (n = 35) and the other a placebo (n = 35) for a duration of 12 weeks. Key metabolic, endocrine, inflammatory, and oxidative stress biomarkers were measured at baseline and following the 12-week intervention period.	Insulin sensitivity check index, free androgen index, serum triglycerides, plasma total glutathione, and malondialdehyde levels	The 12-week administration of soy isoflavones in women with PCOS resulted in a significant improvement in markers of insulin resistance, hormonal balance, triglyceride levels, and oxidative stress biomarkers.	28
The study included 43 participants in total, of whom 24 were allocated to the intervention group and 19 to the control group.	The research sought to explore differences in equol metabolism between women with PCOS and a comparison group of women who were hormonally and metabolically healthy. To achieve this, a short-term interventional pre–post study design was employed.	Participants in the study consumed 200 mL of a soy-based drink twice daily (morning and evening) for a duration of three consecutive days.	Urinary isoflavone concentrations were assessed in both PCOS and control participants prior to and three days following a controlled isoflavone intervention with soy milk. Bacterial equol production was evaluated through analysis of the microbiome, metabolic pathways, and predicted metagenomic profiles.	Following the isoflavone intervention, there was an improvement in predicted stool metagenomic pathways, microbial alpha diversity, and glucose homeostasis in the PCOS group, with their profiles closely resembling those of the control group at baseline.	15

Table 2. Continued...

Subjects	Study Design, Aim	Dosage and Duration	Outcomes Measured	Findings	References
Twelve Caucasian women with PCOS, exhibiting obesity, hyperinsulinemia, and dyslipidemia, were included in the study.	A pilot prospective study was conducted to assess the impact of the soy isoflavone genistein on the metabolic and hormonal disturbances associated with polycystic ovary syndrome.	Participants were administered 36 mg per day of genistein for a duration of six months.	Basal hormonal assays, lipid profile, and glycoin insulinemic assessment were measured.	Phytoestrogen supplementation resulted in a significant improvement in overall cholesterol levels, characterised by a reduction in low-density lipoprotein (LDL) cholesterol and a consequent marked decline in the LDL-to–high-density lipoprotein (HDL) ratio.	32

metabolic and physiological abnormalities associated with PCOS. Specifically, these interventions may positively influence hormonal imbalances, modulate inflammatory markers, and alleviate disturbances in lipid metabolism commonly observed in individuals with PCOS. Dysregulation of these systems, including hyperandrogenism, chronic low-grade inflammation, and altered lipid profiles, are hallmark feature of the syndrome and contributes to its clinical manifestations as well as its long-term health risks. Probiotic and symbiotic formulations, which combine beneficial bacteria with prebiotics to foster their growth, may help restore gut microbiota homeostasis, a key factor implicated in the pathophysiology of PCOS[33]. Probiotics are living microorganisms that, when ingested in adequate amounts, confer beneficial effects on the health of the host[34].Some probiotics have been demonstrated to influence the regulation of gene expression of pro and anti-inflammatory molecules in a strain-specific manner.Prebiotics are compounds that are selectively fermented, leading to targeted changes in the composition and/or activity of the gut microbiota, thereby promoting the health and well-being of the host[35].

Through suppression of LPS-mediated inflammatory signalling, synbiotics reduce activation of pathways such as NF-κB and subsequently lower circulating pro-inflammatory cytokines, including TNF-α and IL-6. In addition, synbiotics enhance the production of short-chain fatty acids (SCFAs), which act as metabolic regulators to improve insulin sensitivity, glucose utilisation, and lipid metabolism via receptor-mediated and epigenetic mechanisms[36]. Furthermore, synbiotics influence the gut–brain–ovarian axis, thereby indirectly modulating endocrine regulation, insulin signalling, and ovarian function. Clinical evidence from randomised trials and systematic reviews reports improvements in insulin resistance, inflammatory markers, lipid profiles, and androgen levels following synbiotic supplementation in women with PCOS, supporting their potential role as adjunctive metabolic and reproductive therapy[37]. Table 3 explicates the pro- and prebiotics interventions in PCOS.

6. Effect of Home-used Herbs and Spices Intervention in PCOS

Numerous studies have highlighted the potential of herbal medicines in the management of PCOS, particularly due to their relatively low incidence of adverse effects compared to conventional pharmacological treatments. These natural remedies are increasingly being recognised for their ability to address various aspects of PCOS, including hormonal imbalances, insulin resistance, and metabolic dysfunction, while offering a safer alternative for

Table 3. Pro- and prebiotics intervention in PCOS

Subjects	Study Design, Aim	Dosage and Duration	Outcomes Measured	Findings	References
Fifty women with PCOS were assigned to the intervention group, while forty-nine PCOS individuals were included in the control group.	A double-blind, randomised, placebo-controlled clinical trial was carried out to assess the effects of probiotic supplementation on both hormonal and clinical outcomes in women with PCOS.	The participants were instructed to take either the probiotic or placebo capsules daily for 12 weeks, with two capsules consumed after meals alongside a glass of cold water. Each probiotic capsule contained a blend of seven strains of beneficial bacteria, while the placebo capsules were composed of 250 mg of starch and 250 mg of maltodextrin.	Measurements included serum concentrations of luteinizing hormone (LH), follicle-stimulating hormone (FSH), sex hormone-binding globulin (SHBG), dehydroepiandrosterone sulfate (DHEAS), total testosterone (TT), and the free androgen index (FAI), along with clinical features of PCOS such as acne and hirsutism.	After 12 weeks of supplementation, probiotic intake significantly elevated serum levels of sex hormone-binding globulin (SHBG) compared to the placebo group. However, no other significant improvements were observed in the hormonal or clinical parameters assessed.	38
A total of 68 overweight or obese women, aged 20 to 44 years, diagnosed with PCOS, were enrolled in the study.	A randomised, double-blind, placebo-controlled clinical trial was performed to investigate the impact of synbiotic supplementation on glycemic control, lipid profiles, apelin concentrations, and anthropometric parameters in women with PCOS.	Over a period of eight weeks, participants in the treatment group (n = 34) were administered one synbiotic capsule daily, while those in the placebo group (n = 34) received a placebo capsule, both to be taken after lunch. Each synbiotic capsule contained a blend of seven beneficial bacterial strains, while the placebo capsules were composed of starch and matched the synbiotic capsules in colour and shape.	Fasting blood specimens, anthropometric measurements, Serum lipids, and apelin levels	Synbiotic supplementation led to improvements in glycemic indices, lipid profiles, and anthropometric measures in women with PCOS.	39
A total of 65 women with a diagnosis of PCOS and a body mass index (BMI) greater than 25 were recruited for the study.	The study was designed to evaluate the impact of lifestyle interventions combined with synbiotic supplementation on women with PCOS. To examine these effects, a randomised, double-blind, placebo-controlled trial was conducted using a 1:1 allocation ratio.	Participants in the placebo group were instructed to take four placebo capsules daily. Those in the synbiotic group received a supplement containing two probiotic strains, along with the prebiotics fructooligosaccharides and inulin.	Change in body mass index (BMI) and testosterone level.	Synbiotic supplementation enhanced the effects of lifestyle modifications on weight loss and resulted in a significant reduction in serum testosterone levels.	40

Table 3. Continued...

Subjects	Study Design, Aim	Dosage and Duration	Outcomes Measured	Findings	References
Sixty participants diagnosed with PCOS, based on the Rotterdam criteria, were included in the study.	The study was designed to investigate the effects of synbiotic supplementation on hormonal levels and markers of inflammation and oxidative stress in women with PCOS. A randomised, double-blind, placebo-controlled clinical trial was conducted to evaluate these outcomes.	Participants were randomly allocated to receive either a synbiotic supplement or a placebo (n = 30 per group) over 12 weeks. The intervention group's synbiotic formulation included *Lactobacillus acidophilus*, *Lactobacillus casei*, and *Bifidobacterium bifidum* (each at 2×10^9 CFU/g), combined with 0.8 g of inulin.	Anthropometric measurements, hirsutism using an mFG scoring system, and blood sugar levels	Synbiotic supplementation led to a significant increase in serum levels of sex hormone-binding globulin (SHBG). However, no significant effects were observed on other hormonal markers or biomarkers of oxidative stress.	41

Table 4. Home used herbs and spices intervention in PCOS

Subjects	Study Design, Aim	Dosage and Duration	Outcomes Measured	Findings	References
A total of 84 women with PCOS, aged 20 to 38 years, were randomly assigned to two groups, with 42 participants in each group.	A double-blind, randomised controlled clinical trial was carried out to examine the impact of cinnamon supplementation on antioxidant capacity and serum lipid levels in women diagnosed with polycystic ovary syndrome (PCOS).	The participants were assigned to receive either three cinnamon capsules (each containing 500 mg of cinnamon) or a placebo daily for a period of 8 weeks.	Fasting blood samples, anthropometric measurements	Cinnamon supplementation enhanced antioxidant status and serum lipid profiles in women with PCOS, suggesting its potential as a beneficial intervention for mitigating risk factors associated with the condition.	43
A total of 103 adolescents with PCOS participated in the study, with 53 in the control group and 50 in the intervention group.	A randomised clinical trial was conducted to assess the impact of *Nigella sativa* supplementation on the symptoms and severity of PCOS in adolescents.	Participants were randomly assigned to either the intervention group (receiving 1000 mg/day of *Nigella sativa*) or the control group (receiving 10 mg/day of medroxy progesterone). The study was conducted over 16 weeks.	Ovarian volume, anthropometric and blood pressure; serum testosterone, dehydroepiandrosterone dehydroepiandrosteronesulfate luteinizing hormone, hirsutism severity levels	Short-term supplementation with *Nigella sativa* may help decrease ovarian volume, restore hormonal balance, and improve menstrual regularity in adolescents with PCOS.	44

Table 4. Continued...

Subjects	Study Design, Aim	Dosage and Duration	Outcomes Measured	Findings	References
A total of 107 female volunteers, aged 18 to 45 years, were recruited for the study.	This randomised, single-arm study evaluated the efficacy of a novel fenugreek seed extract.	Participants received capsules containing a novel fenugreek seed extract at a dose of 1,000 mg per day for 12 consecutive weeks.	The study assessed both physical and biochemical parameters. Physical measurements included sonographic evaluation, hirsutism score, menstrual cycle regularity, body weight, body mass index (BMI), height, waist circumference, and blood pressure. Biochemical assessments comprised LH/FSH ratio, TSH, prolactin, fasting insulin and glucose, triglycerides, cholesterol, HOMA-IR index, total and free testosterone, 2-hour glucose tolerance test (GTT), and DHEAS levels.	The efficacy of a novel fenugreek seed extract was assessed as a safe phytotherapeutic intervention for reversing the reproductive system damage associated with PCOS.	45
A total of 54 women with PCOS were included in the study, with 27 participants assigned to the intervention group and 27 to the placebo group.	A triple-blind, randomised controlled trial was carried out to investigate the impact of curcumin on metabolic parameters and androgen levels as primary outcomes, alongside its effects on menstrual patterns and hirsutism as secondary outcomes in women with PCOS.	The treatment group was administered two 500 mg curcumin tablets daily, taken together, for a duration of 12 weeks, while the control group received placebo tablets, indistinguishable from the curcumin tablets, for the same period.	Measurements included fasting blood insulin (FBI), fasting blood glucose (FBS), triglycerides, total cholesterol, low-density lipoprotein cholesterol (LDL-C), and high-density lipoprotein cholesterol (HDL-C).	Curcumin supplementation for 12 weeks in women with PCOS positively impacted body weight, blood sugar control, serum lipids (excluding triglycerides), VLDL-C levels, and markers such as peroxisome proliferator-activated receptor gamma (PPAR-γ) and LDL receptors.	46

long-term management. Several studies have shown that herbal medicines offer a valuable adjunct or alternative to conventional treatments; they should be considered within the broader context of individualised care, with further research needed to validate their clinical utility in managing PCOS.

Home-used herbs commonly used in PCOS management, such as cinnamon, fenugreek, spearmint, ginger, and turmeric, exert their effects through multiple interconnected mechanisms targeting the core pathophysiology of the disorder. A primary action is the improvement of insulin sensitivity and glucose metabolism via enhanced insulin receptor signalling, increased peripheral glucose uptake, and regulation of key metabolic enzymes, thereby reducing insulin resistance and compensatory hyperinsulinemia[42]. This, in turn, contributes to decreased ovarian androgen excess and improved ovulatory function. In addition, many of these herbs exhibit anti-androgenic properties by modulating steroidogenesis and lowering circulating testosterone levels, supporting menstrual regularity and hormonal balance.

Table 5. Nutraceuticals and functional foods intervention in PCOS

Subjects	Study Design, Aim	Dosage and Duration	Outcomes Measured	Findings	References
A total of 136 women aged 15-40 were recruited for the study period of 24 months.	A prospective study was carried out to evaluate the effects of berberine, metformin, and myoinositol on women diagnosed with polycystic ovary syndrome (PCOS).	Participants were allocated to one of three treatment groups using computer-generated randomisation. Group 1 was administered berberine hydrochloride 500 mg twice daily, Group 2 received metformin hydrochloride 500 mg twice daily, and Group 3 was given myoinositol 1000 mg twice daily.	Assessments included fasting blood glucose, serum fasting insulin, hormonal parameters (serum testosterone, sex hormone-binding globulin [SHBG], and free androgen index), along with lipid profile and anthropometric measurements.	After three months of treatment, significant changes were observed across the three groups in weight, BMI, waist circumference, waist-to-hip ratio, fasting blood sugar (FBS), fasting insulin (FI), fasting glucose/insulin ratio, total testosterone, free androgen index (FAI), SHBG, total cholesterol, triglycerides, LDL, VLDL, and HDL. Among the groups, berberine demonstrated the most pronounced improvements in clinical, hormonal, and lipid parameters compared with metformin and myoinositol.	51
A total of 90 women aged 18 to 40 years who were diagnosed with PCOS, according to Rotterdam's criteria, were included in the study for a period of 18 months.	A prospective clinical study was conducted to assess the effectiveness of myo-inositol and its impact on the clinical, hormonal, and metabolic profiles of women with PCOS.	Participants were administered myo-inositol tablets at a dose of 1 g twice daily for six months. Before initiating treatment, a comprehensive medical history was obtained, and baseline investigations were conducted, which were then repeated at the conclusion of the six months.	Assessments included serum FSH and LH levels (measured on day 2 or 3 of a spontaneous or induced menstrual cycle), fasting blood sugar (FBS), fasting serum insulin, and derived indices such as the LH/FSH ratio and HOMA-IR.	Myo-inositol resulted in a significant enhancement of both hormonal and metabolic parameters in women with PCOS.	52
A total of 86 women with PCOS participated in the study.	A randomised, double-blind, placebo-controlled trial was carried out to examine the impact of CoQ10 and/or vitamin E supplementation on cardiometabolic parameters in women with PCOS.	Patients were assigned to take CoQ10, vitamin E, CoQ10 plus vitamin E or placebo for 8 weeks.	Serum triglyceridestotal cholesterol levels, low-density lipoprotein-cholesterol, and high-density lipoprotein-cholesterol	The results indicated that supplementation with CoQ10 and/or vitamin E may serve as an effective and well-tolerated approach to reducing the risk of cardiometabolic complications in women with PCOS.	53

Table 5. Continued...

Subjects	Study Design, Aim	Dosage and Duration	Outcomes Measured	Findings	References
148 PCOS Patients aged 18-29 years with Clomiphene Citrate resistance participated in the study	A randomised controlled trial was conducted to assess the potential advantages of supplementing Clomiphene Citrate with the active form of Coenzyme Q10 (Ubiquinol) compared to treatment with Human Menopausal Gonadotropins (hMG) in PCOS patients resistant to Clomiphene Citrate.	In Group A, controlled ovarian stimulation was initiated with Clomiphene Citrate at a dose of 150 mg daily (3 tablets) for 5 days, administered from day 2 to day 6 of the menstrual cycle. Concurrently, Ubiquinol (the active form of Coenzyme Q10) was given orally at 100 mg once daily, starting on day 2 and continuing until the day of human Chorionic Gonadotropin (hCG) trigger, taken immediately after a meal. In Group B, intramuscular Human Menopausal Gonadotropin (hMG) was administered starting on day 2 of the menstrual cycle, with doses ranging from 75 to 225 IU, adjusted based on the individual patient's response.	The primary outcomes evaluated included the number of patients achieving follicular growth to a mature size (≥18 mm) in 1–3 follicles across three stimulation cycles, the total number of stimulated cycles, endometrial thickness on the day of trigger, and luteal function assessed via mid-luteal serum progesterone levels. Secondary outcomes comprised the number of patients with a positive serum pregnancy test and the clinical pregnancy rate in the two groups over the three treatment cycles.	Supplementing Clomiphene Citrate with the active form of Coenzyme Q10 (Ubiquinol) enhanced ovarian responsiveness in patients resistant to Clomiphene Citrate, as reflected by increased follicular growth to mature size, a higher number of stimulated cycles, greater endometrial thickness on the day of trigger, improved luteal function, and ultimately, an increased pregnancy rate.	54
Trial was conducted among 56 patients with PCOS, aged 18–40 years old.	A randomised, double-blind, placebo-controlled clinical trial was carried out to assess the impact of melatonin supplementation on clinical, hormonal, inflammatory, and genetic markers in women with polycystic ovary syndrome (PCOS).	Participants were randomly assigned to receive either 5 mg of melatonin or a placebo twice daily for a duration of 12 weeks.	Serum total testosterone, high-sensitivity C-reactive protein, plasma malondialdehyde (MDA) levels, plasma total antioxidant capacity, and total glutathione	A 12-week course of melatonin supplementation in women with PCOS led to a significant reduction in hirsutism, total testosterone, hs-CRP, and MDA levels, while enhancing TAC and GSH concentrations. Furthermore, melatonin intake was associated with decreased gene expression of IL-1 and TNF-α.	55

Table 5. Continued...

Subjects	Study Design, Aim	Dosage and Duration	Outcomes Measured	Findings	References
Participants with PCOS were diagnosed based on the Rotterdam criteria. A total of 34 women were enrolled in the study, with 30 completing the trial.	A randomised (1:1) double-blind, placebo-controlled trial was designed to evaluate the endocrine and metabolic effects of resveratrol on PCOS.	Resveratrol was administered orally at a dose of 1,500 mg per day, with a matching placebo given to the control group.	The primary outcome measured was the change in serum total testosterone levels.	Resveratrol administration resulted in a significant reduction in total testosterone. Additionally, it produced a 22.2% decrease in dehydroepiandrosterone sulfate, lowered fasting insulin levels, and improved the Insulin Sensitivity Index. However, levels of gonadotropins, lipid profiles, and markers of inflammation and endothelial function remained largely unchanged.	56
The study included 110 patients with PCOS participated in the study.	A double-blind clinical trial was carried out to evaluate the impact of L-carnitine supplementation during controlled ovarian stimulation (COS) using an antagonist protocol in women with PCOS undergoing IVF/ ICSI treatment.	In the experimental group, participants were given three tablets daily, each containing 1000 mg of L-carnitine, starting from the second day of menstruation in the preceding cycle and continuing until the day of oocyte retrieval for freeze-all embryo cases (6 weeks) or until the pregnancy test in fresh embryo transfer cycles (8 weeks). The control group received three placebo tablets daily over the same duration.	Body weight, fasting blood glucose and insulin levels, and serum lipid profiles were also evaluated at baseline and on the day of oocyte retrieval.	Oral supplementation with L-carnitine for six weeks during the COS cycle in women with PCOS did not influence ovarian response or pregnancy outcomes. However, this regimen was associated with reductions in body weight and improvements in serum glucose levels and lipid profiles.	57

Furthermore, these herbal agents demonstrate strong anti-inflammatory and antioxidant activities by suppressing pro-inflammatory cytokines such as TNF-α and IL-6 and inhibiting pathways like NF-κB, while enhancing endogenous antioxidant defenses including SOD, catalase, and glutathione systems. They also contribute to improved lipid metabolism and body weight regulation, which further supports metabolic homeostasis in PCOS. Emerging evidence additionally suggests a potential role in modulating gut microbiota and related metabolic signalling pathways, collectively making home-use herbs a multi-targeted adjunct in improving both metabolic and reproductive outcomes in PCOS. Table 4explicates the herbs and spices intervention in PCOS.

7. Novel Nutraceuticals and Functional Foods for PCOS

While pharmacological interventions remain a cornerstone in its management, there is a growing interest in novel nutraceuticals and functional foods as complementary approaches to support hormonal regulation, improve metabolic outcomes and enhance

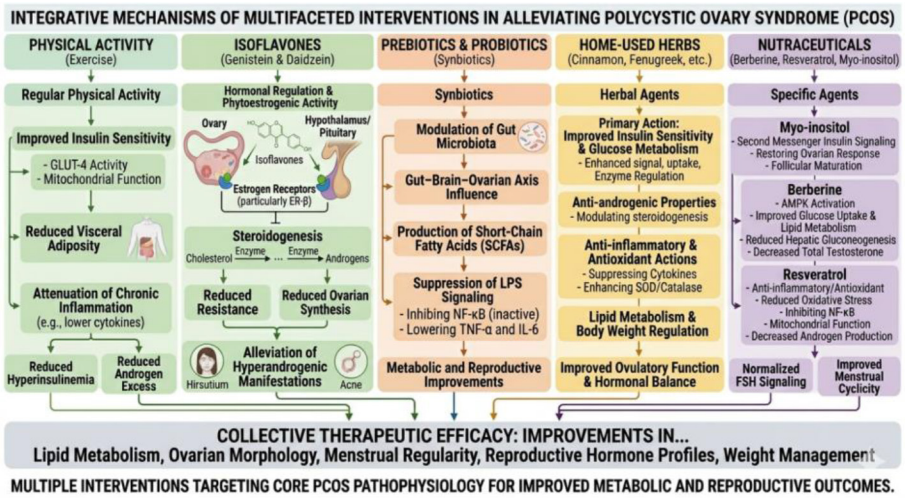


Figure 3. Illustrates the integrative mechanisms of multifaceted interventions in alleviating PCOS.

overall quality of life. Nutraceuticals are the bioactive compounds derived from food sources and functional foods[47] those that provide health benefits beyond basic nutrition are emerging as evidence-informed strategies in PCOS care. These compounds are often plant-based, antioxidant-rich and possess adaptogenic insulin-sensitising or anti-inflammatory properties, aligning well with the multifactorial nature of PCOS. Recent studies highlight the role of ingredients such as myoinositol, omega-3 fatty acids, berberine, curcumin and maca root in addressing common PCOS concerns like insulin resistance, anovulation, hyperandrogenism and chronic low-grade inflammation. The novel bioactives, when integrated into a personalised nutrition and lifestyle framework, can offer promising outcomes in symptom management and reproductive health.

Nutraceuticals such as berberine, resveratrol, and myo-inositol play a central role in PCOS management through complementary metabolic, endocrine, and anti-inflammatory mechanisms. Myo-inositol acts as a key second messenger in insulin signalling and improves insulin sensitivity by enhancing intracellular glucose uptake and restoring ovarian response to gonadotropins. It also supports follicular maturation, improves oocyte quality, and helps regulate menstrual cyclicity by normalising FSH signalling and reducing hyperinsulinemia-induced androgen excess[48]. Berberine exerts potent insulin-sensitising effects primarily through activation of AMP-activated protein kinase (AMPK), a central metabolic regulator. This leads to improved glucose uptake, reduced hepatic gluconeogenesis, and enhanced lipid metabolism. In PCOS, berberine has also been associated with reductions in total testosterone, improvement in ovulation rates, and amelioration of dyslipidemia, making it a strong metabolic and endocrine modulator[49]. Resveratrol, a polyphenolic compound, improves PCOS outcomes through anti-inflammatory, antioxidant, and endocrine-regulating pathways. It inhibits inflammatory mediators such as NF-κB, reduces oxidative stress, and improves mitochondrial function. Additionally, resveratrol modulates steroidogenesis in ovarian tissue, leading to decreased androgen production and improved follicular development. Collectively, these nutraceuticals target insulin resistance, hyperandrogenism, oxidative stress, and ovarian dysfunction, thereby improving both metabolic and reproductive outcomes in women with PCOS[50]. Table 5 explicates the nutraceuticals and functional foods intervention in PCOS.

8. Discussion

PCOS is a complex endocrine condition impacting a considerable number of women of reproductive age, marked by irregular menstruation, elevated androgen levels, ovulatory irregularities, and various metabolic abnormalities. Over the years, research has focused on understanding the complex aetiology and pathophysiology of PCOS, exploring both pharmacological and non-pharmacological

interventions to alleviate its symptoms and long-term health consequences. PCOS in women is influenced by a complex interplay of various factors, including poor dietary habits, sedentary lifestyles, inadequate healthcare management, delayed diagnosis, and a general lack of awareness. These factors collectively contribute to the rising incidence and often undiagnosed nature of the condition, leading to prolonged suffering and an increased risk of associated comorbidities. Early detection of PCOS is crucial, as it allows for timely intervention and the implementation of targeted treatment strategies[58]. By restoring balance to the gut microbiome, probiotics and synbiotics may mitigate the metabolic dysregulation and chronic low-grade inflammation commonly observed in women with PCOS, which are often implicated in the syndrome's clinical manifestations, such as insulin resistance, obesity, and irregular menstrual cycles[59]. Emerging evidence underscores the therapeutic efficacy of personalised dietary interventions in the management of PCOS, particularly in addressing key pathophysiological concerns such as insulin resistance, central obesity, and anovulation[60]. Therapeutic lifestyle interventions constitute the foundational, first-line strategy upon which the clinical management of polycystic ovary syndrome is built[61]. Lifestyle-based interventions have been shown to have positive effects on the reduction in body weight and body mass index, while concurrently improving the free androgen index – a critical marker of hyperandrogenism[62].

Comprehensive lifestyle modification encompassing intentional weight reduction, adoption of balanced and nutrient-dense dietary practices, and engagement in consistent physical activity constitutes a foundational strategy in the multidisciplinary management of PCOS[63]. Integrating lifestyle interventions with evidence-based herbal therapeutics offers a holistic and multidimensional strategy for the management of PCOS[64]. Despite the promising findings, herbal treatments typically require longer durations to produce noticeable effects, and the evidence supporting their efficacy remains mixed. Furthermore, the lack of standardisation in herbal product formulations, differences in dosages used across studies, and limited long-term safety data highlight the need for caution when considering herbal remedies.

The 2023 international evidence-based guidelines address a set of prioritised clinical questions and outcomes, culminating in 254 recommendations and practice statements aimed at standardising care, strengthening evidence-based practice, and improving both patient experience and long-term health outcomes in polycystic ovary syndrome (PCOS). Notable revisions include: (i) further refinement of diagnostic criteria, incorporation of a simplified diagnostic pathway, and recognition of anti-Müllerian hormone (AMH) as an alternative diagnostic marker to ultrasonography in adult populations only; (ii) enhanced emphasis on the multisystem nature of PCOS, with greater attention to associated metabolic dysfunction, cardiovascular risk, obstructive sleep apnea, a high prevalence of psychological comorbidities, and elevated risk of adverse pregnancy outcomes; (iii) increased acknowledgement of the substantial and often under-recognized disease burden, underscoring the need for improved healthcare professional education, dissemination of evidence-based patient resources, implementation of patient-centred and shared decision-making models, and expansion of appropriate care pathways, alongside prioritization of future research; (iv) continued focus on lifestyle optimisation, psychological well-being, and health-related quality of life, while explicitly addressing the impact of weight stigma; and (v) reinforcement of evidence-based pharmacological approaches and more accessible, safer, and cost-effective strategies for fertility management. Despite the publication of these comprehensive guidelines, real-world implementation remains inconsistent, with many healthcare settings not yet fully integrating the updated diagnostic pathways, multidisciplinary management strategies, or patient-centred care recommendations into routine clinical practice, resulting in an ongoing gap between evidence-based guidance and day-to-day care delivery[65].

Consideration of safety profiles, standardisation challenges, regulatory frameworks, and long-term therapeutic efficacy is critical when interpreting the potential role of herbal and nutraceutical interventions in PCOS management. Although several natural compounds have demonstrated beneficial effects on metabolic, hormonal, and inflammatory parameters, substantial variability exists in their formulation, bioactive composition, dosage, extraction methods, and manufacturing quality, which may influence

clinical reproducibility and treatment outcomes. In addition, inadequate standardisation and the absence of universally accepted regulatory guidelines raise concerns regarding product consistency, contamination risk, pharmacological interactions, and patient safety. The limited availability of long-term randomised controlled trials further restricts definitive conclusions regarding sustained efficacy and adverse effects associated with prolonged use. Therefore, future research should prioritise rigorous quality control measures, standardised therapeutic protocols, regulatory validation, and large-scale longitudinal investigations to facilitate the safe and evidence-based integration of herbal and nutraceutical therapies into comprehensive PCOS management.

9. Conclusion

In conclusion, while the management of PCOS remains complex and multifactorial, lifestyle modification continues to be the most effective intervention for improving metabolic health and reproductive outcomes. Probiotic supplementation and herbal medicines also show promise as adjunct therapies, particularly in modulating the gut microbiome, reducing inflammation, and improving insulin sensitivity. However, further research is needed to better define their roles, establish optimal protocols, and determine their long-term safety and efficacy. With continued advancements in our understanding of PCOS and its management, a more personalised, integrative approach can offer hope for improved outcomes for women living with this challenging condition. The current findings align with Goal 3 - Good Health and Well-being of the Sustainable Development Goals.

10. Limitations

This review is limited by the heterogeneity of study designs, intervention protocols, treatment duration, and outcome measures across the included studies. Evidence supporting probiotics, synbiotics, herbal therapies, and nutraceuticals remains insufficient due to limited large-scale randomised controlled trials and long-term follow-up data. Variations in dosage, formulation, and diagnostic criteria for PCOS further affect the consistency and generalisability of findings. Therefore, well-designed multicentric and longitudinal studies are needed to establish standardised protocols, safety, and long-term clinical efficacy.

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Author Contribution

Dr. N. Preetha and Dr. Dhanalakshmi MG conceived the study and designed the experimental framework; C.V. Aishwarya drafted the manuscript and searched for the appropriate literature review; Dr. N. Preetha supervised and corrected the final manuscript; Dr. Dhanalakshmi MG verified the analytical methods and provided suggestions to enhance the manuscript further. All authors have read and agreed to the published version of the manuscript.