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Effect of Yoga Training and High Probiotic Food Supplements on Insulin-Resistance in Polycystic-Ovarian-Syndrome: A Randomized Controlled Trial

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ABSTRACT

Background of the study: Polycystic ovarian syndrome (PCOS) is a prevalent endocrine disorder that affects 5% to 10% of females globally during their reproductive years and can lead to other complications, such as diabetes. While PCOS can develop due to various factors, insulin resistance (IR) is a crucial underlying cause. **Objective:** The study aimed to investigate the effects of Yoga, high probiotic-food supplements, and the Mediterranean diet on insulin resistance in women with polycystic ovary syndrome. **Methods:** In this RCT, 52 females diagnosed with PCOS and IR participated. The subjects were assigned into two groups, with the study group (n=26) following to a Mediterranean diet rich in probiotics and engaging in daily one-hour yoga sessions. In contrast, the control group (n=26) practiced Yoga for 1 hour daily. The intervention duration in both groups was 12 weeks. We planned a Mediterranean diet rich in probiotics and Yoga practice. The diet was prepared as the macronutrient of 55–60% of calories from carbohydrates (with simple sugars representing less than 10%), 10–15% of calories from protein, and 30–35% of calories from fat (mostly monounsaturated (MUFA) and polyunsaturated (PUFA) fats) following WHO recommendations. The Yogo practice includes "warming-up exercises (Jathi(s))", "characteristic body postures (Asana(s))", "symbolic gestures (Mudra(s))", "chanting of sacred sounds (Om japa)", and "breathing techniques (Pranayama)". The primary outcome measures, including FBG, homeostatic model assessment of IR, and serum insulin, were measured at pretest and after twelve weeks. The homeostatic model assessment of IR was calculated using a specific formula. Serum insulin levels were measured using an ELISA kit. Secondary outcomes such as body weight, BMI, and waist circumference (WC) were also assessed. **Results:** After twelve weeks of treatment, both groups showed important enhancements in insulin resistance, serum insulin, and fasting blood glucose ($p < 0.05$). Group A significantly improved weight, BMI, hip circumference, insulin resistance, serum insulin, and fasting blood glucose than group B ($p < 0.05$). There was no significant difference in waist circumference between the groups ($p > 0.05$). **Conclusion:** Integrating high-probiotic supplements into the diet alongside Yoga for 12 weeks significantly enhances various health parameters, including serum insulin levels, homeostatic model assessment of IR, fasting blood glucose, and body measurements such as waist and hip circumference, as well as BMI, in women with PCOS, compared to practicing Yoga alone.

Key words: Polycystic Ovary Syndrome, Insulin Resistance, Microbiota, Probiotics, Yoga, Mediterranean Diet

INTRODUCTION

PCOS is a widespread endocrine syndrome affecting 5% to 10% of females worldwide during their generative years (Shahid et al., 2022). Initially characterized by Stein and Leventhal in 1935, PCOS manifests as a combination of "hirsutism, amenorrhea, chronic anovulation, infertility, and obesity" (Cincione et al., 2023). This disorder predominantly impacts the reproductive system and is linked to abdominal obesity, insulin resistance (IR), reduced glucose absorption, and dyslipidemia (Shahid et al., 2022). Women with PCOS typically display heightened luteinizing hormone levels, diminished follicle-stimulating hormone (Dennett & Simon, 2015), increased androgen, and elevated insulin levels. Such hormonal imbalances may result in oligomenorrhea or amenorrhea (infrequent or absent menstruation). Furthermore, PCOS leads to reduced estrogen production and excessive androgen secretion (testosterone, dehydroepiandrosterone, and androstenedione) by the ovaries, giving rise to addition-

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al clinical features, including ovarian cysts and various hair and skin symptoms (Dennett & Simon, 2015). Consequently, PCOS is recognized as one of the principal causes of anovulatory infertility (Al Khalifah et al., 2021).

IR commonly manifests in women with PCOS (Xu & Qiao, 2022). The precise mechanism of IR in PCOS remains inconclusive (Xu & Qiao, 2022). However, it is believed to entail disruptions in the "post-receptor phosphatidylinositol 3-kinase (PI3-K) insulin pathway", influencing insulin's metabolic effects (Muscogiuri et al., 2022). Women diagnosed with PCOS exhibit a 5 to 7-fold heightened vulnerability to emerging type 2 diabetes mellitus (T2DM) relative to those without PCOS due to irregular glucose metabolism stemming from insulin resistance or hyperinsulinemia (Zheng et al., 2019). The "Mediterranean-diet" is renowned for its health advantages, encompassing diminished total and regional adiposity, reduced insulin resistance, and prophylaxis against T2DM, cognitive decline, and unipolar depression (Mirabelli et al., 2020). Yoga, a conventional form of mind-body training, has gained recognition for its efficacy in managing diverse chronic conditions (Gowri et al., 2022). Research has demonstrated that Yoga can notably ameliorate BMI, fasting blood glucose (FBG), postprandial blood glucose, glycated hemoglobin (HbA1c), HOMA-IR, cholesterol, triglycerides, and low-density lipoproteins (LDL) (Dhali et al., 2023).

Current research has underscored the critical role of gut microbiota in the pathogenesis of obesity, obesity-related inflammation, and IR, which can impede follicle development (Gu et al., 2022). "Dysbiosis of the gut microbiome" may contribute to manifestations resembling those of PCOS, suggesting that interventions targeting the gut microbiome, such as "prebiotics, probiotics, fecal microbiota transplantation, and traditional Chinese medicine", could serve as a potential healing approach for PCOS (Zhang et al., 2019). Probiotics, defined by the WHO as live microbes convening health benefits when ingested in adequate quantities, have exhibited efficacy in modulating human gut microbial composition and function (Kerry et al., 2018). While the use of probiotic complements has been extensively studied for their favorable effects on metabolic diseases and infections (Aggarwal et al., 2013), their impact on insulin resistance in women with PCOS remains contentious. Studies have reported no discernible benefits of probiotic supplementation on insulin metabolism in PCOS patients (Miao et al., 2021), while others have indicated that probiotics may aid in the management of obesity and IR in adolescents with PCOS (Calcaterra et al., 2023).

The current literature has gaps in understanding how the Mediterranean diet, Yoga, and high-probiotic food supplements combined affect IR in women with PCOS. Prior studies have focused on these interventions individually without exploring their potential combined effects. Inconsistent results have been found due to variations in study designs, populations, and probiotic strains. The combined effects of Yoga, high-probiotic food supplements, and the Mediterranean diet on IR in women with PCOS were investigated in this study. These interventions are hypothesized to synergistically work together to improve insulin resistance and overall metabolic health significantly.

METHODS

Participants and Study Designs

This research focused on female participants diagnosed with PCOS and IR at the outpatient clinic of "Kafr Elsheikh University Hospital" in Kafr Elsheikh governorate, Egypt. The inclusion criteria comprised females aged 20 to 30 with a BMI ranging from 24 to 36 kg/m² and a low-level-of-physical activity. The study, conducted between September 2023 and January 2024 and compliance with the Pan African Clinical Trial Registry requirements (PACTR 202211578683612) was ensured. Baseline assessments were carried out for the experimental and control groups, followed by a 12-week intervention involving dietary modifications and yoga practices. Post-intervention reassessments were then conducted using the same parameters.

The research utilized RCT to explore the impact of a "Mediterranean diet" rich in probiotics and daily yoga practice on IR in females diagnosed with PCOS. The subjects were assigned into two groups: an experimental group adhering to the "Mediterranean diet" and engaging in daily Yoga for 1 hour, and a control group solely undertaking the yoga practice. Pre-post measurements were conducted at parallel timings to minimize the influence of circadian rhythm, with a minimum 48-hour rest period after the final treatment to mitigate the effects of fatigue. The test sequence and the participant lineup remained unchanged for the baseline and post-intervention assessments.

Sample Size

The study's minimum "sample size" 26 was determined using "G*power software, version 3.1.9.7". This was for a study involving two groups (study and control), two measurements (pre- and post-intervention), with α <.05, "a non-sphericity correction of 1, a correlation of 0.7 between repeated measures, and a desired power (1-ß error) of.80". "A medium effect size (f=0.25) was chosen for the repeated measures ANOVA due to the limited number of comparable studies focusing on the physical fitness variables of interest". To account for potential participant attrition, 65 individuals were contacted and evaluated based on specific eligibility criteria, including healthy adrenal, prolactin, cortisol, and thyroid function, average blood glucose levels, healthy liver function, and willingness to undergo a twelve-week diet and yoga intervention with biomarker assessments before and after the intervention.

Randomization

All female subjects were randomly assigned to the study or the control group in a 1:1 ratio using an online randomization tool (http://www.randomizer.org/). The study group (Group A) comprised 26 participants who followed a diet and practiced Yoga, while the control group (Group B) also comprised of 26 subjects who only trained Yoga. To ensure allocation concealment, an investigator with no clinical role generated random numbers to create systematically numbered index cards placed in sealed, blinded envelopes. The first author, who was responsible for administering the interventions, then used these envelopes to assign participants to their respective groups. Participants were unaware of their group assignments, and no withdrawals occurred after the randomization process (Figure 1).

Mediterranean Diet Rich in Probiotics

Each participant in group A, referred to as the study group, adhered to a 12-week Mediterranean diet abundant in probiotics. Initially, calculating the total daily calorie intake necessary to maintain each participant's body weight was undertaken utilizing the "Harris-Benedict Equation: total daily energy outlay (TDEE) = basal metabolic rate (BMR) x activity factor". The formula for "BMR is 447.593+(9.247 x weight in kg)+(3.098xheight in cm)–(4.330 x age) in years". As the study participants were characterized as sedentary with minimal or no exercise, an activity factor of 1.2 was assigned based on the Harris-Benedict Equation (Eckerson, 2018).

Subsequently, the dietary plan was developed to align with the macronutrient distribution of the Mediterranean diet, comprising 55–60% of caloric intake from carbohydrates (with simple sugars constituting less than 10%), 10–15% from protein, and 30–35% from fat MUFA and PUFA fats, by guidelines from the WHO (Shaheen et al., 2023).

Following this, the allocation of carbohydrate, fat, and protein servings across daily and weekly meals from diverse food groups, subgroups, and components was determined following the recommendations delineated in the US Department of Agriculture dietary guidelines for 2020-2025. An integral facet of this dietary regimen involved the consumption of seasonal, locally sourced, unprocessed, or minimally processed foods of natural provenance. The recommended food groups to be included in every meal encompassed vegetables, fresh fruit, extra virgin olive oil, bread, pasta, rice, and other cereals. The diet entailed the consumption of an assortment of fresh vegetables and fruits; utilization of "olive oil as the principal" (and nearly exclusive) source of dietary fat for seasoning and cooking; regular incorporation of nuts and seeds; periodic consumption of legumes; daily intake of whole grains; consumption of fish and seafood 2 to 3 times weekly; consumption of 2 to 4 eggs per week; and the consumption of yogurt, predominantly "Greek yogurt," recognized as a superior vehicle for delivering probiotic bacteria in comparison to traditional yogurt, as substantiated by the process employed (Comerford et al., 2023).

Yoga Therapy Protocol

The Yogo practice encompasses a series of elements, including warm-up exercises (Jathi(s)), characteristic body postures (Asana(s)), symbolic gestures (Mudra(s)), chanting of sacred sounds (Om japa), and breathing techniques (Pranayama). In order to enhance compliance, all participants

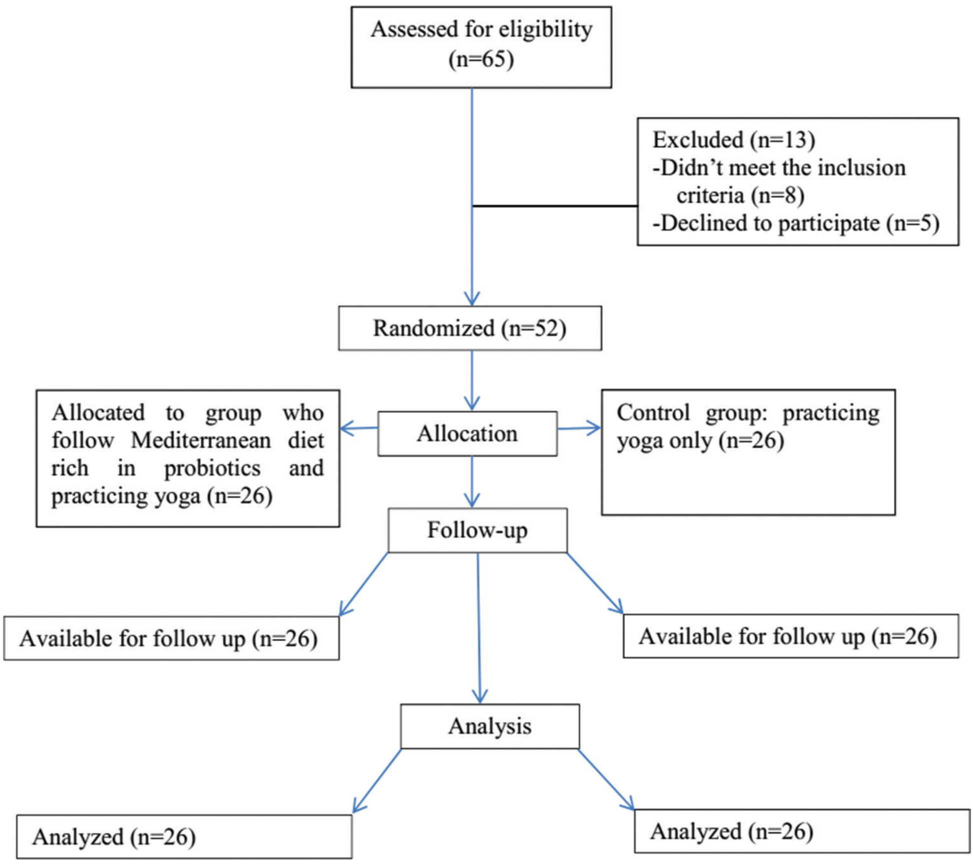

Figure 1. Study design flow diagram

received brief motivational messages on their mobile devices, encouraging them to adhere to the prescribed diet and engage in daily yoga practice. Both group A and group B participants were engaged in yoga therapy, which was initially taught in a graded manner. Participants were directed to dedicate one hour per day for 12 weeks to practicing Yoga at home to maintain consistency and rhythm. The "yoga-based intervention protocol" is delineated in Table 1, along with suggested benefits for each posture (Gowri et al., 2022).

Outcome Measures

The study assessed fasting blood glucose (FBG), insulin resistance, and serum insulin levels before and after a 12-week treatment. Measurements were taken after a 12-hour fast and analyzed at the Kafr ElSheikh University laboratory using commercial kits (Samimi et al., 2016). Secondary measures included weight, BMI, waist circumference, and hip circumference, as per the recommendations of Bertin et al. (2021) and Kałużna et al. (2021).

Statistical Analysis

After checking for all parametric test assumptions, MANOVA was used to examine the effects within and between groups on the measured variables. The effect size was ascertained using partial η^2 (partial eta squared) values, typically ranging from 0 to 1. "A small-effect-size is generally represented by 0.01, a medium-effect-size by approximately 0.06, and a large-effect-size by around 0.14". These values are crucial for comprehending the practical significance of the results in an analysis of variance (MANOVA) or similar statistical tests. SPSS version 25 was used to process the data with $p \leq 0.05$ as alpha value.

Table 1. Yoga therapy protocol

Yoga Therapy	Duration	Benefits
"Jathis (warm-up)"	5 min	It facilitates the loosening of the joints and readies the body for practicing *asanas* (the postures employed in Yoga).
"Standing-postures" "Palm-tree-posture) Talasana)" "Triangle-posture-Trikonasana" "Extended-side-angle-posture) Parsvakonasana)" "Hero-pose-Veerasana"	Total: 10' 20" each asana 3 sets	This exercise regimen is designed to stretch and tone all back and leg muscles while providing relief from upper and lower extremity stiffness. Moreover, it aids in reducing fat buildup around the waist and hip regions, thereby enhancing insulin sensitivity through the amelioration of insulin resistance.
"Sitting-postures" "Wind-relieving-pose: (Pavanamukthasana)"	Total 7'for all 10 sec/5 rounds	The product enhances digestive processes and facilitates the efficient elimination of waste. Additionally, it aids in reducing adipose tissue accumulation in the abdominal, waist, and hip regions, thereby contributing to the reshaping of the body's structural contours.
"Compact-pose-drawing everything"	10 sec/5 rounds	This posture generates beneficial tension and promotes increased blood flow to the pelvic region. "It is efficacious in addressing disorders of the intestines, pancreas, liver, gall bladder, and spleen while simultaneously stretching and toning the back, arm, and leg musculature."
"Half-spinal-twist pose: Vakrasana"	10" each side /five rounds	Regular practice of these asanas aids in diminishing fat buildup in the abdominal, waist, and hip regions, leading to a reshaped body structure and contributing to the battle against obesity. Moreover, these postures are conducive to enhancing insulin sensitivity.
"Half-Lord-of-the-Fishes-pose":	10" each side	It aids in the correction of structural deformities of the spine.
"Mudras (gestures) Topsy-turvy-gesture: Viparitakarani*"	30 ''/30 sec relaxation	"It facilitates healthy metabolic function by stimulating in insulin-sensitive body cells, such as adipose tissue, heart muscle, and skeletal muscle."
"Meditation-Primordial-chant-with gesture: Om 5 min japa with mudras"	Total: 12'	It induces relaxation in the body, mind, and emotions, facilitating complete healing by emitting therapeutic vibrations across all levels of existence.
"Dynamic-body –relaxation (Kaya)": "Part-by-part body relaxation technique: Marmanasthana kriya"	Six rounds 8'	"Mind-body-relaxation".
"Relaxation-Corpse posehavasana"	5' Total=60'	"Mind-body-relaxation".

Min=minutes

RESULTS

Demographic Profiles of Subjects

The data presented in Table 2 indicates that the unpaired t-test did not demonstrate a statistically significant difference in the mean values of age and height between the two groups (p =.230 and.733).

Results of Mixed Design MANOVA

In a mixed-design multivariate analysis, we investigated the differences in the scores on outcome measures between the two groups. Our study revealed significant effects for Groups (Wilks' λ =.75, F(1, 50) = 2.1, p =.001, partial η^2 =.25), Time (Wilks' λ =.30, F(1, 50) = 14.3, p =.001, partial η^2 =.70), as well as the interaction between Groups and Time (Wilks' λ =.60, F(1, 50) = 5.0, p =.001, partial η^2 =.44).

Impact of Treatments on Insulin Markers

Both groups showed a statistically significant decrease in HOMA-IR, serum insulin, and IR. The percentage of change was (22.7% versus 4.8%), (19.6% versus 6.8%) and (10.6% versus 5.9%), respectively. By comparing both groups post-treatment, there was a statistically significant decrease in HOMA-IR (p =.007), serum insulin (p =.012), and IR (p =.016) in favor of group A (Table 4).

Impact of Treatments on Anthropometric Measures

In the study, Group A showed significant decreases in weight, BMI, waist, and hip circumference, while Group B only showed a significant reduction in WC. The percentage of change was 5.4% versus 1.1% for weight, 7.2% versus 2% for waist circumference, 5.4% versus 0.9% for hip circumference, and 5.6% versus 1.3% for BMI. Comparing both groups post-treatment, there was a significant decrease in body weight (p = 0.025) and BMI (p=.009) in favor of Group A. However, there was no statistically significant difference in WC (p =.260 and p =.037, respectively) (Table 4).

Table 2. Demographic profiles of participants

Demographic data	Group A	Group B	t-value	p-value
Age (years)	24.8±2.3	25.6±2.2	-1.2	0.230
Height (cm)	163.7±3.7	163.3±5.1	0.3	0.733

SD: standard deviation

Table 3. Among groups, a 2 x 2 mixed MANOVA design for all dependent variables

Source	Wilks' λ	F	df1	df2	p-value	Partial η^2
Groups	0.75	2.1	1	50	0.001	0.25
Time	0.30	14.3	1	50	0.001	0.70
Interaction	0.60	5.0	1	50	0.001	0.44

Wilk's Λ: Wilk's Lambda of MANOVA, η^2: Partial eta square

DISCUSSION

This study aimed to investigate the impact of practicing yoga and consuming high-probiotic food supplements as part of the Mediterranean diet on insulin resistance (IR) in women with PCOS. The findings revealed that both groups experienced a significant reduction in the homeostatic model assessment of IR, serum insulin, and fasting blood glucose levels post-treatment compared to pre-treatment. Additionally, Group A showed a notable decrease in weight, WC, and BMI, whereas Group B only exhibited a reduction in WC. When comparing the two groups after the treatment, Group A demonstrated a significant decrease in weight, BMI, hip circumference, homeostatic model assessment of IR, serum insulin, and fasting blood glucose levels compared to Group B, with no significant difference in WC.

PCOS is a prevalent disorder affecting adolescent females, involving gynecological, endocrine, and metabolic aspects (Falcone & Hurd, 2020). Notably, around 50% of PCOS patients experience IR regardless of their weight status (Barber & Franks, 2021). IR, a metabolic irregularity in PCOS, leads to elevated insulin levels, resulting in hyper insulinemia, which exacerbates symptoms such as high androgen levels (hyperandrogenemia), irregular ovulation, and the formation of multiple ovarian cysts (polycystic ovaries) (Zhang et al., 2023). While some patients opt for dietary interventions due to fewer side effects than medication, sustaining these changes can be challenging for many (Falcone & Hurd, 2020). Research has shown that the "Mediterranean diet is strongly associated with lower insulin levels, reduced homeostatic model assessment of IR values, and improved insulin sensitivity". Moreover, using probiotics to manipulate gut microbiota can restore gut health and integrity (Vetrani et al., 2023). Consumption of prebiotics and probiotics has been linked to positive effects on glucose metabolism and insulin resistance (Bock et al., 2024). Additionally, a comprehensive analysis strongly supports the potential health benefits of probiotics/synbiotic supplementation in managing blood sugar levels (Pavlidou et al., 2024). Encouragingly, in a study, both groups experienced a significant decrease in homeostatic model assessment of IR, serum insulin, and fasting blood glucose levels following treatment compared to before. This underscores the potential of dietary interventions in effectively managing PCOS-related insulin resistance. The positive effect of Yoga on decreasing waist circumference in the control group could be explained as Yoga poses target core muscles, which help pull in the stomach and create a toned appearance (Bryan, 2024). These results agree with Littman et al. (2012), who observed a decrease in waist circumference without any weight loss within six months of home-based yoga intervention, suggesting that there may have been a gain in lean muscle mass and a loss of fat. Likewise, Cramer et al. (2016) reported that a twelve-week yoga program for women with abdominal obesity significantly reduced WC compared with an untreated control group.

Engaging in yoga can positively impact glycemic control using controlled breathing, meditation, and diverse body postures, ultimately leading to relaxation. This process helps

Table 4. Mean±SD of measured variables (pre-treatment and post-treatment in both groups)

Measured variables	Group-A Mean±SD	Group-B Mean±SD	Mean difference	f-value	p-value
Weight (kg)					
Pretest	77.7±14	82.5±13.8	-4.8	1.6	0.216
Posttest	73.5±11.4	81.6±13.6	-8.1	5.4	0.025*
% of change	5.4%	1.1%			
p-value	0.001*	0.082			
Waist circumference (cm)					
Pretest	93.1±12.5	91.9±11.1	1.2	0.14	0.705
Posttest	86.4±12.1	90.1±11.1	-2.7	1.3	0.260
% of change	7.2%	2%			
p-value	0.001*	0.037*			
Hip circumference (cm)					
Pretest	107.2±10.9	104.9±12.2	2.3	0.52	0.475
Posttest	101.4±9.2	104±11.4	-2.6	0.8	0.374
% of change	5.4%	0.9%			
p-value	0.001*	0.118			
BMI (kg/m2)					
Pretest	28.8±4.7	30.6±4.4	-1.8	2.1	0.145
Posttest	27.2±3.7	30.2±4.4	-3	7.3	0.009*
% of change	5.6%	1.3%			
p-value	0.001*	0.066			
HOMA-IR					
Pretest	2.2±0.4	2.1±0.4	0.1	0.69	0.410
Posttest	1.7±0.4	2±0.3	-0.3	7.9	0.007*
% of change	22.7%	4.8%			
p-value	0.001*	0.023*			
Insulin (IU/m					
Pretest	13.8±3.5	14.7±2.9	-0.9	1.1	0.297
Posttest	11.1±4.2	13.7±3	-2.6	6.8	0.012*
% of change	19.6%	6.8%			
p-value	0.001*	0.026*			
FBG (mg/dl)					
Pretest	86.8±8	88.5±6.4	-1.7	0.77	0.386
Posttest	77.6±7.7	83.3±8.9	-5.7	6.2	0.016*
% of change	10.6%	5.9%			
p-value	0.001*	0.001*			

SD: standard deviation, *: Significant

regulate cortisol and other stress hormones, reducing blood pressure and blood glucose levels (Bryan & Zipp, 2014). Moreover, oxidative stress is identified as a crucial component in metabolic syndrome, contributing to insulin resistance in peripheral tissues by influencing insulin receptor signal transduction, consequently leading to decreased expression of the GLUT4 transporter in cellular membranes (Verdile et al., 2015). The various interventions associated with yoga can directly contribute to the rejuvenation of pancreatic cells and reduction of oxidative stress, potentially leading to enhanced glucose utilization and improved metabolism in peripheral tissues, liver, and adipose tissues (Varne & Balaji, 2023). These findings have been linked to both groups' insulin resistance improvements and WC reductions.

The research by Sagana et al. (2024) aligns with the hypothesis that "yoga can enhance glucose tolerance, insulin sensitivity, lipid profiles, and blood pressure in diabetic individuals". Sahay (2007) also noted improved insulin sensitivity and decreased insulin resistance, indicating potential benefits for diabetes prevention. Furthermore, Shetty et al. (2017) found that a three-month yoga regimen significantly improved oxidative stress markers in both obese men and women. Similarly, Cowan et al. (2023) demonstrated that yoga was more effective than conventional physical exercises in enhancing glucose, lipid, and insulin levels, as well as reducing insulin resistance, in adolescent girls with PCOS, regardless of changes in body measurements. Conversely, our results contradict those of Elder et al. (2006), who observed no significant effect of yoga training on glucose levels. This discrepancy might be due to their participants having average glucose and insulin levels, with yoga-asana training not impacting relatively normal glucose balance (Kacker et al., 2019). Likewise, Matthews et al. (1985) did not report any changes in glucose control markers after eight weeks of yoga training in adolescents, suggesting the necessity for longer interventions. Given that extended yoga training has shown positive effects on insulin resistance in diabetic patients, our study implemented a twelve-week yoga program to address this gap. The Mediterranean diet, enriched with high-probiotic supplements, enhances anthropometric measures, HOMA-IR, serum insulin, and fasting blood glucose (FBG) through various mechanisms. Butyrate, a short-chain fatty acid (SCFA), acts as the main energy source for enterocytes, regulates cell differentiation and proliferation, and stimulates the production of glucagon-like peptide 2 (GLP-2). GLP-2 reduces intestinal permeability, boosts intestinal glucose transport, and decreases inflammation and oxidative damage (Shimizu et al., 2019). Additionally, SCFAs interact with G protein-coupled receptors to regulate energy metabolism and modify insulin sensitivity in adipocytes and peripheral organs (Di Vincenzo et al., 2024).

Probiotic intake may improve glycemia by reducing oxidative stress, which is prevalent in hyperglycemia (Ejtahed et al., 2011; Guasch-Ferré & Willett, 2021). Research supports that probiotics can significantly reduce BMI compared to a placebo (Kunnackal et al., 2018). However, a meta-analysis of seven randomized controlled trials (RCTs) found that "probiotic supplementation did not significantly impact anthropometric measurements in patients with PCOS, possibly due to the short duration of the intervention (Heshmati et al., 2019; Kadooka et al., 2013)". Probiotic supplementation has also shown promise in improving hormonal profiles, inflammatory markers, and lipid metabolism disturbances caused by PCOS (Calcaterra et al., 2023; Ahmadi et al., 2017). Furthermore, probiotic yogurt has been associated with a significant decrease in insulin concentrations and HOMA-IR, especially among healthy, obese women in a calorie-restricted program (Kadooka et al., 2013). Studies also indicate that probiotic yogurt and probiotic capsules can significantly improve glycemia among patients with T2DM (Ejtahed et al., 2011; Shoaei et al., 2015), with HOMA-IR levels significantly reduced in type 2 diabetes patients who received probiotic supplements (AkbariRad et al., 2023). Our findings contrast with those of Shoaei et al. (2015), who found that an 8-week multispecies probiotic supplementation in women with PCOS did not affect markers of insulin resistance (IR). Similarly, Moravejolahkami et al. (2023) reported that the combined effect of probiotics (or synbiotics) on fasting blood glucose (FBG) was not significant. Additionally, Hajipoor et al. (2022) and Zhang et al. (2023) observed that 8-week and 9-week multispecies probiotic supplementation in women with PCOS did not influence IR markers. The differences between our study and these studies could be due to variations in the dosage of probiotic supplements, the dietary intake during the intervention, and the purity and bioavailability of the supplements.

Strengths and Practical Implications

The study's strengths include its use of a randomized controlled design and a carefully determined sample size, enhancing the findings' reliability and validity. Additionally, combining dietary intervention and physical activity provides a comprehensive approach to managing PCOS and insulin resistance. The findings of this study suggest that integrating high-probiotic supplements into a Mediterranean diet, along with regular yoga practice, can significantly improve IR and other health variables in females with PCOS. This holistic approach can be recommended as a non-pharmacological strategy for managing PCOS, potentially reducing the need for medication and its associated side effects. Healthcare providers can consider incorporating these lifestyle modifications into treatment plans for women with PCOS.

Limitations of the Study

The lack of long-term patient follow-up means that the sustainability of the observed benefits over time is uncertain. Additionally, the study did not thoroughly examine the effects of reducing insulin resistance on the hypothalamus-pituitary-ovarian axis in the subjects under review. Future research should encompass longer follow-up periods and investigate the broader endocrine effects of the interventions.

CONCLUSION

Finally, it can be concluded that adding high-probiotic supplements to food and Yoga for 12 weeks is much better than Yoga without any dietary modification in improving serum insulin, HOMA-IR, FBG, weight, waist, and hip circumference, as well as BMI, in women with PCOS.

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AUTHOR CONTRIBUTIONS

MME, DMK, and REH: "study concept and design, data collection, article drafting, and critical revision". AS and AMB: "data analysis and interpretation and final approval of the version to be published". "All authors read and approved the final version of the manuscript".

DATA AVAILABILITY

The datasets utilized and examined during the present study are accessible from the corresponding author upon reasonable request.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study received approval from the institutional review board at the Faculty of Physical Therapy, Cairo University, under reference number (No. P.T.REC/012/003884).

SUPPORTING AGENCIES

This study received no financial support.

DISCLOSURE STATEMENT

No potential conflicts of interest reported.

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