

Herbal Strategies for Managing Polycystic Ovary Syndrome: A Comprehensive Review of Potential Therapeutics

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ABSTRACT

Polycystic Ovary Syndrome (PCOS) is a multifaceted endocrine condition impacting 6–20% of women of reproductive age, characterized by hyperandrogenism, anovulation, insulin resistance, and polycystic ovarian morphology. The pathogenesis of PCOS represents complicated hormonal imbalances, chronic inflammation, and metabolic dysfunctions, resulting in reproductive issues, type 2 diabetes, cardiovascular risks, and psychological discomfort. Traditional therapies, including oral contraceptives, anti-androgens, and insulin sensitizers, provide symptomatic relief but remain limited by adverse effects and inadequate personalized efficacy. Herbal medicine is now recognized as an acceptable replacement as a result of its multi-targeted efficacy and advantageous safety profile. This article outlines the therapeutic functions of various medicinal herbs—including Ashwagandha (*Withania somnifera*), Shatavari (*Asparagus racemosus*), Cinnamon (*Cinnamomum* spp.), Licorice (*Glycyrrhiza glabra*), Spearmint (*Mentha spicata*), Chasteberry (*Vitex agnus-castus*), Berberine (*Berberis* spp.), Curcumin (*Curcuma longa*), Green Tea (*Camellia sinensis*), Black Cohosh (*Actaea racemosa*), and Fenugreek (*Trigonella foenum-graecum*)—in the modulation of insulin sensitivity, androgen levels, oxidative stress, and menstrual regulation. These plants possess bioactive constituents such as flavonoids, polyphenols, phytoestrogens, and alkaloids, which exhibit antioxidant, anti-inflammatory, and hormone-regulating effects. Clinical trials demonstrate improvements in ovulation, hirsutism, menstrual cycle, and reproductive outcomes. The paper examines current trends, including herbal nanomedicine and genomics-guided tailored medicines, while recognizing issues associated with standardization, dose, and herb-drug interactions. This comprehensive review may provide a framework for future studies and innovation in creating standardized, integrative, and individualized herbal strategies for the management of PCOS.

Keywords: PCOS, Herbal medicine, Bioactive compounds, Hormonal imbalance.

INTRODUCTION

1.1 Background and significance of PCOS

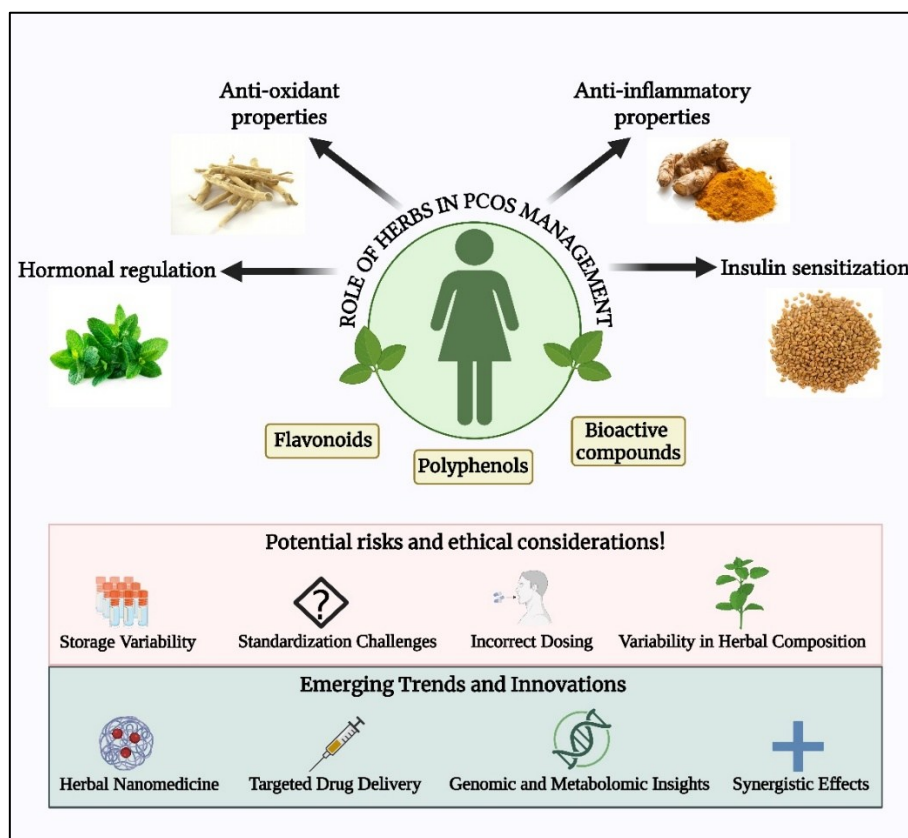
Polycystic Ovary Syndrome (PCOS) is a multifactorial endocrine disorder in 6-20% of reproductive-age women globally. It has been defined by a collection of clinical features, such as hyperandrogenism (elevated male hormone levels), irregular menstruation, polycystic ovaries, and metabolic disturbance. The symptoms of the syndrome are very diverse in different persons, tending to make diagnosis and therapy challenging.

PCOS is a major cause of infertility due to chronic anovulation and is linked with long-term health consequences including type 2 diabetes, cardiovascular disease, and endometrial cancer. In addition to its physical effects, PCOS has a profound impact on mental health, with depression, anxiety, and decreased quality of life in many patients.^[1,2] The condition's precise etiology remains unknown, but it is generally considered a multifactorial disorder with genetic, environmental, and lifestyle factors. Insulin resistance and inflammation are recognized to be central to its pathogenesis and to cause hormonal and metabolic disturbances.^[3] Since it is so commonly found and has such a profound effect on the health of

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women, PCOS is an urgent public health problem. There is an increasing need for comprehensive and individualized treatments to control the condition, including its reproductive and metabolic but also psychological consequences. Appreciation of the

importance of PCOS forms the basis of investigation into novel therapies, such as herbal medications, which are increasingly being found to have potential as adjunctive therapies to standard treatments.^[4]



1.2 Conventional treatments and their limitations

Traditional therapy of Polycystic Ovary Syndrome (PCOS) largely targets the principal manifestations of the disorder, i.e., menstrual disturbances, hyperandrogenism, infertility, and metabolic disorders. Popular drug choices involve the use of oral contraceptives for cycling regulation and suppression of androgens, spironolactone-like anti-androgens to control hirsutism and acne, and metformin as insulin sensitizers to control insulin resistance and enhance ovulation. Ovulation-inducing medications like clomiphene citrate and letrozole are frequently used in cases of infertility.^[5] While their effectiveness in alleviating certain symptoms is well proven, these interventions have significant drawbacks. Oral contraceptives, for example, do not impact underlying metabolic defects and can induce side effects in the form of weight gain, mood swings, and a greater risk of thromboembolism. Insulin sensitizers such as metformin help to enhance glucose metabolism but

induce gastrointestinal side effects and do not directly address reproductive issues. Anti-androgens can cause unacceptable hormonal imbalances when administered chronically.^[6,7] Moreover, traditional treatments tend to take a one-fits-all attitude, without taking into account the heterogeneity of PCOS presentations. Most women are left with dissatisfaction from the partial alleviation of symptoms, resulting in non-compliance. These shortcomings highlight the necessity for alternative or complementary treatments that are safer, more holistic, and able to counteract PCOS's complex nature. Herbal remedies have come into the limelight in this regard, with potential as natural interventions having fewer side effects and more extensive therapeutic targets.^[8]

1.3 Role of herbal medicines in PCOS treatment

Herbal drugs have proven to be viable options or supplements to standard therapies in the treatment of



Polycystic Ovary Syndrome (PCOS). Their long history of use in traditional systems of medicine, including Ayurveda, Traditional Chinese Medicine (TCM), and Western herbalism, underscores their ability to target PCOS's multifaceted hormonal, metabolic, and inflammatory aspects.^[9] The beauty of herbal medicines rests in their mechanisms of action of multiple facets. Most herbs include bioactive secondary metabolites such as flavonoids, alkaloids, and terpenoids that possess antioxidant, anti-inflammatory, and hormonal-modulating action. For example, spearmint and chasteberry are shown to present anti-androgenic activity while cinnamon and berberine exhibit insulin-sensitizing effects and glucose-metabolizing properties. All these qualities project herbal medicines to be possible natural remedies for PCOS's plethora of symptoms.^[10,11,12] In addition, herbal therapies are also thought to be safer, with less adverse effect, in comparison to mainstream drugs, thus appealing to women who look for natural solutions. Nevertheless, regardless of increased demand, scientific confirmation of efficacy and safety continues to be challenging. Heterogeneity of PCOS and differences in herbal formulations make it essential to have stringent clinical trials and standardization. Herbal drugs are a rich potential in the treatment of PCOS, filling gaps in the traditional management by providing holistic therapeutic advantages. They are of special interest in personalized and integrative medicine, which places utmost emphasis on safety, efficacy, and tailor-made treatment plans.^[13]

2. Phytochemicals and Their Therapeutic Potential in PCOS

2.1 Key Bioactive Compounds in Herbs

Phytochemicals from medicinal plants and herbs exhibit high potential in preventing, mitigating, and curing polycystic ovary syndrome (PCOS). The phytochemicals such as flavonoids, polyphenols, phytoestrogens, and polyunsaturated fatty acids (PUFAs) have been shown to exhibit therapeutic effects on PCOS through their roles as anti-inflammatory and antioxidant agents, enhancing hormone disorders and insulin resistance, and mitigating hyperinsulinemia.^[14,15]

2.1.1 Therapeutic Effects of Phytochemicals on PCOS

Phytochemicals show therapeutic actions against PCOS, which are supported by in vivo and in vitro studies, primarily by exerting anti-inflammatory and antioxidant effects, correcting hormone dysfunctions and IR, and relieving hyperinsulinemia. Oral contraceptives, antiandrogens, insulin sensitizers, and ovulation inducers are regularly prescribed to control the symptoms of PCOS, but they merely relieve the symptoms temporarily, produce side effects, and are not preventive in action. Phytochemicals, which are compounds from medicinal plants and herbs, are an important source for the identification of new drugs to treat PCOS symptoms such as oxidative stress, insulin resistance, hyperinsulinemia, hyperandrogenism, and ovarian morphology and function abnormalities. These bioactive compounds inhibit, reduce, and cure PCOS symptoms by various mechanisms (as shown in Figure 1).

2.1.2 Role of Flavonoids in PCOS Treatment

Flavonoids, which are critical compounds in nature, exert anti-inflammatory, antioxidant, hypoglycemic, antiviral, and antitumor activities. Quercetin, a plant dietary flavonoid found in vegetables and fruits, has been investigated for its antioxidant and anti-inflammatory properties and its capability to regulate ovarian function and ensure ovarian morphology.^[14,16] Soy isoflavones, soy secondary metabolites, have antioxidant, anti-inflammatory, and lipid-lowering activities, inhibiting oxidative stress and pro-inflammatory cytokines in PCOS rats. Naringenin, which occurs in traditional Chinese medicine, suppresses steroidogenic enzyme activities, increases antioxidant enzyme activities, and modulates gut microbiota and exhibits therapeutic potential in insulin-resistant PCOS.

2.1.3 Effect of Polyphenols in PCOS

Polyphenols, including resveratrol and curcumin, exert beneficial effects on the treatment of PCOS, although their bioavailability is restricted. Resveratrol, which occurs in peanuts and grapes, possesses antioxidant, anti-inflammatory, and cardiovascular protective properties, improving abnormal angiogenesis and lowering androgen levels



in PCOS. Curcumin, a substance from turmeric, possesses anti-inflammatory, antioxidant, and antiapoptotic effects, which improve disorders in follicle growth and decrease levels of fasting plasma glucose and dehydroepiandrosterone in PCOS patients. ^[14] In addition, natural agents like green tea can serve as a novel auxiliary treatment for PCOS. ^[17]

2.1.4 Herbal Remedies and Bioactive Components

Several herbs and their bioactive compounds contribute to the control of PCOS symptoms. ^[18] For example, spearmint extract is reported to have an effect on PCOS symptoms and consists of essential oils and phenols as principal bioactive compounds. ^[19] Black cohosh consists of phenolic constituents such as hydroxycinnamic acids, ferulic acid, isoferulic acid, and caffeic acid. ^[18] Chamomile extract consists of flavonoid compounds and antioxidants such as gallic acid, kamazelin, farnesene, matricin, coumarin derivatives, apigenin. ^[20]

2.2 Mechanisms of Action in Hormonal Regulation

Herbal medicines act on the regulation of hormones in Polycystic Ovary Syndrome (PCOS) via various pathways, mainly inhibiting androgen excess, ovulation dysfunction, and menstrual disorder. Major

bioactive constituents present in the herbal medicines regulate levels of hormones through effects on the hypothalamic-pituitary-ovarian (HPO) axis, insulin action pathways, and androgen metabolism. ^[21] Some herbs, like spearmint and chasteberry (*Vitex agnus-castus*), have anti-androgenic activities by lowering testosterone levels and inhibiting the enzyme 5-alpha reductase, which converts testosterone into its more active form, dihydrotestosterone (DHT). This relieves symptoms such as hirsutism and acne. ^[22] Herbs such as Shatavari (*Asparagus racemosus*) and licorice (*Glycyrrhiza glabra*) affect levels of gonadotropin, enhancing secretions of luteinizing hormone (LH) and follicle-stimulating hormone (FSH) in harmony, supporting ovulation and normal menstrual cycles every month. ^[23] Moreover, cinnamon (*Cinnamomum* spp.) and berberine increase the sensitivity of insulin, with a subsequent indirect decrease in hyperinsulinemia-mediated androgen production in the ovaries. As insulin resistance is such an important factor in the hormonal disturbance in PCOS, correction of insulin function normalizes ovarian function and hormone balance. By treating the underlying hormonal disturbances of PCOS, herbal medications present a holistic and natural strategy towards the control of the disorder. Yet more clinical trials must confirm their safety and efficacy on the long-term as hormone regulator. ^[9]

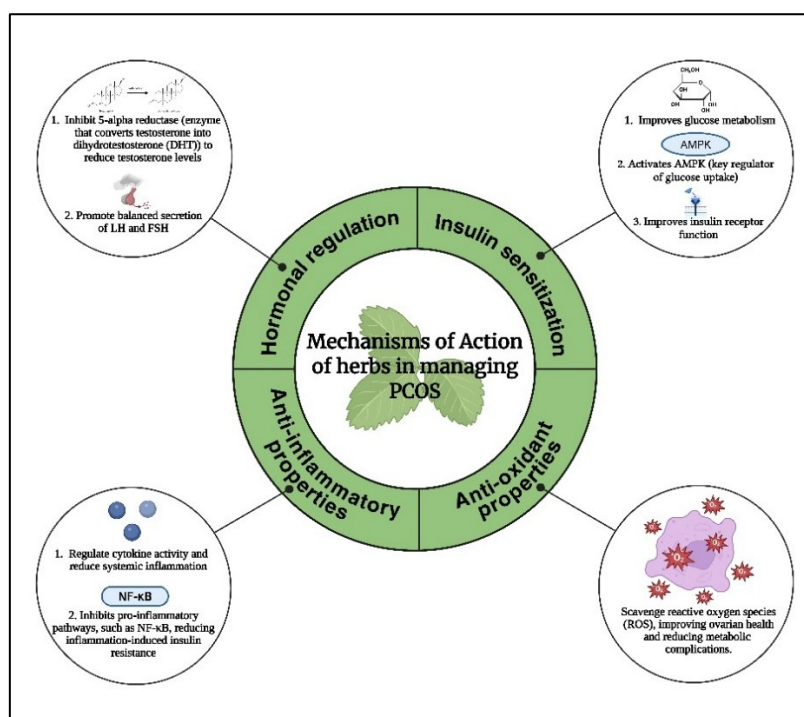


Figure 1. Mechanism of action of herbs involved in the management of PCOS

2.3 Anti-inflammatory and Antioxidant Properties

Inflammation and oxidative stress are the key players in the pathogenesis of Polycystic Ovary Syndrome (PCOS) that lead to insulin resistance, ovarian dysfunction, and metabolic dysfunctions. Anti-inflammatory and antioxidant effects of herbal medicines counteract these effects to facilitate overall hormonal and metabolic well-being.^[24] Some of the herbs employed in the management of PCOS are rich in strong anti-inflammatory agents that modulate cytokine function and suppress systemic inflammation. Turmeric (*Curcuma longa*), which is curcumin-rich, suppresses pro-inflammatory pathways, including nuclear factor-kappa B (NF- κ B), which decreases inflammation-induced insulin resistance. Licorice (*Glycyrrhiza glabra*) and green tea (*Camellia sinensis*) are also rich in bioactive molecules that inhibit inflammatory markers, and they help relieve symptoms of PCOS.^[25] Oxidative stress further complicates PCOS by worsening the state of the ovaries and increasing testosterone levels. Cinnamon (*Cinnamomum* spp.), ashwagandha (*Withania somnifera*), and grape seed extract have the ability to neutralize free radicals while exhibiting some of the strongest antioxidant properties, thus posing a herb of choice for such conditions. The polyphenolic and flavonoid content in these herbs reduces the metabolic complications by scavenging ROS from the ovaries. Herbal medicines target the inflammatory pathways and bolster the antioxidant mechanisms to restore the physiological equilibrium, aiding women with PCOS. Despite looking promising in preclinical trials, further research needs to be done in clinical settings to endorse these treatments and create a standard dosage guideline for sustained use.^[26]

2.4 Insulin Sensitization

Insulin resistance is the key characteristic of Polycystic Ovary Syndrome (PCOS), which is

responsible for hyperinsulinemia, excess androgen levels, and metabolic disorders. The herbal drugs possessing insulin-sensitizing action facilitate the normalization of glucose metabolism, decrease insulin resistance, and re-establish hormonal equilibrium in women affected by PCOS.^[27] Some herbs possess bioactive components that increase insulin sensitivity. Berberine from *Berberis* species has been reported to stimulate AMP-activated protein kinase (AMPK), an important glucose uptake and energy metabolism regulator, in a metformin-like manner. Cinnamon (*Cinnamomum* spp.) enhances insulin receptor function, increases glucose uptake, and lowers fasting blood sugar. Fenugreek (*Trigonella foenum-graecum*) has saponins and fiber that retard carbohydrate absorption and augment insulin response.^[28] Also, green tea (*Camellia sinensis*) polyphenols decrease oxidative stress and inflammation, which further enhance insulin action. *Nigella sativa* (black seed) has also been shown to possess anti-diabetic activity by modulating glucose metabolism and pancreatic function. By acting on insulin resistance, such herbal drugs simultaneously enhance metabolic function and indirectly govern ovarian function through decreased insulin-induced androgenogenesis. While positive results have emerged, additional large-scale clinical studies are required to establish their validity, optimal doses, and prolonged safety in treating PCOS.^[26,29]

3. Herbal Medicines Commonly Used in PCOS Management

3.1 Ayurvedic Herbs

- Example: Ashwagandha (*Withania somnifera*), Shatavari (*Asparagus racemosus*)

Ayurveda, the traditional Indian medicine system, has been using herbal treatments for reproductive health conditions such as polycystic ovary syndrome (PCOS) for centuries (as depicted in Figure 2).



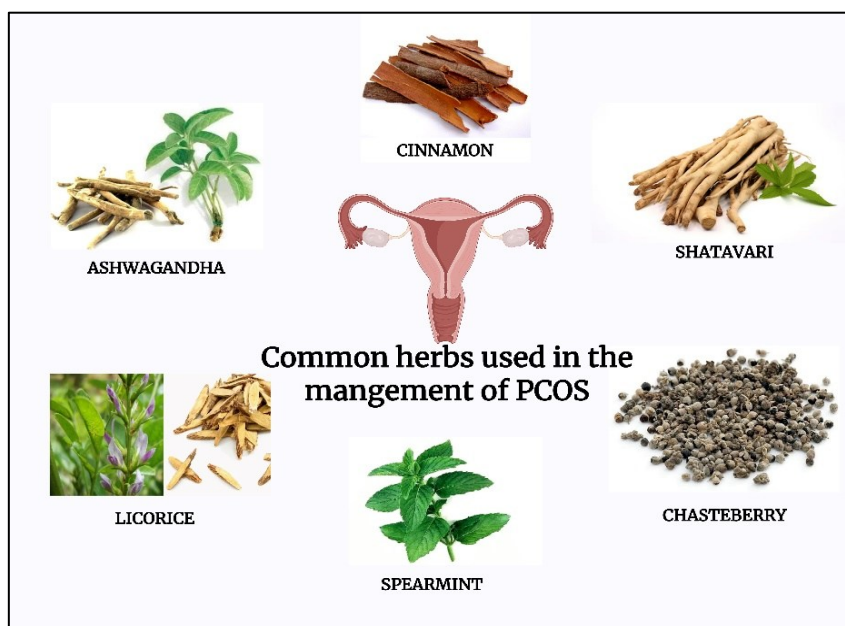


Figure 2. Common herbs used in the management of PCOS

Ayurvedic herbs act by multiple mechanisms including hormonal regulation, stress reduction, insulin sensitization, and anti-inflammatory activity. Of the numerous plants employed in Ayurveda, Ashwagandha (*Withania somnifera*) and Shatavari (*Asparagus racemosus*) stand out to be of special relevance in treating PCOS symptoms and enhancing reproductive health in general.

3.1.1 Ashwagandha (*Withania somnifera*)

Ashwagandha, also known as Indian ginseng, is an adaptogenic plant with a reputation for normalizing stress and maintaining hormonal balance. Stress is a causative factor in PCOS and induces overproduction of cortisol, which can interfere with ovarian function and worsen insulin resistance. Ashwagandha modulates the HPA axis to decrease cortisol levels and alleviate stress-mediated hormonal disturbances. Furthermore, research indicates that ashwagandha can enhance insulin sensitivity, which is of utmost importance in the management of PCOS-associated metabolic disturbances. It is also associated with improved thyroid function, as hypothyroidism tends to accompany PCOS. Ashwagandha also has anti-inflammatory and antioxidant activity, which can counteract oxidative stress—a feature involved in PCOS pathogenesis.^[30,31]

3.1.2 Shatavari (*Asparagus racemosus*)

Shatavari, also called the "queen of herbs" in Ayurveda, is traditionally employed to maintain women's reproductive health. It is rich in steroidal saponins with phytoestrogenic effects, supporting the balance of estrogen and hence hormonal balance. In women with PCOS, shatavari may help to restore ovulation and regular menstrual cycles.^[32] This herb is also an adaptogen, allowing it to counteract the action of stress, a proven factor in PCOS advancement. It also increases fertility through the stimulation of follicle development and enhancement of endometrial health, furthering the chances for conception. Shatavari's immunomodulatory and anti-inflammatory activities also complement its use in PCOS, given that a condition of chronic inflammation is characteristic of the syndrome.^[33] Ayurvedic herbal therapies like ashwagandha and shatavari possess favorable prospects of alleviating PCOS with modes of action relevant to managing stress, endocrine disturbance, and metabolic disorders. These herbal medications were traditionally consumed centuries ago; more clinical evidence in the form of well-regularized doses is necessary for establishment, along with efficacy and safety profiles. Adding Ayurvedic herbal agents to contemporary forms of therapy would impart a balanced, personalized methodology towards managing PCOS.^[34]

3.2 Traditional Chinese Medicine (TCM) Herbs

- Example: Cinnamon (*Cinnamomum spp.*), Licorice (*Glycyrrhiza glabra*)

Traditional Chinese Medicine (TCM) has been in the practice of treating reproductive and metabolic disorders, including polycystic ovary syndrome (PCOS), for centuries using herbal preparations. TCM herbs focus on restoring harmony by regulating Qi (vital energy), promoting blood flow, and balancing endocrine functions. Of the many herbs that have been employed in TCM, Cinnamon (*Cinnamomum spp.*) and Licorice (*Glycyrrhiza glabra*) are well-researched for their therapeutic application in PCOS treatment. [35,25]

3.2.1 Cinnamon (*Cinnamomum spp.*)

Cinnamon has also received tremendous attention due to its potential in enhancing insulin sensitivity, which would be especially valuable for PCOS patients who develop insulin resistance. A number of studies have found that cinnamon supplementation increases glucose metabolism, lowers fasting blood sugar levels, and raises insulin receptor sensitivity. As a primary cause of PCOS-linked metabolic derangement is insulin resistance, cinnamon-induced effects on glucose control can ensure the regulation of ovulatory cycles and decreased levels of androgens. Aside from its metabolic effects, cinnamon also contains powerful anti-inflammatory and antioxidant effects. PCOS pathology significantly contributes to chronic inflammation, which exacerbates insulin resistance and ovarian dysfunction. Cinnamon reduces oxidative stress to some extent, and thereby counteracts some of the underlying pathogenic mechanisms that promote PCOS progression. [28,36,37]

3.2.2 Licorice (*Glycyrrhiza glabra*)

Licorice is also a significant TCM herb with anti-androgenic and anti-inflammatory activities. It has glycyrrhizin, a substance that affects the adrenal function and decreases the level of testosterone, so it is suitable for PCOS patients with hyperandrogenism. Some studies indicate that licorice root in association with peony (*Paeonia lactiflora*) reduces free

testosterone levels successfully and enhances ovulation rates. Secondly, licorice contains adaptogenic compounds that nourish the adrenal glands, which help modulate cortisol levels. As stress itself aggravates PCOS symptoms by raising cortisol and insulin resistance, licorice's action in the modulation of stress can be beneficial in a specific way. Thirdly, its anti-inflammatory properties help overall hormonal equilibrium and enhanced reproductive function. [25,38] TCM herbs like licorice and cinnamon are of great potential in managing PCOS through the addressing of insulin resistance, androgen excess, and inflammation. The herbs are a natural, holistic, and complementary solution for symptom relief that can be used alongside other conventional treatments. Their safety over the long term and standardized dosing, however, need to be investigated further. Blending TCM concepts with contemporary medical interventions would improve treatment for PCOS patients by providing personalized and balanced care. [39]

3.3 Mediterranean and Western Herbal Remedies

- Example: Spearmint (*Mentha spicata*), Chasteberry (*Vitex agnus-castus*)

Conventional Mediterranean and Western traditional herbal medicine have been using plant-based treatments of reproductive health for centuries. Many herbs have proved useful in controlling polycystic ovary syndrome (PCOS) through the treatment of androgen excess, menstrual disorder, and insulin resistance. Among them, two herbs—Spearmint (*Mentha spicata*) and Chasteberry (*Vitex agnus-castus*)—are recognized for their effectiveness in endocrine and metabolic control. [40,41]

3.3.1 Spearmint (*Mentha spicata*)

Spearmint has long been known to exhibit anti-androgenic effects, hence its suitability for PCOS women with symptoms of hirsutism (excessive hair growth) and acne. Consumption of spearmint tea was seen to decrease testosterone levels, raise luteinizing hormone (LH), and follicle-stimulating hormone (FSH), thus inducing ovulation. [42] In addition to its hormonal activity, spearmint has potent antioxidant and anti-inflammatory activities, which can counteract oxidative stress—a central mechanism in



PCOS pathology. It also aids in gastrointestinal health, which is important as gut dysbiosis is becoming more associated with metabolic derangements in PCOS. Daily intake of spearmint tea has been found to enhance menstrual regularity, and thus it is a useful natural treatment. ^[43,19]

3.3.2 Chasteberry (*Vitex agnus-castus*)

Chasteberry is perhaps the most commonly used herbal remedy for hormonal disturbances in women. It acts by influencing dopamine levels, which subsequently reduces prolactin release. Increased prolactin is a feature of PCOS and may lead to menstrual abnormalities and infertility. By normalizing prolactin, chasteberry enhances regularity of the menstrual cycle and aids ovulation. ^[18] Furthermore, *Vitex* affect progesterone concentration by promoting corpus luteum function, which is often impaired in PCOS. Consequently, it can be especially useful for those women who are afflicted with luteal phase defects or those who have anovulatory cycles. Furthermore, it has been observed by some research that chasteberry might also be beneficial for mild hyperandrogenism reduction and that this supports the role of chasteberry in PCOS management. ^[44] Spearmint and chasteberry are the two most well-known herbal medicines in the West and the Mediterranean used for treating hormonal imbalances in PCOS. Their ability to control androgen levels, help in over activity of the ovaries, and reduce inflammation are the qualities that make them the promising natural remedies. However, the specific use of these herbs needs to be scientifically prescribed further to confirm safety and optimal dosing long-term. The combination of natural treatment with conventional treatments for PCOS will be the answer to a balanced and effective symptom management. ^[45]

4. Clinical Evidence and Studies

4.1. Summary of clinical trials and observational studies

Clinical studies on herbal therapies for polycystic ovary syndrome (PCOS) have gained traction, with several trials examining the effectiveness and safety of various plant drugs. Clinical trials and observational research have largely addressed herbs

with activities in insulin sensitivity, androgen regulation, and ovulation. Below is a brief overview of some major outcomes of scientific research into herbal treatment of PCOS. ^[20]

4.1.1 Herbs for Insulin Sensitivity and Metabolic Regulation

A number of studies have established the efficacy of herbal remedies in enhancing insulin sensitivity, an important parameter in PCOS treatment. A randomized controlled trial (RCT) on Cinnamon (*Cinnamomum* spp.) established that supplementation on a daily basis lowered fasting blood glucose and insulin resistance substantially in women with PCOS. Comparable results were obtained in a study on Berberine, an alkaloid from *Berberis*'s species, which exhibited more effective insulin-sensitizing activity than metformin, a standard treatment for PCOS. ^[46]

4.1.2 Herbs for Hormonal Regulation and Androgen Reduction

Herbs with anti-androgenic action have been most extensively researched for their use in controlling symptoms of hyperandrogenism like hirsutism and acne. A clinical trial involving Spearmint (*Mentha spicata*) showed a marked decrease in testosterone levels and a change in menstrual cycle regularity following regular consumption of spearmint tea. Another trial on Licorice (*Glycyrrhiza glabra*) + White Peony (*Paeonia lactiflora*) showed decreased androgen levels and enhanced ovulation rate. ^[22] Chasteberry (*Vitex agnus-castus*) has been studied for menstrual cycle regulation effects. A study with a placebo found that *Vitex* supplementation corrected luteal phase defects and normalized the menstrual cycles by affecting prolactin and progesterone levels. ^[18,44]

4.1.3 Clinical Evidence on Fertility and Ovulatory Function

A meta-analysis of herbal therapies in PCOS proposed that Shatavari (*Asparagus racemosus*) and Black Cohosh (*Actaea racemosa*) increase ovulation and endometrial thickness, with positive pregnancy outcome. Furthermore, Inositol, a plant compound consisting of carbs without vitamins and sometimes regarded as a vitamin-like substance, has been



extensively studied for its function in the restoration of ovulation and improving fertility in patients with PCOS. [47,48]

4.2 Efficacy and safety of herbal treatments in PCOS patients

Herbal therapy has demonstrated potential efficacy in the control of polycystic ovary syndrome (PCOS) with action against primary areas of insulin resistance, hormonal dysregulation, and menstrual disturbance. Despite their beneficial effects, concerns about safety, standardization, and long-term outcomes are ongoing. Assessing both the therapeutic benefits and potential hazards of herbal intervention is imperative to its integration into PCOS treatment. [17]

4.2.1 Efficacy of Herbal Treatments

Clinical trials have yielded evidence for the efficacy of a number of herbs in the treatment of PCOS. Berberine, an alkaloid of plants, has shown insulin-sensitizing properties similar to metformin, enhancing glucose metabolism and lowering testosterone levels. In a randomized controlled trial (RCT), berberine supplementation increased ovulation rates and lipid profiles in women with PCOS. [49] Inositol, a plant compound that occurs naturally, has been extensively researched for its function in the ovaries. Studies show that myo-inositol and D-chiro-inositol supplementation corrects ovulatory cycles and enhances fertility outcomes in PCOS patients and is a suitable alternative to traditional fertility therapy. [50] Anti-androgenic herbs, including Spearmint (*Mentha spicata*) and Licorice (*Glycyrrhiza glabra*), have been demonstrated to reduce levels of testosterone and treat symptoms such as hirsutism and acne. Equally, Vitex agnus-castus (Chasteberry) has helped regulate menstrual periods and normalize levels of progesterone. [22,51]

4.2.2 Safety Concerns and Adverse Effects

Although they are beneficial, herbal remedies pose risks such as herb-drug interactions, inconsistencies in composition, and side effects. For instance, Licorice has glycyrrhizin, which causes hypertension and electrolyte disturbances when taken in excess. Berberine can interfere with liver enzymes, impacting the metabolism of drugs such as anticoagulants and

antihypertensives. [52,53] Yet another issue is that there are no standardized dosing regimens and thus variable study results. Additionally, variability of active phytochemical levels in the final products because of disparity in cultivation conditions and processing is another confounding factor for comparing efficacy and safety. Herbal treatment long-term safety information in many is currently limited. Despite short-term investigations showing beneficial findings, additional testing is necessary for evaluating toxicity potential, endocrine disruption, and reproductive impacts due to extended utilization. [54]

5. Integrative Approaches

5.1 Combining herbs with conventional treatments

The combination of herbal medicine with standard therapies provides a promising strategy for the management of polycystic ovary syndrome (PCOS). As PCOS is complex in nature and encompasses hormonal dysregulation, insulin resistance, and inflammation, a combination of pharmaceuticals with evidence-based herbal therapies can improve the efficacy of treatments while reducing side effects. [41]

5.1.1 Possible Synergistic Effects

Pharmacologic therapies for PCOS, including oral contraceptives (OCPs), insulin sensitizers (e.g., metformin), and anti-androgens (e.g., spironolactone), are commonly employed but frequently accompanied by side effects such as nausea, gastrointestinal upset, and hormonal disturbances. Some herbs, including Berberine and Cinnamon (*Cinnamomum* spp.), have shown insulin-sensitizing activity comparable to metformin, with the potential to improve glycemic control without severe gastrointestinal side effects. [55,46] Likewise, anti-androgenic herbs such as Spearmint (*Mentha spicata*) and Licorice (*Glycyrrhiza glabra*) can enhance pharmaceutical anti-androgens by naturally reducing testosterone levels, thus enhancing symptoms such as hirsutism and acne. Chasteberry (*Vitex agnus-castus*) can also regulate menstrual cycles and ovulation and can be a valuable adjunct to fertility therapies such as clomiphene citrate. [22,56]



5.1.2 Challenges and Considerations

Although there may be advantages of using herbal and conventional therapies in combination, care must be exercised to avoid interactions between herbs and drugs. Licorice can change the metabolism of cortisol and blood pressure and could thus compromise the use of antihypertensive medication or medication used in adrenal deficiency. Berberine also suppresses liver enzymes, thereby impacting the metabolism of some drugs. ^[57,58] Combining herbal treatment with standard PCOS therapy is likely to add therapeutic benefit along with minimizing unwanted effects. A consideration of each patient's own profile and active monitoring of drug interactions, though, will help provide a sound and effective plan. Standard clinical trials are indicated to determine maximum combination therapy regimes for the care of PCOS. ^[59]

5.2 Potential for personalized medicine

Personalized medicine is transforming the treatment of polycystic ovary syndrome (PCOS) by designing therapies to fit an individual's genetic, hormonal, and metabolic makeup. As PCOS is heterogeneous with clinical features ranging from insulin resistance to hyperandrogenism and irregular menstruation, a uniform treatment plan typically yields unsatisfactory outcomes. Personalized medicine strives to maximize effectiveness by adapting herbal treatments to a patient's particular profile, maximizing therapeutic benefits and minimizing adverse effects. ^[60]

5.2.1 Genetic and Metabolic Variability in PCOS

Genetic variations contribute significantly to PCOS development and response to treatment. Genetic variations in insulin signaling, androgen metabolism, and inflammation genes determine the response of patients to various herbal agents. For example, certain women with PCOS have polymorphisms in the IRS1 gene, which influences their sensitivity to insulin. Such patients are likely to respond better to Berberine or Cinnamon, which have been shown to improve insulin action. ^[61,46] Likewise, women with androgen receptor gene mutations might have varying degrees of response to anti-androgenic herbs like Spearmint or Licorice. ^[40,62]

Metabolomic profiling, which examines biochemical markers in the body, further enhances personalization of treatment. Increased levels of oxidative stress markers, for instance, signify the necessity for antioxidant-rich herbal supplements like Green Tea Extract or Curcumin. Inflammatory marker-high women can be benefitted more from anti-inflammatory plant-based drugs like Nigella sativa and Turmeric. ^[63,24]

5.2.2 Customized Herbal Protocols and Lifestyle Factors

In addition to genetics, lifestyle factors including diet, gut microbiome composition, and stress levels impact the effectiveness of herbal treatments. Personalized treatment involves combining dietary changes with herbal supplementation to maximize overall results. For example, women with gut dysbiosis—a metabolic disorder associated with PCOS—can be helped with herbal adaptogens such as Shatavari in combination with probiotics. Likewise, those with elevated cortisol levels from long-term stress would derive more relief from adaptogenic herbs such as Ashwagandha. ^[64,65] The future of PCOS treatment lies in personalized medicine, integrating genetic, metabolic, and lifestyle factors to develop individualized herbal interventions. Through the application of pharmacogenomics and new diagnostics, clinicians can maximize the use of herbal medicine for safer, more effective results. More studies are required to make personalized protocols more uniform, opening the door to precision herbal therapy in PCOS management. ^[66]

5.3 Safety and Toxicological Considerations

While herbal therapies for polycystic ovary syndrome (PCOS) are promising in terms of therapeutic outcomes, their safety profile needs cautious assessment. Unlike pharmaceutical medications, herbal remedies typically do not have standardized dosing, quality assurance, and regulatory monitoring, posing risks such as toxicity, herb-drug interactions, and lack of consistency in composition. Familiarity with these issues is necessary to secure the safe inclusion of herbal therapy in PCOS treatment. ^[67]

5.3.1 Risks of Herb-Drug Interactions



Most women with PCOS traditional drugs like hormonal contraceptives, insulin sensitizers (e.g., metformin), and anti-androgen medications. Certain herbs interact with these drugs, inhibiting their effectiveness or causing side effects. For instance, Berberine, which is a very potent insulin-sensitizing herb, can block liver enzymes that are responsible for metabolizing drugs, thus potentially impairing the clearance of drugs like anticoagulants and antihypertensives. Likewise, Licorice (*Glycyrrhiza glabra*) can also interfere with corticosteroids and cause high blood pressure because of its impact on potassium levels. [55,53,68]

5.3.2 Concerns Regarding Dosage Standardization

Unlike chemically manufactured drugs, which are tested extensively to identify optimal dosages, herbal remedies tend to vary in strength because of variations in cultivation, extraction, and preparation of plants. This variability can lead to unpredictable therapeutic responses and toxicity. For example, excessive Spearmint intake for its anti-androgenic activity can result in endocrine disturbances, and excessive doses of Cinnamon can be hepatotoxic owing to its coumarin content. [69,70]

5.3.3 Long-Term Safety and Toxicity

The long-term consequences of a number of herbs used in PCOS therapy are not well understood, as most clinical trials are interested in short-term effects. Chronic use of some herbs could result in unexpected adverse effects on health, including endocrine disruption, hepatotoxicity, or gastrointestinal disturbances. Hence, more research and clinical trials are needed to define safe usage protocols. [71] Although herbal interventions have the potential in the treatment of PCOS, their safety needs to be evaluated judiciously. Standard dosing, herb-drug interaction awareness, and chronic toxicological assessment are essential to make these natural medicines safe and useful in the management of PCOS. Health professionals should be consulted prior to using herbal interventions in order to reduce risks and maximize therapeutic benefits. [72]

6. Challenges and Limitations in Herbal-Based PCOS Treatments

6.1 Variability in Herbal Composition

One of the most significant challenges to applying herbal remedies for the treatment of Polycystic Ovary Syndrome (PCOS) is the lack of consistency in their composition. In contrast to pharmaceutical medications, which have exact and standardized levels of active components, herbal preparations tend to show considerable variation in chemical composition based on plant type, cultivation conditions, harvesting, and processing methods. [73]

6.1.1 Influence of Environmental and Genetic Factors

The content of bioactive constituents in medicinal plants may also differ significantly depending on environmental conditions like soil, climate, and altitude. For instance, the efficacy of Ashwagandha (*Withania somnifera*) cultivated in various locations may be different due to differences in soil nutrients and water supply. Moreover, genetic differences between plant species and subspecies may result in variable levels of active constituents, impacting therapeutic effectiveness. [74]

6.1.2 Processing and Storage Variability

The process of herb processing, such as drying, extraction, and formulation, also influences the stability and bioavailability of active ingredients. Classical preparations, e.g., decoctions and tinctures, can have varying concentrations of phytochemicals from that of standardized extracts. In addition, extended storage, light exposure, and changes in temperature can break down herbal constituents, which may result in varying therapeutic effects. [75]

6.1.3 Quality Control and Standardization Challenges

The absence of standardized quality control is another key challenge in herbal medicine. While pharmaceuticals go through intense testing and regulatory review, herbal preparations tend to have variable active ingredient concentration. In the absence of proper standardization, patients will receive variable doses, which translate into uncertain therapeutic effects or side effects. [76]



6.1.4 Impact on Clinical Effectiveness

Variability in herbal formulation makes clinical studies on herbal interventions for PCOS challenging. Differences in herbal preparations between studies may lead to inconsistent results, hindering the determination of definitive efficacy and safety outcomes. This variability also impacts the capacity of healthcare providers to advise sound herbal interventions for PCOS management. [77] To address these limitations, better standardization procedures, enhanced regulatory regimes, and scientific proof of efficacy of herbal medicine are increasingly being sought. Further development of phytochemistry and biotechnology has the potential to provide quality control measures that would guarantee consistency, safety, and efficacy of herbal therapy in the treatment of PCOS. [78]

6.2 Regulatory and Ethical Considerations

Herbal treatment of Polycystic Ovary Syndrome (PCOS) raises substantial regulatory and ethical issues. Unlike pharmaceutical drugs, which are submitted to intensive clinical trials and regulatory approvals, herbal remedies do not have standardized protocols, raising concerns regarding their quality control, safety, and efficacy. [73]

6.2.1 Regulatory Challenges

One of the most important regulatory issues is the absence of a unified standard for herbal medicine. It varies from one country to another, with others considering herbal products as dietary supplements instead of drug products. In areas where there is no tight regulation of herbal medicines, there is a chance of adulteration, contamination, and lack of consistency in composition, thereby causing inconsistency in therapeutic effects. [79] A further challenge is the lack of standard dosages. In contrast to traditional drugs, where specific dosages are developed through clinical trials, herbal medications tend to have varying concentrations depending on plant source, processing steps, and extraction methods. Due to this heterogeneity, establishing the right dose for PCOS treatment becomes a challenge and leads to the possibility of under- or over-dosing. [75]

6.2.2 Ethical Considerations

From a moral point of view, advertising and selling herbal medications may be difficult. Most herbal medicines are sold with overstated therapeutic claims but no supporting evidence from science. Such an act could mislead the patient to swap established drugs for unproven ones, exacerbating the illness. [80] Further, patient safety and informed consent are essential issues. Most patients tend to believe that herbal remedies are safe because they are natural in origin, yet certain herbs might have adverse interactions with pharmaceutical medicines or produce untoward effects. Ethical healthcare practice demands health professionals to provide patients with warnings regarding the benefits and risks associated with herbal treatments without substituting evidence-based treatment with unproven therapy. [81] Another ethical concern is the sustainability of herbal medicine sources. Excessive harvesting of medicinal plants, particularly the highly demanded species, poses risks to biodiversity and ecological disruption. Ethical cultivation and sourcing practices should be encouraged to support the long-term viability of herbal medicine as an environmentally sound treatment method. [82]

6.3 Lack of Standardized Dosing Protocols

One of the biggest problems with using herbal medicine for treating Polycystic Ovary Syndrome (PCOS) is the absence of standardized dosing systems. While for pharmaceutical drugs dosages are ascertained through rigorous clinical testing, in herbal therapy different doses are often unevenly concentrated and effective. This variability complicates the task of both healthcare practitioners and patients in ascertaining the best dosage for PCOS treatment. [73]

6.3.1 Herbal Variability in Composition

Herbal remedies include several bioactive compounds, and their level varies depending on geographic origin, type of cultivation, harvesting time, and processing practices. For instance, cinnamon (*Cinnamomum* spp.) is regularly employed to enhance insulin sensitivity in PCOS but its effectiveness changes depending on differences in species, preparation (tea, extract, or powder), and



dose. Likewise, chasteberry (*Vitex agnus-castus*) is utilized for menstrual control, but with different preparations (capsules, tincture, or tea) differing effects may be attained. ^[17,83]

6.3.2 Challenges in Clinical Research and Dosage Determination

Lack of large-scale clinical trials on herbal remedies for PCOS also contributes to the lack of clarity in optimal dosages. Most studies have small patient numbers, and therefore, it is hard to make dose recommendations that apply broadly. Moreover, most herbal studies are not consistent with their formulations, and hence results are difficult to compare among different trials. ^[38] Another issue is the length of herbal treatment. In contrast to pharmaceutical medications, where treatment length is clearly established, herbal treatments tend to have no clear indications of how long they should be used to obtain maximum benefits. Prolonged use without monitoring can be dangerous, such as liver toxicity in some herbs like licorice (*Glycyrrhiza glabra*) or unforeseen hormonal consequences from prolonged use of phytoestrogen-containing herbs like Shatavari (*Asparagus racemosus*). ^[84,85]

6.3.3 Potential Risks of Incorrect Dosing

As a result of the lack of standardized dosing, overdosing or underdosing is likely to occur, and both situations may result in ineffective treatment or side effects. Overdosing on some herbs can lead to toxicity, and underdosing can be incapable of delivering therapeutic effects. Excessive consumption of berberine, for example, a frequently used herbal insulin sensitizer, leads to gastrointestinal upset and impairs liver enzyme activity, thus having the potential to interfere with drug metabolism. ^[86]

6.3.4 Need for Standardization and Guidelines

In order to allow for safe and effective herbal management of PCOS, standards in dosing recommendations, quality assurance, and regulatory control need to be strongly considered. Creating concise protocols using hard science with intense clinical trial evaluations can dictate appropriate doses, which are effective yet safe. With the provision of trained care practitioners, making herbal remedies

available with mainstream medical assistance can render them more credible and therapeutically valuable. ^[67]

7. Emerging Trends and Innovations in Herbal PCOS Management

7.1 Herbal Nanomedicine

Nanotechnology has come as a groundbreaking method in medicine, with increased bioavailability, delivery of drugs to specific locations, and enhanced therapeutic performance. For Polycystic Ovary Syndrome (PCOS), herbal nanomedicine is coming into the limelight as a means of maximizing the efficacy of plant medicines by resolving their low solubility, poor absorption, and short metabolism within the body. ^[87]

7.1.1 Increasing Bioavailability and Absorption

One of the key problems of herbal medications is poor bioavailability, in the sense that limited proportions of active molecules become part of systemic circulation. Various phytochemicals like curcumin of turmeric (*Curcuma longa*) and berberine from *Berberis* genus are very good from therapeutic applications regarding PCOS but experience minimal absorption along with short half-life excretion from the system. Nanotechnology makes it possible to develop nanoformulations, e.g., liposomes, nanoparticles, and nanoemulsions, that improve the stability and adsorption of such compounds with prolonged release and enhanced bioactivity. ^[88] To illustrate, research on nano-curcumin has demonstrated that the encapsulation of curcumin in nanoparticles enhances its bioavailability to as much as 40-fold, considerably augmenting its anti-inflammatory and insulin-sensitizing actions in PCOS models. In the same way, nano-berberine formulations have been shown to exhibit augmented glucose-lowering activities, which make them more effective against insulin resistance in PCOS patients. ^[89,90]

7.1.2 Targeted Drug Delivery for PCOS Treatment

Another significant strength of herbal nanomedicine lies in its therapeutic compounds' potential to be targeted towards affected tissues directly. PCOS is characterized by ovarian dysfunction and metabolic



disorder. Drug delivery systems based on nanoparticles can specifically target ovarian cells to deliver bioactive compounds with better efficiency and modify androgen levels, regain follicular growth, and correct ovulatory function.^[91] For example, nano-quercetin, a flavonoid with high anti-inflammatory and antioxidant potential, has been found to target ovarian tissues, decrease oxidative stress, and enhance ovarian function. Nano-cinnamon extract of similar size can also increase insulin sensitivity and decrease blood sugar levels with greater accuracy and thus becomes a more effective natural treatment for metabolic disorders in PCOS.^[92,93]

7.1.3 Decreasing Toxicity and Side Effects

Conventional herbal remedies, although largely safe, can occasionally be toxic or induce herb-drug interactions upon high-dose intake or when used together with drugs. Nanotechnology enables controlled release of active herbal constituents, reducing the risk of toxicity and undesirable side effects. The controlled release maintains the body at a constant concentration of bioactive substances, avoiding peak levels that can cause hormonal imbalance or metabolic disturbances. For instance, nano-licorice (*Glycyrrhiza glabra*) has been investigated as a therapeutic option for androgen excess and adrenal dysfunction in PCOS. Although excessive doses of licorice can lead to hypertension and electrolyte disturbances, nanoformulations can control its release to provide safer and more efficient therapeutic effects.^[94,95,68]

7.2 Genomic and Metabolomic Insights in Herbal Therapy

Advances in genomics and metabolomics are revolutionizing knowledge regarding Polycystic Ovary Syndrome (PCOS) and the contribution of herbal medicine towards its cure. The new technologies allow for the determination of genetic differences, metabolic pathways, and individualized response to herbal therapy, opening up avenues for better and more tailored treatments.^[96]

7.2.1 Genomic Insights: Elucidating Genetic Impacts on PCOS

PCOS is a very heterogeneous disorder with a significant genetic basis. Genome-wide association studies have shown that multiple genes associated with androgen metabolism, insulin signaling pathways, and ovarian dysfunction, such as LHCGR, FSHR, INSR, and DENND1A, are implicated. Genetic variations in these genes might affect an individual's response to herbal therapy, further necessitating individualized herbal medicine according to genetic profiles.^[97] For instance, women carrying genes for variants in insulin receptor function (INSR gene) will find berberine, a plant insulin sensitizer, to be more effective compared to traditional insulin-sensitizing agents. Likewise, those with FSHR polymorphisms will gain more from *Asparagus racemosus*, Shatavari, that is an estrogen-modulating agent.^[98,99,100] Genomic research also sheds light on the interaction of some herbal constituents with hormone receptors. For example, chasteberry (*Vitex agnus-castus*) has been reported to modulate prolactin levels through modulation of dopamine receptors (DRD2 gene) and thus serves as a specific herbal treatment for PCOS women with hyperprolactinemia.^[96,101]

7.2.2 Metabolomic Approaches: Identifying Biomarkers for Herbal Efficacy

Metabolomics, the field of investigation in small-molecule metabolites found in the human body, can enable scientists to monitor biochemical shifts prior to as well as post-herbal treatment. With this, research can detect those biomarkers useful for anticipating individuals' responses toward certain herbal treatment, resulting in precision herbal therapy. For example, PCOS patients have been found to have changed lipid and glucose metabolism through metabolomic studies, which are modifiable using herbal therapies such as cinnamon (*Cinnamomum spp.*) and fenugreek (*Trigonella foenum-graecum*). Metabolite profiling can now be employed by researchers to identify patients that are more likely to respond to these insulin-sensitizing herbs, minimizing trial-and-error treatment.^[102] Furthermore, compounds like curcumin (turmeric) and resveratrol (grapes) have been found to modulate inflammatory markers and oxidative stress, which are central in causing PCOS. Metabolomic studies can monitor how these drugs impact inflammatory cytokines (TNF- α ,



IL-6) and oxidative stress markers (MDA, SOD), thus giving scientific grounds for them to be used as therapeutics. ^[103]

7.3 Integrative Approaches Combining Herbs and Modern Medicine

The increased demand for holistic medicine has culminated in integrative therapies that merge herbalism with conventional medical therapy in the treatment of Polycystic Ovary Syndrome (PCOS). The rationale behind this strategy is to tap into both conventional and natural therapies' advantages such that hormonal imbalance, metabolic disorder, and inflammation are treated more comprehensively than with either treatment modality individually. ^[41]

7.3.1 Synergistic Effects of Herbs and Conventional Treatments

Numerous traditional treatments of PCOS, including oral contraceptives, insulin sensitizers (metformin), and anti-androgens (spironolactone), efficiently control symptoms but tend to be accompanied by side effects and constraints. Herbal drugs can augment such treatments, their efficacy enhanced without increasing side effects. ^[55] For instance, research indicates that the combination of metformin and berberine enhances insulin sensitivity better than metformin alone. Berberine both activates AMP-activated protein kinase (AMPK), like metformin, and offers other anti-inflammatory and lipid-lowering effects. In a similar way, a combination of chasteberry (*Vitex agnus-castus*) and hormonal treatment may enhance menstrual regularity by normalizing prolactin and luteinizing hormone (LH) levels, increasing ovulation without the risk of long-term hormone exposure. ^[104,105]

7.3.2 Reducing Side Effects and Enhancing Tolerability

A major benefit of incorporating herbal medication into standard therapies is the possibility of reducing side effects. Most pharma medication applied in the treatment of PCOS has the potential to induce gastrointestinal upset, weight gain, mood changes, or liver toxicity. Herbal adaptogens like *Ashwagandha* (*Withania somnifera*) and *Rhodiola rosea* counteract the effects of stress-induced hormonal imbalances,

thus inhibiting cortisol-induced insulin resistance and enhancing overall well-being. ^[106] Secondly, hepatoprotective herbs like milk thistle (*Silybum marianum*) can shield liver function in drug users of prolonged medications like oral contraceptives or metformin. As these adjunct herbs are used, patients should become more tolerable to drug regimens, potentially resulting in compliance and treatment successes. ^[17]

8. CONCLUSION

Polycystic Ovary Syndrome (PCOS) is a prevalent and complex endocrine condition in women of reproductive age, marked by a complicated pathophysiology that includes hormonal abnormalities, insulin resistance, chronic inflammation, and oxidative stress. Despite significant advances in traditional therapeutic approaches, current medications frequently prove inadequate due to their limited efficacy, adverse effects, and lack of personalization. In this context, herbal medicine presents a potential, holistic, and safer alternative or complementary method for addressing PCOS. This article has examined the many mechanisms by which herbal medications produce therapeutic benefits on PCOS. It highlights the biological activity of phytochemicals, including flavonoids, polyphenols, alkaloids, and phytoestrogens, which interact with many targets such as the hypothalamic-pituitary-ovarian axis, insulin signalling pathways, androgen production, and inflammatory cascades. Herbs like *Ashwagandha*, *Shatavari*, *Cinnamon*, *Green Tea*, *Black Cohosh*, and *Fenugreek* have shown effectiveness in enhancing menstrual regularity, lowering testosterone levels, improving insulin sensitivity, and restoring ovulatory function. This article highlights the increasing clinical and preclinical evidence that supports the efficacy of these herbs in managing PCOS. Numerous randomized controlled trials have demonstrated that herbal therapy can significantly enhance hormonal profiles, metabolic indices, and fertility results, frequently with reduced adverse effects compared to pharmaceutical agents. Nonetheless, challenges remain, especially concerning the absence of standardization in herbal formulations, variability in dosing methods, and possible herb-drug interactions. These limitations highlight the necessity for more



thorough comprehensive, and precisely organized clinical trials. Novel advances, including herbal nanomedicine and genomic/metabolomic-guided tailored medicines, present promising avenues for enhancing the bioavailability, efficacy, and precision of herbal treatments. Nanotechnology-based delivery systems have demonstrated potential in improving the stability and therapeutic efficacy of significant herbal components such as curcumin and berberine. Personalized medicine, utilizing genetic and metabolic analysis, facilitates focused herbal therapies customized to the individual's distinct biochemical and hormonal environment. These advancements have the potential to combine traditional knowledge with present scientific standards. Moreover, the combination of herbal medicine with conventional therapies may offer a synergistic approach for managing PCOS. Herbal medicines exhibiting insulin-sensitizing or anti-androgenic properties can enhance pharmaceutical therapies, potentially enable dosage reductions and minimize adverse effects. However, this integration requires comprehensive assessment of herb-drug interactions and rigorous clinical monitoring. In conclusion, herbal therapy constitutes a significant and underexploited asset in the integrative management of PCOS. This study strengthens existing research on beneficial herbs and their processes while suggesting for a more integrative and customized therapeutic approach. Despite the increasing interest in natural and integrative healthcare, future research must focus on the evaluation of herbal efficacy using standardized trials, the formulation of evidence-based dosing protocols, and the establishment of safety standards. By doing so, we can facilitate more effective, sustainable, and patient-centered methodologies for PCOS therapy, utilizing the complete therapeutic potential of nature.

Authors' Contributions:

All authors equally contributed in the conduct of article and preparation of manuscript. All authors participated in the design, interpretation of the studies and analysis of the data and review of the manuscript; Dr. Ritu Rani and Mr. Sandeep Yadav wrote the review and analysed the data, Mr. Asif Khan, Mr. Anuj Singh and Ms. Sujain Gautam conceptualized the study and reviewed the manuscript.

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