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Herbal Pathways to Hormonal Balance: A Comprehensive Review on Natural Treatments for Polycystic Ovary Syndrome (PCOS)

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Abstract

Background: Polycystic Ovary Syndrome (PCOS) is one of the most prevalent endocrine-metabolic disorders affecting women of reproductive age. It is clinically characterised by polycystic ovarian morphology, chronic anovulation, and elevated androgen levels, leading to menstrual irregularities, infertility, hirsutism, and metabolic complications. Contributing factors such as insulin resistance, obesity, sedentary lifestyle, suboptimal diet, and psychological stress further exacerbate the condition. Limitations of conventional allopathic therapies have encouraged exploration of herbal alternatives with fewer side effects. **Aim:** To review the therapeutic potential of selected medicinal plants- *Asparagus racemosus, Grifola frondosa, Lepidium meyenii,* and *Tinospora cordifolia* in alleviating PCOS symptoms through their hypoglycaemic, anti-obesity, and hormone-modulating activities. **Methods:** Relevant literature from scientific databases was analysed for studies reporting the effects of these plant extracts on hormonal regulation, ovarian morphology, metabolic parameters, and insulin sensitivity in PCOS-induced models. **Results:** The reviewed plants demonstrated multiple beneficial mechanisms including anti-hyperandrogenic activity, modulation of estrogen and progesterone levels, improvement in insulin resistance, and reduction in ovarian weight and cyst formation. Phytoestrogen-rich extracts showed the ability to regulate serum sex hormones and support follicular development. Additionally, several plants exhibited hypoglycaemic and anti-obesity effects, contributing to better metabolic balance. Evidence also suggests their potential to stimulate ovulation and restore menstrual cyclicity. **Conclusion:** Herbal medicines from plants such as *A. racemosus, G. frondosa, L. meyenii,* and *T. cordifolia* demonstrate promising therapeutic effects in the management of PCOS. Their availability, multifaceted mechanisms, and lower side-effect profile make them attractive complementary options alongside lifestyle modifications. These findings highlight the potential of plant-based bioactive compounds in developing novel therapeutic strategies for PCOS, warranting further clinical investigation.

Major Findings: The reviewed herbal extracts exhibited significant anti-hyperandrogenic effects, improved insulin resistance and metabolic balance, and supported restoration of normal ovarian function and ovulation. Phytoestrogen-rich plants showed effective modulation of sex hormones and reduction of ovarian cysts.

Keywords: Anti-hyperandrogenic, Estrogens, Herbals, Polycystic Ovarian Syndrome, Progesterone

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1. Introduction

Polycystic ovary syndrome is an important multifaceted endocrine disorder that interferes with a significant number of reproductive-age women[1]. A syndrome characterised by elevated levels of androgen, menstrual malfunctions, and the existence of cysts within the ovaries, PCOS is increasingly known for its complex

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etiology and pathophysiology[2]. According to the World Health Organisation report, in 2012, PCOS afflicted more than 116 million women worldwide. In India, PCOS affects nearly one in five women[3]. A very recent large-scale survey has shown that 16% of Indian women between the ages of 20 to 29 suffer from this condition, representing a worldwide increase in reported cases of 4.47% from 2007 to 2017[4,5]. The actual causes of PCOS are unknown. Some scientists think that factors such as genetics, metabolic issues, and environmental influences may cause it. Another aggravating factor is obesity, since it can exacerbate many manifestations of PCOS, particularly insulin resistance, which is extremely prevalent in affected women[6]. Infertility is the most clinically relevant issue since an ovulation accounts for about 75% of infertility cases among women with PCOS. Published prevalence rates of PCOS vary by region. In Europe, rates varying between 5.6% and 8% have been noted, while up to 19.5% prevalence has been reported from Iran using Rotterdam criteria[7-9]. Whereas a lot is still unknown about PCOS, much remains unknown, although with very high prevalence, and hence, it is still under study concerning multifactorial etiology besides lifestyle factors such as diet and exercise, among others.

Traditionally, the treatment of PCOS includes lifestyle alteration in the form of dietetics and exercise, which relieves most symptoms. Pharmacological interventions range from antiandrogens such as spironolactone to insulin sensitising agents like metformin[10]. Such pharmacological treatments are associated with side effects such as weight gain, gastrointestinal disturbances, and irregular menstruation, thus making it imperative to develop alternative therapies. The term PCOS was identified way back when the clinical entity was first described by the pioneering researchers known as Dr. Irving Stein and Dr. Michael Levinthal in the early 20th century, 1935 being the year that they had set out an amalgam of symptoms in women that included conditions such as or infrequent menstrual periods, hirsutism or excessive hair growth, and the presence of cystic ovaries, which would later be referred to as PCOS[11]. This condition was also initially not well understood and, therefore, was not properly diagnosed because it was always incorporated with some other form of reproductive disorder. Over the years, research has grown to increase our understanding of PCOS, especially in terms of the hormonal, metabolic, and genetic aspects connected with it. In 1990, the NIH held a consensus conference, hence further clarifying the diagnostic criteria for PCOS, and also formed a framework to include clinical and biochemical signs of ovulatory dysfunction and the presence of polycystic ovaries. Further, the definition was extended by the Rotterdam criteria that resulted in 2003, which allowed the diagnosis with any two of the three criteria, namely, irregular ovulation and polycystic ovarian morphology[11].

2. Types of PCOS

This condition is generally considered to be a singular condition, but various specific forms of the condition have been identified and defined. Probably the most commonly described are;

2.1 Insulin-resistant PCOS

This form is characterised by a state of decreased sensitivity to insulin, causing increased insulin levels, which is usually associated with obesity. Women with insulin-resistant PCOS often have more significant metabolic disorders, such as diabetes mellitus Type 2 and dyslipidemia[12,13].

2.2 Inflammatory PCOS

The hallmark of this variant is low-grade inflammation. Women with this type often present with symptoms that are thought to be like inflammation-increased inflammatory markers. Obesity is very common with this particular type, and all these factors synergistically influence each other to produce insulin resistance[14].

2.3 Post-pill PCOS

These are patients who may not exhibit manifestations of PCOS till after they have stopped their hormonal contraceptives. It could mainly present with symptoms of irregular menstrual cycles. In some, it could be a transient phenomenon for the others, long-term PCOS[15,16].

2.4 Adrenal PCOS

This form of PCOS presents with a high level of androgens resulting from the dysfunction of the adrenal glands. Women suffering from the adrenal form of PCOS would manifest signs of but not the abnormalities in the ovaries as in others. Knowing

these types is of great help in proper management and treatment because causes and manifestations are different from one person to another[17].

3. Signs and Symptoms of PCOS

The severity and range of symptoms of PCOS can also be quite divergent among the populations of affected women and may also change with time. Some common symptoms include the following;

3.1 Menstrual Irregularities

Women with PCOS commonly suffer from irregular or absent menstrual periods due to an ovulation; this means that their cycles are indeterminable, and they are at risk of infertility. An example of the disorder is that a level of androgens that is too high can cause some physical signs, such as hirsutism-excessive hair growth that occurs in areas typically seen in men-acne, androgenic alopecia-thinning hair or hair loss[17,18].

3.2 Polycystic Ovaries

Most women with PCOS have enlarged ovaries containing multiple small cysts described in (Figure 1), which may be diagnosed through ultrasound imaging. However, not all women with polycystic ovaries develop clinical symptoms[12].

3.3 Weight Gain and Insulin Resistance

Many women have PCOS accompanied by overweight or obesity, which often leads to insulin resistance. This combination may put a patient at risk for Type 2 diabetes[16].

3.4 Mood Disorders

Women with PCOS are also at risk for anxiety and depression. These could be secondary to the hormonal imbalances and psychosocial consequences of the condition. It significantly affects her quality of life and overall wellbeing, and thus early diagnosis and management are critical[18].

4. Diagnosis of PCOS

It is always challenging to diagnose PCOS because of the diversity of its symptoms and to distinguish the condition from other disorders that may be clinically similar. Generally, the diagnosis involves;

4.1 Clinical Assessment

History and a physical exam will be done in detail. Providers will consider the menstrual history, symptoms of and any family history[12].

4.1.1 Laboratory Tests

Blood tests may be given to assess the level of various hormones, including androgens, estrogen, progesterone, and others such as insulin and glucose levels, to determine if there is an abnormal resistance to insulin[16].

4.1.2 Other Imaging Studies

It must include transvaginal ultrasound to exclude cysts in the ovaries and must visualise polycystic ovaries according to the Rotterdam criteria, which stipulates the visualisation of the disorder on at least one ovary for the diagnosis[14].

4.1.3 Exclusion of Other Medical Conditions

It would mimic PCOS include thyroid disorders, adrenal tumors, *etc.* These exclusions are often achieved through blood tests and imaging studies. PCOS is diagnosed with specific criteria developed under the Rotterdam guidelines. This helps in standardising the diagnosis of the disorder in a female[15].

5. Causes and Risk Factors of PCOS

PCOS is an intricate condition initiated multifactorially and manifested as a wide array of symptoms that impinge the hormonal and metabolic well-being of an individual. Its causes are linked to the interplay of

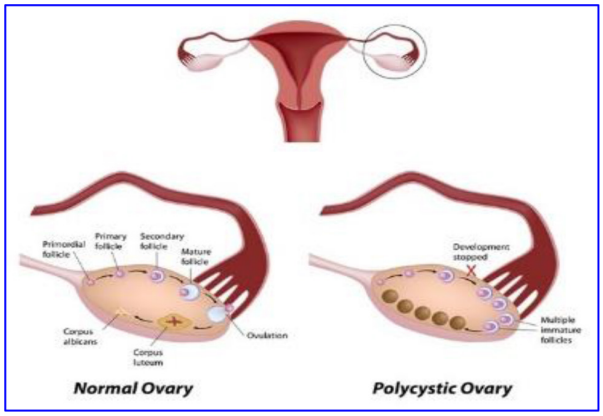


Figure 1. Difference between a normal and polycystic ovary.

several environmental pollutants, diet and lifestyle choices, genetic predispositions, obesity, and gut symbiosis, all of which cause excessive secretion of androgens, insulin resistance, impaired, and chronic inflammation that can actually worsen metabolic syndrome.

5.1 Environmental Pollutants

Researchers have given more attention to the role of environmental pollutants in PCOS pathogenesis. Such substances as heavy metals, insecticides, and EDC's were shown to be detrimental to human health and reproduction. For instance, Takashi and Kandaraki hypothesised that serum levels of bisphenol A were significantly higher among women with PCOS than among non-hyper androgenic women and healthy women[19,20]. Other researches even more had given a positive correlation of high blood concentration of BPA with increased serum testosterone in PCOS[21,22]. The case-control study by Magi *et al.*, revealed that women suffering from PCOS have evidenced increased serum concentration of perfluorooctanoic and perfluorooctanoic sulfonate[23,24]. On the other hand, a low concentration of mono benzyl phthalate was seen in cases of PCOS, thereby suggesting an alteration in the xenobiotic metabolism[25]. Initially, it was thought that EDC's merely acted through the interaction of hormone receptors. However, new research seems to expose the fact that EDC's also interfere with non-nuclear hormone receptors and can straight interacted with[26]. The association of EDC's with PCOS is quite significant because these have been found to associate with oxidative stress as well as chronic inflammation that have been implicated in the causation of insulin resistance and infertility[27,28]. Smoking has also been constantly established as one of the potential risk factors for PCOS. This has been hypothesised to be dose-dependently related to ovulatory dysfunction. Indeed, the noxious constituents in cigarette smoke-including polycyclic aromatic hydrocarbons (Pass) - have been found to increase inflammatory mediators and interfere with normal[29]. One of the most popular population-based cohort studies from Taiwan even showed that exposure to fine particulate air pollution is associated with a higher risk of developing PCOS. Such studies have further been supported by those who were conducting animal studies, where it demonstrated the possibility of exposing different kinds of pesticides in pregnancy to further cause abnormalities in subsequent generations on the ovaries[30].

5.2 Diet and Lifestyle

Diet and lifestyle are the decisive factors in managing PCOS, in which lifestyle interventions are often first-line treatment. A diet rich in calories and lack of a life of activity worsen the condition. The diet rich in sugar affects the gut microbiota, leads to chronic inflammation, increases resistance to insulin, and causes an increase in the level of androgen[31]. Obesity also significantly worsens PCOS symptoms primarily through interference with insulin resistance and hormonal balance. Interventions targeted towards CGI diets have been reported with promising results, including reduced fasting insulin levels, testosterone, and waist circumference in PCOS subjects[32]. Contrary to this, saturated fats induce inflammation that often complicates insulin sensitivity, thus a need for lifestyle alterations among the patients of PCOS exists. Omega-3 fatty acids and fermentable fibers may offer metabolic benefits and gut health along with dietary inclusion. The lifestyle changes accompanying weight loss are also reported to be related to increased menstrual regularity and a better reproductive outcome in women with PCOS[33,34]. In general, both aerobic and resistance exercise enhance the state of sensitivity to insulin, potentially lowering the risk for complications with patients. New meta-analyses inform the concept that vigorous exercise can be of the most benefit with exercise and training; therefore, the combination of the two has been recommended to improve or manage the symptoms of PCOS[35].

5.3 Genetics and Gene Interactions

The second major area upon which factors of PCOS lie is genetics. It is a polygenic disorder, and that is, many genes contribute to susceptibility for the disorder[36]. Through such research, specific single-nucleotide polymorphisms and mutations have been identified with the various symptoms of PCOS. These genetic factors mainly regulate gonadotropin action, insulin signalling, and chronic inflammation processes[37]. All these genetic markers could thus be identified with the use thereof in more personalised intervention in diagnosing PCOS at an earlier stage[38].

5.4 Gut Microbiota Symbiosis

The gut microbiota is actually a highly complex community of microorganisms that plays an important role in general health and therefore implies significant meanings related to PCOS. The phenomenon of symbiosis, defined as the imbalance of the gut microbiota, was proved to play a role in the various health conditions, including PCOS. According to the results, reduced microbial diversity along with alterations in gut bacteria composition are recurrently observed in PCOS and may be influenced by such factors as insulin resistance, sexual hormone levels, and obesity[39]. The DOGMA (Symbiosis of Gut Microbiota in PCOS) theory proposes that fecundity-impairing dietary habits trigger gut symbiosis, thereby enhancing gut permeability[40]. LPS of Gram-negative bacteria entering into the circulation, triggers inflammatory responses, impairing insulin receptor function, enhancing serum insulin, and promoting androgen output from the ovaries, thus impairing the normal maturation of follicles and exacerbating manifestations of PCOS[40]. Overall, PCOS is a condition that must be understood about cause and risk factors.

5.5 Insulin Resistance in PCOS

Insulin resistance is universal in the great majority of women with PCOS, although contrasting figures abound, but it is believed that between 50 and 70% of those afflicted has a degree of insulin resistance, independent of body weight[16]. The pathogenesis for insulin resistance in PCOS is multifactorial and complex. This condition is often compounded by obesity, as too much adipose tissue causes the secretion of pro-inflammatory cytokines and free fatty acids, which blunt the insulin signalling pathways. May thus establish a vicious circle where the production of is stimulated because of enhanced compensation for the reduced efficacy, which on its part stimulates further increases in ovarian androgen production. The extra insulin causes the ovaries to produce androgens, such as testosterone. Elevated androgen contributes to most of the classical symptoms of PCOS, including hirsutism, acne, and irregular menstrual cycles[12]. It can also cause the disturbance of the regulation of the Hypothalamic-pituitary-Ovarian (HBO) axis, which results in an ovulation and infertility[13].

5.6 Hormonal Disturbance in PCOS

In PCOS, the hormone imbalance extends beyond androgens to other hormones that include Luteinizing Hormone (LH), Follicle-Stimulating Hormone (FSH), and estrogen. The majority of women with PCOS have an elevated LH-to-FSH ratio, which is a classic finding in the condition. This imbalance results in abnormal, giving birth to multiple cysts within the ovaries, and causes irregular ovulation[36]. Moreover, chronic low-grade inflammation that typically accompanies insulin resistance may also affect hormone synthesis and regulation. Inflammatory cytokines may be the culprits behind disrupted ovarian function and altered hormone signaling, which would disturb both metabolic and reproductive patterns of this species[41].

6. Complications

6.1 Early Term Complications

6.1.1 Infertility

In PCOS throughout history, PCOS has been associated with infertility as it is still the most common cause of ovulatory disorders. However, recent studies show that nearly 50% of women with PCOS encounter primary infertility, and 25% encounter secondary infertility[50]. The most major risk factors include IR and obesity, which increase the risk of miscarriages and reduce pregnancy and live-birth rates. The endometrial abnormalities also include ovarian factors like quality of follicular fluid and vascularity, impacting the reproductive outcomes. More recent studies offer mixed evidence regarding the reproductive impairment in PCOS[51]. Many women with the condition conceive spontaneously, especially with advancing age, and live birth and spontaneous miscarriage rates seem to be comparable to those in women without PCOS. The risk of infertility should be put into perspective by regarding the ovulatory status rather than a diagnosis of PCOS as the sole Indian of miscarriage risk.

6.1.2 Obstetric Complications

From mainly concentrating on infertility problems in PCOS, there is now an expansion to even the most general reproductive problems, such as obstetric complications, primarily due to associated conditions like obesity and insulin resistance. Metabolic dysfunction and

inflammation could partly be responsible for pregnancy complications[41]. Miscarriage rates are still somewhat controversial, though some consensus indicates they may be similar between women with and without PCOS, especially in the context of assisted reproductive technologies[41]. Nonetheless, there is well-documented increased risk for such conditions as preeclampsia and pregnancy-induced hypertension, which have been found to be three-fold higher for women with PCOS[42].

6.1.3 Gestational Diabetes Mellitus (GDM)

This is also much more common among these women, with risks between 6% and 22%. There is conflicting evidence regarding cesarean delivery and adverse fetal outcomes, although there is an increased rate of preterm delivery, especially in the women[43].

6.1.4 Neonatal Outcomes

Infants born to mothers with PCOS are at a greater risk of admission to the neonatal intensive care unit and at increased rates of mortality. More recently, studies suggest there is possibly a doubling of the risk for small-for-gestational age infants, although those on large-for-gestational age and macroscopic varied[44,45].

6.2 Long Term Complications

6.2.1 Cardiovascular Disorder

Women with PCOS have higher levels of risk factors for CVD, including hypertension, dyslipidemia, diabetes, and obesity, and are often overweight. Studies have found an increased prevalence of markers such as C-reactive protein and homocysteine that indicate systemic inflammation[46]. Although subclinical atherosclerosis and risk markers are elevated, the direct relationship to greater morbidity or mortality for CVD from PCOS is not established[47]. Some studies even suggest that the incidence of myocardial infarction or stroke among PCOS women does not differ from others. Recent meta-analyses, however, indicate the possibility that the rate of nonfatal strokes and coronary heart disease might be increased in this group, which may justify further investigating lifestyle impact and treatment effects on cardiovascular risks[48].

6.2.2 Metabolic Risk

One of the key concerns in Polycystic Ovary Syndrome (PCOS) among women is obesity. The overall prevalence of overweight and obesity has been up to 61%[49]. Obesity and PCOS can be in a complex relationship that could vary with cultural and ethnic input. The increase in IR and poor metabolic profile in women with PCOS are generally characterised by central fat distribution[50,51]. Although excess weight worsens, intrinsic IR can persist without obesity in approximately 75% of lean women with PCOS[52]. Both conditions are independently associated with increased risk of Type 2 diabetes, and PCOS has been identified as an independent risk factor of significant importance, thus requiring standardised screening and treatment strategies for all PCOS phenotypes[53].

6.2.3 Oncology Risk

Polycystic ovary syndrome has been shown to be associated with an increased risk of certain cancers, primarily endometrial cancer, which is mediated through chronic an ovulation and resulting in unopposed estrogen exposure[54]. While the relative risk of endometrial cancer is raised in women with PCOS, particularly the premenopausal women, evidence regarding increased ovarian and breast cancer risk is not consistent. Complicating this association is the further presence of obesity, Type 2 diabetes, and inflammation, which makes it challenging to conclude whether the increased risk is from PCOS itself or its metabolic complications[54]. Those presenting with amenorrhea are at particular risk and therefore guidelines recommend routine endometrial surveillance. Ovulation-inducing agents and metformin can help mitigate risks, though evidence for the latter's preventive effects is scarce. Current guidelines do not endorse regular screening for ovarian or breast cancers in women with PCOS; there is still a need for further research in order to clarify the associations and develop effective prevention strategies[55].

6.2.4 Other Disorders

Women with Polycystic Ovary Syndrome (PCOS) are at increased risk for psychological disorders and reductions in quality of life. Meta-analyses report prevalence rates for depression ranging from 14% to 67%, with an increased risk of depression four times higher than that of the age-matched control[56]. Anxiety also has an incidence greater in PCOS subjects, although few data are available in adolescents. It is assessed

through various validated questionnaires, such as the Hospital Anxiety and Depression Scale and the PCOS questionnaire[57]. While higher rates of mood disorders have been identified among PCOS patients, it is difficult to distinguish specific contributions of the disease itself versus its symptoms - obesity, hirsutism, and infertility[58]. Obesity was linked with decreased QoL and depression, while improved mental status was observed after weight loss. Despite encouraging psychological assessments in the evaluation of PCOS, the ESHRE/ARM Consensus Group believes that systematic screening is premature and suggests the conduct of further research on appropriate screening tools and interventions[59].

7. Pathophysiology

PCOS is a multifaceted disorder influenced by neuroendocrine, metabolic and genetic factors. At

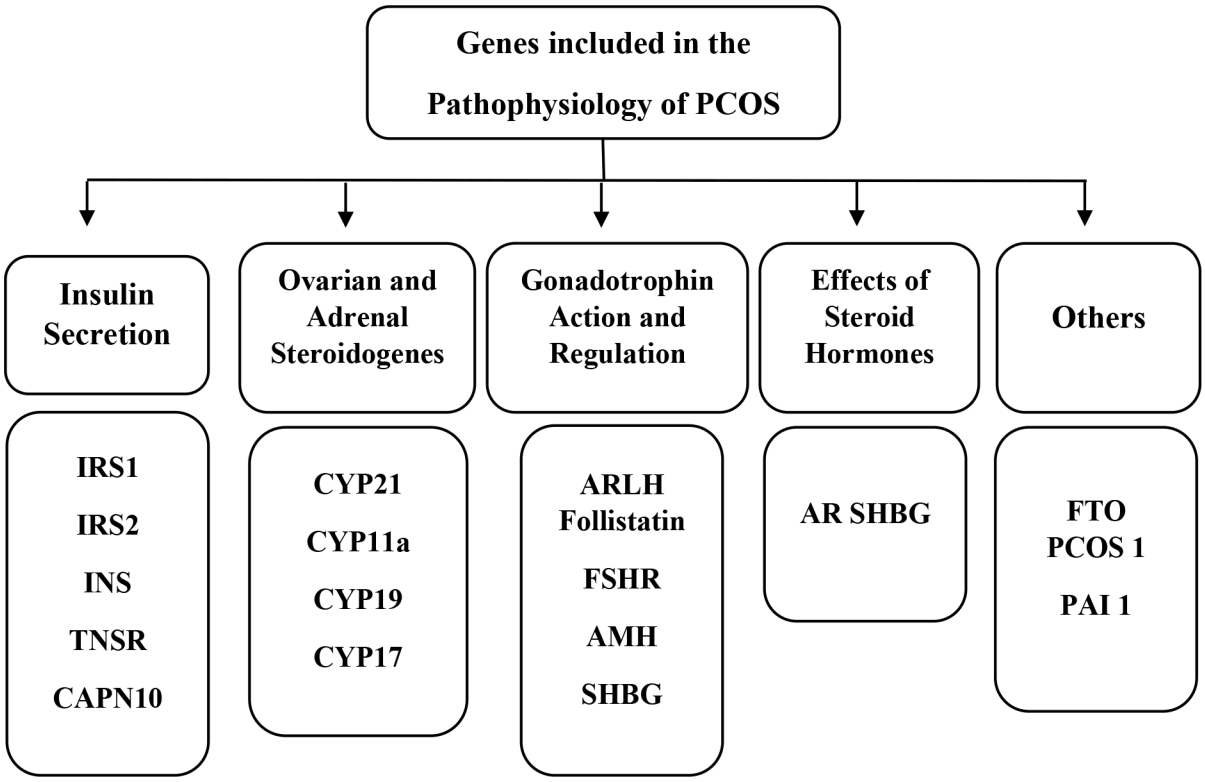


Figure 2. Genes involved in the pathophysiology of PCOS, including insulin secretion/signaling, ovarian and adrenal steroidogenesis, gonadotropin regulation, steroid hormone effects, and other susceptibility genes[36,37,60-64].

Table 1. Allopathic Remedies for PCOS

Medication	Class of Medication	Used as	References
Metformin	Biguanide	Insulin sensitiser	65
Letrozole	Aromatase inhibitor	Ovulatory agents	66
Oral Contraceptive Pills (OCPS)	Combination estrogen- progestin	Hormonal therapies	67
Clomiphene citrate	Selective Estrogen Receptor Modulator (SERM)	Ovulatory agents	68
Dexamethasone	Corticosteroid	Anti-androgens	69
Spironolactone	Aldosterone antagonist	Anti-androgens	68,69
Gonadotropins	Fertility drugs (FSH, LH)	Hormonal therapies	66,68
Finasteride	5-alpha reductase inhibitor	Anti-androgens	69
Medroxyprogesterone	Progestins	Hormonal therapies	68

the heart of the pathophysiology are insulin resistance and obesity, which significantly dysregulated the hypothalami-pituitary-ovarian axis and contribute to the pathophysiology[60]. It is caused by high levels of insulin, which in turn increase the production of androgens by the ovaries. Hormone disruption leads to increased levels of free fatty acids and proinflammatory cytokines, such as TNF and IL-6, as well as factors that contribute to systemic inflammation and metabolic dysfunction. Increased androgen levels inhibit androgen secretion from adipose tissue. This reduces insulin sensitivity, which increases insulin resistance. Increased insulin levels increase Aldo-Keto Reductase 1C3 (AKR1C3), which in turn stimulates the release of androgens from adipose tissue[61]. This results in the formation of a cycle that sustains. Oxidative stress is another critical aspect of the pathogenesis of PCOS, which also leads to many reproductive complications such as infertility, recurrent miscarriages and preeclampsia in pregnant women. Blood levels of most amino acids in women with PCOS are significantly lower compared to healthy controls. This can lead to disturbances in the general metabolic activity. The lack of essential vitamins can also be involved in the metabolic changes that lead to the development of ovarian cysts[62]. Genetic factors also contribute for the development of PCOS shown in the (Figure 2). Variants in genes involved in insulin signalling and androgen receptor activity, such as CYP1A1, CYP17A1 and the insulin receptor are associated with this disorder. Genetic factors vary from person to person, predisposing them to different stages of PCOS[63]. Clinical features of the syndrome include varying degrees of elevated androgen and glucose levels, ovarian cysts, and several psychological effects, including anxiety and depression. The metabolic syndrome from which the patients suffered also increased their risk of hypertension and cardiovascular disease. The diagnosis of PCOS is basically based on the assessment of hormone levels, diagnostic ultrasounds that determine the morphology of the ovaries and the heterogeneity of the presentation[64]. Understanding the underlying pathophysiology of PCOS is essential for the development of targeted therapy and effective management, which often considers lifestyle interventions, Allopathic treatments given in the Table 1 and, increasingly, herbal medicines to address the multifaceted nature of this disease. The major genes involved in insulin signalling, steroidogenesis, gonadotropin regulation, and hormonal imbalance contributing to PCOS are illustrated in Figure 2. Commonly used allopathic medications for the management of PCOS along with their pharmacological class and therapeutic role are summarised in Table 1.

8. Plants Used for Management

PCOS is very common lifestyle disease which associated with numerous symptoms. There are many herbs which are used to manage the various symptoms of PCOS, such as;

8.1 Plants with Anti-androgenic Activities

8.1.1 Mentha spicata

Mentha spicata, or spearmint, is a medicinal plant traditionally used for managing hyperandrogenism in PCOS, as shown in Figure 3. It is rich with many beneficial compounds, such as carotenoids like lutein and flavonoids such as rutin and quercetin, phenolic acids like rosmarinic and caffeic acids, which have very strong antioxidant effects[71]. A 30-day study on animal models revealed spearmint lowers testosterone levels and hirsutism and seems to be helpful for ovarian cysts of PCOS, as this treatment enhances the growth of normal follicles. This herb is also anti-inflammatory, antidiabetic, and anticancer and has the potential to control blood LH and FSH levels, suggesting its use for PCOS. Preclinical studies further specify its anti-androgen activity[72,73].

8.1.2 Linum usitatissimum

Linum usitatissimum (flax seed) is a phytoestrogen-rich medicinal plant beneficial in PCOS management, as shown in Figure 4, belongs to the *Linaceae* family, rich in fixed oils 30 to 40%, mucilage 6 to10%, proteins 25%, fatty acids, and lignans. Important lignans in this composition include secoisolariciresinol and its diglycoside, SDG. The composition includes many sugars, l-galactose and d-xylose, among others, flaxseed's secondary metabolism controls the production of estrogen, induces fertility, and regulates menstrual cycles and they decrease androgen levels[74]. This may provide benefits to patients with conditions like PCOS. In preclinical studies, supplementation

with flaxseed has suggested the values of decreased androgen levels, enhancement of corpus luteum formation, and decreases in ovarian cysts in female rats. Intake of flaxseed regularly could regulate ovarian volume and menstrual frequency. Flaxseed is beneficial in neoplasms, diabetes, arrhythmia, obesity, and problems of coagulation[75].

8.1.3 *Glycyrrhiza glabra*

Glycyrrhiza glabra, commonly called liquorice, is a plant of the *Fabaceae* family. The roots and rhizomes contain 2 to 9% glycyrrhizin, glycyrrhizin acid, flavonoids, isoflavonoids, carbohydrates, amino acids, and triterpenoid saponins. Liquiritigenin, isoliquiritigenin, and glabridin are the most important phytoestrogens in liquorice. Liquorice is an extremely potent anti-androgen that stimulates synthesis and discharge of estrogen. In turn, flavonoid moiety interacts with estrogen receptors, enhancing the anti-androgenic activity. They also further enhance the secretion of insulin which reduces blood sugar levels, thus alleviating problems in PCOS patients. Apart from PCOS, liquorice has other medicinal uses of cough suppressant, being antibacterial and antiviral and is effective in treating disease disorders like hepatitis, digestive system problem, and mouth ulcers[76].

8.1.4 *Punica granatum*

Punica granatum, or pomegranate, is a plant belonging to the *Punicaceae* family and rich in folic acid, vitamins (B1, B2, C) sugars, organic acids, and fatty acids. Seeds are rich in positive phenolic compounds such as catechins and flavonoids, together with phytosterols, which have been proven to reduce the complications associated with Polycystic Ovary Syndrome (PCOS). Overall, frequent consumption of pomegranate normalised women's blood levels of free testosterone, serum estrogen, and androstenedione, suggesting a promise of its effects in alleviating complications related to PCOS[77].

8.1.5 *Cocos nucifera*

Cocos nucifera exhibits hormone-modulating and anti-androgenic properties useful in PCOS, as shown in Figure 5, rich in compounds such as alpha-tocopherol and lauric acid, with other phenolic compounds like flavonoids and saponins present in its roots[78]. There are many phytoconstituents in the plant, some of which are lupeol methyl ether and skimmiwallin. Flavonoids in the coconut may be emerging as agents capable of lowering blood glucose level, and the lipid methyl (9Z,12Z)-9,12-octadecadienoate are seen as anti-androgenic[79].*C. nucifera* modulates sex hormones such as FSH and LH, and preclinical evidence suggests that *C. nucifera* is beneficial for ovarian histology of PCOS patients by reducing the count and size of cysts, decreasing ovarian weight, and increasing uterine weight. The coconut inflorescence infusion is commonly used as an indigenous medicine in India for menstrual disorders, and coconut milk has been documented to possess contraceptive activity[80].

8.1.6 *Ocimum tenuiflorum*

Ocimum tenuiflorum (Tulsi) possesses anti-androgenic and metabolic regulatory effects relevant to PCOS management, as illustrated in Figure 6. It has shown promising effects in polycystic ovarian syndrome, due to having very potent anti-androgenic properties that help suppress or elevate androgen production (hyperandrogenism). Conversely, it is applied for



Figure 3. *Mentha spicata* plant.



Figure 4. *L. usitatissimum* seeds.

countering all sorts of health problems and exhibits its usefulness in the management of obesity and related conditions[81].

8.2 Plants that Enhance FSH and Reduce LH Secretions

8.2.1 *Panax ginseng*

Panax ginseng, also known as the "king of herbs", has been used medicinally for over 2000 years, due to its active saponins called ginsenosides, both major (*e.g.* Rb1, Rb2, Rd) and minor forms. These compounds have also been shown to enhance the growth of estrogen receptor-positive cells and to display estrogen-like activity, especially in ginsenosides Rb1 and Rg1, which would raise serum levels of estradiol, concurrent with FSH and LH suppression[72]. This latter reduction in LH may actually enhance the fertility of women affected by PCOS who harbor an ovulation. Ginseng also has great potential in helping patients overcome postmenopausal symptoms such as sleeping difficulties, anxiety, and depression and is often used for natural estrogen replacement therapy. Other than that, ginsenosides are known to induce alterations in the estrus cycle and increase estrogen receptors in the tissues of the reproductive system, which also supports its use in treating PCOS.

8.2.2 *Trigonella foenum-graecum*

Trigonella foenum-graecum has been reported to reduce ovarian cyst size and normalise LH/FSH ratio in PCOS, as shown in Figure 7. It contains 8-10% moisture, 45% carbohydrates, 15-28% protein, 6-12% lipids, 4-8% ash, 8-16% fiber, and 0.2-0.3% essential oil. Crucial constituents of fenugreek seed oil responsible for cyst-suppressing properties include β-pinene, β-caryophyllene, camphor, and neryl acetate[82]. The seeds are said to contain a great deal of sesquiterpenes, phytosterols, terpenoids, and several flavonoids and alkaloids. Clinical trials are able to prove that two capsules daily have provided considerable help for the patients who suffer from polycystic ovary syndrome. The size of cysts and ovarian volume decreased during a period of 90 days, thus alleviating the symptoms of PCOS[83]. Fenugreek reduces the ratio of LH/FSH, which gives it significant potential in managing PCOS, in addition to regular menstrual cycles[84].

8.2.3 *Foeniculum vulgare*

Foeniculum vulgare is a plant species belonging to the family *Apiaceae* shown in the (Figure 8), known commonly as fennel. The oil contents for this drug vary between 4-5% volatiles. It is described to contain several medicinal compounds, including trans-anethole, α-pinene, estragole, fenchone, β-carotene, and phenolic acids with several flavonoids like kaempferol, quercetin. Fennel contains 50-60% anethole and 18-22% fenchone, along with vitamins such as α-tocopherol and ascorbic acid, which may provide powerful antioxidant activities for protecting cells against oxidative damage. The anethole in fennel has been shown to stimulate menstruation and exhibit an estrogenic activity in ovarian follicles and could, therefore, be helpful in the treatment of Polycystic Ovary Syndrome (PCOS). In addition, fennel has been found useful for various pharmacological benefits like helminthic infection, neurological disorders, hirsutism, and tumor-suppressive, anti-diabetic, and hepatoprotective properties[85,86].



Figure 5. *C. nucifera* plant.



Figure 6. *O. tenuiflorum* L. plant.

8.2.4 *Pimpinella anisum L.*

Pimpinella anisum L. or sweet cumin, is the common name for this species within the family *Apiaceae*. The composition includes 9% moisture, 35% sugars, 18% proteins, 16% lipids, and 2-7% essential oil, among others[87]. The principal component of its essential oil is trans-anethole (90%), the other members of which are anisaldehyde and methyl chavicol. Treatment with anethole resulted in a relief of oligomenorrhea and the quality of life in women. The phenolic compounds present in aniseed exhibit phytoestrogenic activity and control menstrual cycles by regulating the secretion of LH/FSH, thereby alleviating complications caused by PCOS[88].

8.2.5 *Cimicifuga racemose*

The black cohosh, botanically classified as *C. racemosa*, is a member of the *Ranunculaceae* family. This herb has gained wide attention due to its two significant classes of constituents: Triterpene glycosides and phenolic acids. Some of the most significant phenolic entities are hydroxycinnamic acids, ferulic acid, isoferulic acid, and caffeic acid in addition to the cimicifugic acids; these have been shown to inhibit ovarian cysts[89]. Interaction of these compounds with estrogen receptors in the hypothalamus and pituitary gland, these compounds interact with estrogen receptors in the hypothalamus and pituitary gland. They bind specifically to α-estrogen receptors, a fact that decreases production of Luteinizing Hormone (LH)[90]. Flavonoids in black cohosh are associated with decreased levels of LH and improvement in pregnancy rates in women who have used clomiphene during their cycles.

8.3 Plants that Improve Ovulatory Cycle and Reduce Cyst Formation

8.3.1 *Asparagus Racemosus (Shatavari)*

Asparagus racemosus is more commonly known as *Shatavari*. It has long been used in traditional Indian *Ayurvedic* medicine in supporting ovarian follicle development and menstrual cycle while rejuvenating the female reproductive system, largely because of its phytoestrogen component. It also boasts the advantage of fighting hyperinsulinemia[91]. In addition to the properties above, *A. racemosus* demonstrates other pharmacological benefits that involve affecting conditions related to nervous disorders, dyspepsia, tumours, and inflammation, together with properties that are associated with antioxidant, antiulcer, and immune-modulatory actions. There are also anti-aging improvements as well as improvements in mental function[92].

8.3.2 *Curcuma longa*

Curcuma longa is an aromatic spice of the family *Zingiberaceae* known by various names, such as yellow ginger and Indian saffron shown in the Figure 9. The rhizomes consist of more than 250 phytoconstituents, mainly carbohydrates (60-70%), proteins (5-10%), terpenes (1.5-5%), and resins. Secondary metabolites occur in largest content as curcuminoids at 2.5-8%, while curcumin makes 71.50-94%, desmethoxycurcumin 6-19.4%, and bisdemethoxycurcumin 0.30-9.10% are the most significant. These also comprise phenolic compounds such as ferulic acid, eugenol, ascorbic acid, vanillic acid, caffeic acid, syringic acid, protocatechuic acid, and p-coumaric acid, as well as the terpenoids turmerone, α-turmerone, camphene,



Figure 7. *T. foenum-graecum* seeds.



Figure 8. *F. vulgare* seeds.

β-sesquiphellandrene, γ-terpinene, and carotene. Curcuminoids seem to act most potently on PCOS with thinning of the follicular sheath, improvement in corpus luteum development, and enhancement of ovulation. They have been shown to lower the levels of serum progesterone while raising the levels of estradiol in women suffering from PCOS. Moreover, their estrogenic, antihyperlipidemic, antioxidant, and hypoglycemic qualities have provided assistance in the management of PCOS and prevented dysfunction of ovarian cells, thus promoting ovulation and fertility[93,94].

8.3.3 *Vitex agnus castus*

Chaste berry, also known as *Vitex agnus castus,* is a plant in the *Verbenaceae* family that has been employed in herbal medicine for over 2,000 years. This is a large shrub native to Europe and grows widely throughout the southern United States. It is used in treating estrogen imbalances due to menstrual cycle abnormalities, premenstrual syndrome, corpus luteum insufficiency, cyclical mastalgia, and menopausal hot flashes[96]. The fruits of Vitex contain a variety of compounds, which fall in the categories of monoterpenoids, including bornyl acetate and limonene, labdane-type diterpenoids, such as viteagnusin, and flavonoids, including luteolin and apigenin. Importantly, the diterpenoid viteagnusin and several flavonoids exhibit an inhibition of prolactin secretion by blockade of dopamine-2 (D-2) receptors, thereby assisting in modulating ovulatory cycles. Additional pro-ovulatory activity is provided by the estrogen receptor-selective effect of apigenin[97]. Collectively, these mechanisms may be useful in reducing ovarian cyst formation and could have a potential application in the treatment of PCOS.

8.3.4 *Pergularia daemia (Veli paruthi)*

Pergularia daemia or "*Veliparuthi*" in Tamil and "*Uttaravaruni*" in Sanskrit belongs to the *Asclepiadaceae* family, and this plant has been used traditionally for a variety of pharmacological benefits. This is known to provide normalisation of menstrual irregularities and restrains the estrous cycle, which can prevent the development of follicular cysts. In case of albino Wistar rats with PCOS, it resulted in the decrease of LDL and a level of FSH, LH, estradiol, progesterone, and testosterone. However, according to Poornima *et al*, the said hormonal conditions went back to normal range after supplements of *P. daemia*[98].

8.4 Plants that Increase Insulin Sensitivity, Enzyme Activity and Estrus Cyclicity

8.4.1 *Aloe barbadensis*

Aloe barbadensis improves insulin sensitivity and restores estrous cyclicity in PCOS, as illustrated in Figure 10. It contains secondary metabolites like anthraquinone derivatives, flavonoids, phytosterols, and polyphenols. Its major constituents included aloe emodin and barbaloin. Administration with Aloe vera gel has been reported to give partial reversion of estrous cyclicity and increased steroidogenic activity in women. In the preclinical study conducted on rats, Aloe vera is reported to inhibit the activity of 3β-HSD and 17β-HSD enzymes, reduces ovarian weight, and lowers the overall secretion of androgen as it enhances the synthesis of estrogen through the stimulation of the steroidogenesis pathway. On the other hand, Aloe vera restores glucose sensitivity, maintains the estrus cycle, and controls the plasma lipoprotein levels by reducing cholesterol in the liver. These properties make Aloe vera useful in mitigating metabolic problems that have been identified with polycystic ovary syndrome[99].

8.4.2 *Cinnamomum cassia*

Cinnamomum cassia enhances insulin sensitivity and metabolic balance in PCOS, as shown in Figure 11, belonging to the *Lauraceae* family, include cinnamyl alcohol, linalool, eugenol, eugenol acetate, methyl eugenol, benzaldehyde, and procyanidins with cinnamaldehyde and caryophyllene. The content of carbohydrates was 80.59%, dietary fiber 59.55-53.1%, moisture 9.5-10.5%, protein 3.89-4.65%, ash 3.55%, and other vitamins. Cinnamon phenolic compounds regulate blood insulin



Figure 9. *C. longa* dried rhizome and powder.

levels, enhance glucose uptake, and stimulate glycogen synthesis in the liver. Thus, cinnamon extract could be administered to improve insulin sensitivity in women with Polycystic Ovary Syndrome (PCOS). Procyanidins and polyphenols of cinnamon activate the insulin signaling pathways and contribute to hypoglycemic activity. Oral supplementation of an adequate amount of medication also during the luteal phase may regulate progesterone levels, normalise menstrual cycles, and alleviate symptoms of PCOS[100]. The anti-inflammatory and antioxidant properties of cinnamon raise levels of Superoxide Dismutase (SOD), Glutathione Peroxidase (GPX), and Catalase (CAT) while reducing levels of Malondialdehyde (MDA). Clinical trials involving 183 patients established that cinnamon significantly reduces fasting blood glucose, insulin, Total Cholesterol (TC), Low-density Lipoprotein (LDL), and Triglyceride (TG) levels, thereby proving useful in the management of PCOS[101].

8.4.3 Tinospora Cordifolia (Guduchi)

Medicinal properties of the plant *T. cordifolia* belonging to the family *Menispermaceae* are especially its hypoglycemic characteristics[102]. The anti-inflammatory herb is for chronic inflammation in tissues; one of the leading causes behind this is the imbalance of insulin, and the formation of ovarian cysts in women. Because of these reasons, *T. cordifolia* reduces body insulin resistance, revives tissues with a better metabolism, and helps one to reach overall health along with specific benefits in cases of polycystic ovary syndrome, otherwise known as PCOS[103].

8.4.4 Grifola frondosa (Maitake Mushroom)

Grifola frondosa is a perennial fungus classified in the family *Meripilaceae*, which has recently received attention for its hypoglycemic activity and potential use as a drug for treating diabetes. Animal experiments have indicated the stimulation of ovulation in PCOS women by extract of *G. frondosa*. The modulation of blood glucose level could be another mechanism besides enhancing insulin sensitivity, by which *G. frondos*a exerts influence. Hence, this species could be useful in improving reproductive health and metabolic functions in PCOS patients[104].

8.4.5 Galega officinalisi (Goats Rue)

Currently, the same species was used in "*G. officinalis*, *Fabaceae*" is also a plant to be studied with further clinical research by confirming the benefit for women suffering from Polycystic Ovarian Syndrome (PCOS). This plant has been recognised historically for being used to relieve symptoms of diabetes mellitus with guanidine, being a natural source that lowers blood sugar by reducing insulin resistance. Since Metformin is a widely used drug to treat PCOS, belonging to the biguanide class of drugs, *G. officinalis* is once again worthy of interest as herbal drug treatment for the treatment of PCOS and related metabolic disorders[105].

9.1 Plants Act as Ovulation Induction Agents

9.1.1 Tribulus terrestris

Tribulus terrestris, also known as *Gokharu* or puncture vine, is a *Zygophyllaceae* family member that contains significant chemical constituents such as furostanol, spirostanol, and several saponins like diosgenin and protodioscin. Another therapeutic compound included is kaempferol with its derivatives[106]. Saponins from *Tribulus* demonstrated hypoglycemic effects, causing severe reductions in serum glucose, triglycerides, and cholesterol. This plant has been said to normalise

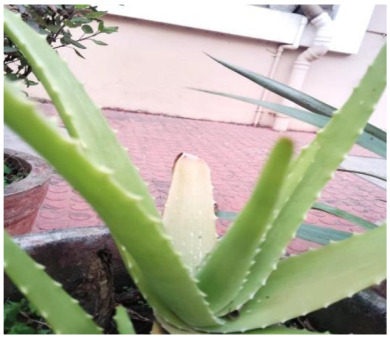


Figure 10. *A. barbadensis* plant.



Figure 11. *Cinnamomum cassia* bark.



Figure 12. *Z. officinalis* rhizome.



Figure 13. *B. vulgaris* plant.

the estrous cycles and steroid hormonal levels by stimulating growth in ovarian follicles. It promises much, being an ovarian stimulant and a fertility tonic, for women suffering from polycystic ovaries[107].

9.1.2 *Zingiber officinalis*

Commonly known as the ginger, *Z. officinalis* species shown in the Figure 12 from the family of *Zingiberaceae* generally contains about 60-65 essential oil compounds, and its major active phytochemical components include geraniol, gingerol, curcumin, and α-curcumene[108]. The resin of this species includes components such as paradol, zingerol, and shogaol, in addition to vitamins and phenolic compounds, for the management of PCOS. Gingerol and shogaol are antioxidants with anti-prostaglandin properties that reverse prostaglandin and arachidonic acid synthesis. Ginger possesses the ability to boost the fertility enhancement, augment testosterone levels, and also increase sperm motility and count in males[109]. Besides this, the flavonoids and phenolics present in ginger normally maintain the hormonal balance because it regulates the estrogen and progesterone levels. Hence, the presence of phytoestrogen in ginger can be used as a treatment for PCOS[110].

9.1.3 *Bambusa vulgaris*

Bambusa vulgaris, or simply bamboo shown in the Figure 13, has recently become known as a potential agent for inducing ovulation. The extracts of the plant have been found to have a beneficial effect on the reproductive cycle, especially in cases involving Polycystic Ovary Syndrome (PCOS). The extracts possess an antioxidant and antidiabetic property, thus modulating hormonal balance and improving metabolic health. Other than this, its effects decrease blood glucose levels and lowers cholesterol and triglycerides, enhancing ovarian function and ovulation. Such effects make *B. vulgaris* an effective natural agent for women experiencing fertility problems who are undergoing the treatment of ovulation induction[112].

10. Conclusion

Polycystic Ovary Syndrome (PCOS) is probably the most common hormonal disorder that affects women between puberty and perimenopause and leads to problems such as infertility, metabolic disorders and cardiovascular disease. Although synthetic medications can help control the symptoms of PCOS, side effects are still a problem when used for long periods of time. Therefore, herbal therapies have become more important as an alternative treatment for PCOS. This article includes various medicinal plants, described in terms of their main chemical components and their potential role in the management of PCOS complications such as insulin resistance, hyperandrogenism and obesity. The results of this research highlighted the many multidimensional benefits of these herbs for the treatment of many symptoms of PCOS. Although promising, the results of these studies pave the way for more preclinical and clinical studies aimed at establishing the effectiveness of herbal interventions. These analyses will help enrich the research group of scientists and health professionals interested in exploring herbal alternatives to improve the management of PCOS, as well as their holistic approaches aimed at improving outcomes for women.

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Vishin Ashish Patil: Conceptualisation, literature review, manuscript drafting and final editing. Shruti Prashant Killedar: Literature collection, data compilation, and writing initial sections. Shreyash Ekshinge: Data organisation, analysis, and contribution to manuscript writing. Sejal Magdum: Support in literature review, summarisation, and proofreading. All authors have read and agreed to the published version of the manuscript.