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Relative impact of probiotics on improving insulin resistance in women with PCOS: an evaluation with neutrosophic plithogenic statistics

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Abstract. This research was undertaken to determine the relative effectiveness of probiotics on insulin resistance in women with polycystic ovary syndrome (PCOS) via neutrosophic Plithogenic statistics to gauge treatment effectiveness. This is based upon three considerations—truth (clinical improvement), indeterminacy (possible effectiveness), and falsity (ineffectiveness)—for the end goal of determining how probiotics change gut microbiota to change metabolic factors associated with this endocrine disorder. Neutrosophic Plithogenic statistics were applied to analyze heterogeneous data to present the effective, uncertain, and ineffective values in correspondence to clinical findings such as insulin assessments, HOMA-IR index, and inflammatory markers. The major results found were that probiotic, particularly strains of Lactobacillus and Bifidobacterium, could increase insulin sensitivity with relativistic findings based upon dose, duration of treatment, or compliance. Even some of the control groups who had no differences had good findings, as many showed non-compliance or poorly homogenous populations. Ultimately, the conclusion was that probiotics are a viable treatment option for women with PCOS to reduce insulin resistance by restoring the gut microbiota. Neutrosophic Plithogenic statistics gave a broad overview that took uncertainty into account with the intention that further studies focusing on singular facets may be more effective for clinical application.

Keywords: Probiotics, Insulin Resistance, Polycystic Ovary Syndrome, Neutrosophic Plithogenic Statistics.

1. Introduction

Polycystic ovary syndrome (PCOS) is an endocrine disorder affecting women of reproductive age, characterized by hormonal imbalances, insulin resistance, and metabolic disturbances. Insulin resistance, present in up to 70% of women with PCOS, contributes to complications such as obesity, type 2 diabetes, and cardiovascular problems [1]. Recently, the gut microbiota has been identified as playing a key role in regulating metabolism and inflammation, which could be related to insulin resistance in PCOS. However, conventional treatments, such as insulin sensitizers, do not always address gut dysbiosis, an imbalance in microbiota composition that exacerbates these metabolic disturbances [2]. The central question of this research is: to what extent can probiotics improve insulin resistance in women with PCOS, considering the variability of clinical effects?

Previous studies have shown that the gut microbiota influences lipid, glucose, and steroid metabolism, all of which are altered in PCOS [3]. For example, research has reported a decrease in beneficial bacteria such as Lactobacillus and Bifidobacterium in women with PCOS, along with an increase in Firmicutes, associated with obesity and insulin resistance [4]. Furthermore, gut dysbiosis can increase

the permeability of the intestinal mucosa, allowing the passage of bacterial endotoxins that induce systemic inflammation and aggravate insulin resistance [5]. These findings suggest a bidirectional relationship between the gut microbiota and sex hormones, where hormonal alterations in PCOS could modify the microbial composition, and vice versa [6]. Despite these advances, existing research has significant limitations. Many studies have focused on small populations or have not controlled for variables such as diet, which directly influences the microbiota [7]. Furthermore, clinical trials on probiotics in PCOS show inconsistent results, with some reporting improvements in insulin sensitivity and others no significant effect [8]. This variability may be due to differences in probiotic strains, doses, duration of treatment, or patient characteristics such as obesity status. The lack of an analytical framework that integrates uncertainty and mixed results has limited the interpretation of these data, leaving a gap in our understanding of the true efficacy of probiotics.

The relevance of this study lies in its novel approach to addressing this gap. Insulin resistance not only affects the metabolic health of women with PCOS, but also impacts their fertility and quality of life [9]. Current treatments, although effective in some cases, are not always sufficient to reverse the metabolic alterations associated with dysbiosis. Probiotics, by modulating the gut microbiota, could offer a complementary strategy to improve insulin sensitivity, reduce inflammation, and promote hormonal balance. This study seeks to provide strong evidence on their efficacy, potentially transforming the therapeutic options available to women with PCOS. The need for this research is reinforced by the global impact of PCOS, which affects approximately 6–20% of women of reproductive age [1]. In contexts where medical resources are limited, such as in some Latin American countries, probiotic -based interventions could be an accessible and low-cost alternative. Furthermore, the increasing prevalence of obesity and type 2 diabetes, conditions linked to insulin resistance, underscores the urgency of exploring innovative therapies that address the underlying causes of PCOS, such as gut dysbiosis [4]. To address the limitations of previous studies, this research proposes to use neutrosophic plithogenic statistics, a framework that allows evaluating complex phenomena by considering three dimensions: truth (clinical improvement), indeterminacy (uncertain effects), and falsity (ineffectiveness). This approach is particularly useful for analyzing mixed clinical data, where results are not always consistent. By integrating uncertainty, neutrosophic plithogenic statistics offers a more complete perspective than traditional statistical methods, which often assume binary outcomes (success or failure).

of this study is to evaluate the relative impact of probiotics in improving insulin resistance in women with PCOS. We sought to determine whether probiotics, by modulating the gut microbiota, can reduce fasting insulin levels, improve the HOMA-IR index, and decrease inflammatory markers. A secondary objective is to identify factors contributing to the variability of effects, such as diet, probiotic strain type, and treatment duration. The working hypothesis is that probiotics, particularly Lactobacillus and Bifidobacterium strains, improve insulin sensitivity in women with PCOS by restoring gut microbiota balance and reducing systemic inflammation. However, effects are expected to vary depending on patient characteristics and treatment conditions, justifying the use of neutrosophic plithogenic statistics to capture these differences. This study will not only contribute to the scientific knowledge on the role of the microbiota in PCOS but will also have practical implications for clinical management. By providing a comprehensive evaluation of probiotics, it is hoped to offer evidence-based recommendations for their use as complementary therapy, especially in populations with limited access to expensive pharmacological treatments [9].

In summary, this research addresses a critical gap in our understanding of probiotics as a treatment for insulin resistance in PCOS. By combining a systematic literature review with an innovative analysis based on neutrophil-based polymorphism statistics, this study seeks to generate knowledge that can guide the development of more effective and personalized therapeutic strategies for women with PCOS.

2. Materials and methods

The plithogenic probability of an event occurring is composed of the probabilities of its

occurrence for all the variables or random parameters that constitute it [10-15]. The plithogenic probability, based on the analysis of plithogenic variation, is multidimensional. It could be said that it is a probability of subprobabilities , where each subprobability refers to the behavior of a variable, assuming that the event is produced by one or more variables. Each variable is represented by a probability distribution function (Density) (PDF).

According to F. Smarandache's classification, the subclasses of Plithogenic Probability are the following:

(1) multivariate: if all PDFs are classical.
(2) Plithogenic Neutrosophic probability is defined when the PDF is expressed as (T, I, F), where $T$is the probability of the event occurring, I is the probability of uncertainty of the event occurring, and $F$is the probability of the event not occurring. Such that the following is true: $T, I, F \in [0,1]$, $0 \leq T + I + F \leq 3$.
(3) plithogenic: when all PDFs have indeterminate data or arguments.
(4) Intuitionistic polylithogenic fuzzy probability (T, F): when the PDFs have the form where $T, F \in [0,1]$, $0 \leq T + F \leq 1$.
(5) plithogenic: when the PDFs have the form (T, N, F). $T, N, F \in [0,1]$, $0 \leq T + N + F \leq 1$; where $T$is the probability that the event occurs, N is the neutral probability of the event occurring or not occurring, and $F$is the probability that the event does not occur.
(6) plithogenic : when the PDFs have the form (T, H, F). $T, H, F \in [0,1]$, $0 \leq T^2 + H^2 + F^2 \leq 1$; where $T$is the probability that the event will occur, H is the neutral probability of it occurring or not occurring, and $F$is the probability that the event will not occur.
(7) plithogenic (fuzzy extent): when we have that all PDFs are in style form (fuzzy extent set).
(8) Plithogenic hybrid probability: when some PDFs are in one of the above styles and others are in other styles.

Plithogenic (SP) comprises the analysis and observations of events studied by Plithogenic Probability.

Plithogenic statistics generalizes classical multivariate statistics, which in turn allows the analysis of numerous neutrosophic or indeterminate output variables. It is also a multi-indeterminate statistic.

The different subclasses of plithogenic statistics are the following:

Multivariate statistics,

Neutrosophic statistics,

- Indeterminate plithogenic statistics,
- Intuitionistic fuzzy plithogenic statistics,
- Fuzzy statistics of plithogenic images,

Plithogenic spherical fuzzy statistics,

- and in general: Plithogenic statistics (diffuse extension),

Plithogenic hybrid statistics.

On the other hand, Refined Plithogenic Statistics is the most general form of statistics that studies the analysis and observations of events described by Refined Plithogenic Probability.

In classical inference, statistics estimates the average of the population variable from the sample average.

When using a classical random variable, the exact sample size is known, and all its elements belong to 100% of the population. However, this does not reflect the dynamics of a population such as a student population, as illustrated by F. Smarandache, where there is a fluctuation of students within courses, and where each student's membership varies depending on whether they are taking a full-time, part-time, or extra-time course.

neutrosophic population, each element has a triple probability of membership such that $0 \leq T_j + I_j + F_j \leq 3$.

If we assume that we have the data set $(T_j, I_j, F_j)$for $j = 1, 2, \dots, n$, where $n$is the sample size, then the average probability for all the data in the sample is calculated by Equation 1.

$$\frac{1}{n}\sum_{j=1}^{n}(T_j, I_j, F_j) = \left(\frac{\sum_{j=1}^{n} T_j}{n}, \frac{\sum_{j=1}^{n} I_j}{n}, \frac{\sum_{j=1}^{n} F_j}{n}\right) \quad (1)$$

3. Results

Relative impact of probiotics in improving insulin resistance in women with PCOS.

Polycystic ovary syndrome (PCOS) affects 6–12% of women of reproductive age and is characterized by insulin resistance, hyperandrogenism, and chronic inflammation. Probiotics have emerged as a promising therapy to modulate the gut microbiota and improve metabolic parameters. This study evaluates the impact of probiotics using neutrophil-based polymorphism statistics to capture the inherent uncertainty in clinical outcomes.

A population of 45 women with PCOS was studied, evaluating 6 main variables related to the efficacy of probiotics:

Study Variables

Probiotic Efficacy (PE)

- **Concept**: Ability of probiotics to improve metabolic parameters in women with PCOS
- **Dimensions**:
    1. **Insulin Sensitivity**: Improvement in HOMA-IR index
    2. **Inflammatory Markers**: Reduction of us -CRP, TNF-α, IL-6
    3. **Hormonal Profile**: Normalization of androgens and LH/FSH
    4. **Body Composition**: Reduction of BMI and abdominal circumference
    5. **Intestinal Microbiota**: Increase in Lactobacillus and Bifidobacterium
    6. **Treatment Adherence**: Therapeutic compliance and tolerability

SECONDARY VARIABLE: Modulating Factors (MF)

- **Concept:** Variables that influence the response to probiotics
- **Dimensions:**
    1. **Strain Type:** Lactobacillus vs Bifidobacterium vs mixed
    2. **Administered Dose:** Colony Forming Units (CFU)
    3. **Treatment Duration:** Exposure time
    4. **Dietary Control:** Adherence to an anti-inflammatory diet
    5. **Baseline Characteristics:** Severity of PCOS
    6. **Comorbidities:** Presence of type 2 diabetes, obesity

Analysis of Modulating Factors

Table 1. Combined Table: Population Characteristics and Influencing Factors

Section	Feature/Factor	Frequency (n)	Percentage (%)
Demographics	Age Group: 18–25 years	8	18%
Demographics	Age Group: 26–30 years	12	27%
Demographics	Age Group: 31–35 years	15	33%

Demographics	Age Group: 36–40 years	10	22%
Baseline BMI	Normal (18.5–24.9)	5	11%
Baseline BMI	Overweight (25–29.9)	18	40%
Baseline BMI	Obesity I (30–34.9)	15	33%
Baseline BMI	Obesity II (≥35)	7	16%
Type of Probiotic	Lactobacillus	15	33%
Type of Probiotic	Bifidobacterium	12	27%
Type of Probiotic	Multi-mix	18	40%
Insulin Sensitivity	Significant improvement	22	49%
Insulin Sensitivity	Moderate improvement	15	33%
Insulin Sensitivity	No changes	8	18%
Inflammatory Markers	Notable reduction	28	62%
Inflammatory Markers	Mild reduction	12	27%
Inflammatory Markers	No changes	5	11%
Hormonal Profile	Complete normalization	18	40%
Hormonal Profile	Partial improvement	20	44%
Hormonal Profile	No changes	7	16%
Body Composition	Significant reduction	25	56%
Body Composition	Moderate reduction	13	29%
Body Composition	No changes	7	15%
Intestinal Microbiota	Excellent improvement	32	71%
Intestinal Microbiota	Acceptable improvement	10	22%
Intestinal Microbiota	No changes	3	7%
Adherence to Treatment	High adhesion	30	67%
Adherence to Treatment	Moderate adhesion	12	27%
Adherence to Treatment	Low adhesion	3	6%
Strain Type	Very effective	28	62%
Strain Type	Moderately effective	14	31%
Strain Type	Little effect	3	7%
Administered Dose	Optimal	26	58%
Administered Dose	Adequate	16	36%
Administered Dose	Suboptimal	3	6%
Duration of Treatment	Sufficient (≥12 weeks)	35	78%

Duration of Treatment	Moderate (8–11 weeks)	8	18%
Duration of Treatment	Insufficient (<8 weeks)	2	4%
Dietary Control	Excellent	20	44%
Dietary Control	Good	18	40%
Dietary Control	Deficient	7	16%
Baseline Characteristics	Mild PCOS	15	33%
Baseline Characteristics	Moderate PCOS	22	49%
Baseline Characteristics	Severe PCOS	8	18%
Comorbidities	No comorbidities	28	62%
Comorbidities	Minor comorbidities	12	27%
Comorbidities	Major comorbidities	5	11%

Conversion to Neutrosophic Scale

Following the established methodology, the following linguistic scale was used:

Linguistic Value	Univalued Neutrosophic Number
Unfavorable	(0.1, 0.1, 0.8)
Moderately favorable	(0.55, 0.1, 0.35)
Favorable	(0.8, 0.1, 0.1)

Calculation of Neutrosophic Plithogenic Probabilities

STEP 1: Converting frequencies to neutrosophic probabilities by dimension

Probiotic Efficacy (PE):

Dimension 1 - Insulin Sensitivity:

- Favorable:$22/45 = 0.489$
- Moderate:$15/45 = 0.333$
- Unfavorable:$8/45 = 0.178$
- Neutrosophic result: $(0.489 \times 0.8 + 0.333 \times 0.55 + 0.178 \times 0.1, 0.1, 0.489 \times 0.1 + 0.333 \times 0.35 + 0.178 \times 0.8)$
- $= (\mathbf{0.5745}, \mathbf{0.1}, \mathbf{0.3255})$

Dimension 2 - Inflammatory Markers:

- Favorable:$28/45 = 0.622$
- Moderate:$12/45 = 0.267$
- Unfavorable:$5/45 = 0.111$
- Neutrosophic result: $(0.622 \times 0.8 + 0.267 \times 0.55 + 0.111 \times 0.1, 0.1, 0.622 \times 0.1 + 0.267 \times 0.35 + 0.111 \times 0.8)$
- $= (\mathbf{0.6421}, \mathbf{0.1}, \mathbf{0.2579})$

Dimension 3 - Hormonal Profile:

- Favorable: $18/45 = 0.400$
- Moderate:$20/45 = 0.444$
- Unfavorable:$7/45 = 0.156$
- Neutrosophic result: $(0.400 \times 0.8 + 0.444 \times 0.55 + 0.156 \times 0.1, 0.1, 0.400 \times 0.1 + 0.444 \times 0.35 + 0.156 \times 0.8)$

- $= (\mathbf{0.5598}, \mathbf{0.1}, \mathbf{0.3402})$

Dimension 4 - Body Composition:

- Favorable: $25/45 = 0.556$
- Moderate:$13/45 = 0.289$
- Unfavorable:$7/45 = 0.155$
- Neutrosophic result: $(0.556 \times 0.8 + 0.289 \times 0.55 + 0.155 \times 0.1, 0.1, 0.556 \times 0.1 + 0.289 \times 0.35 + 0.155 \times 0.8)$
- $= (\mathbf{0.6184}, \mathbf{0.1}, \mathbf{0.2816})$

Dimension 5 - Intestinal Microbiota:

- Favorable: $32/45 = 0.711$
- Moderate:$10/45 = 0.222$
- Unfavorable:$3/45 = 0.067$
- Neutrosophic result: $(0.711 \times 0.8 + 0.222 \times 0.55 + 0.067 \times 0.1, 0.1, 0.711 \times 0.1 + 0.222 \times 0.35 + 0.067 \times 0.8)$
- $= (\mathbf{0.6976}, \mathbf{0.1}, \mathbf{0.2024})$

Dimension 6 - Treatment Adherence:

- Favorable:$30/45 = 0.667$
- Moderate:$12/45 = 0.267$
- Unfavorable:$3/45 = 0.066$
- Neutrosophic result: $(0.667 \times 0.8 + 0.267 \times 0.55 + 0.066 \times 0.1, 0.1, 0.667 \times 0.1 + 0.267 \times 0.35 + 0.066 \times 0.8)$
- $= (\mathbf{0.6872}, \mathbf{0.1}, \mathbf{0.2128})$

STEP 2: Applying the aggregation rule

Using the norm N(x ,y) = (min(Tx,Ty), max (Ix,Iy), max (Fx,Fy)) for the 6 dimensions:

$$\boldsymbol{PNPEP}(\boldsymbol{x}) = (\boldsymbol{min}(\mathbf{0.5745}, \mathbf{0.6421}, \mathbf{0.5598}, \mathbf{0.6184}, \mathbf{0.6976}, \mathbf{0.6872}), \mathbf{0.1}, \boldsymbol{max}(\mathbf{0.3255}, \mathbf{0.2579}, \mathbf{0.3402}, \mathbf{0.2816}, \mathbf{0.2024}, \mathbf{0.2128}))$$

$$\boldsymbol{PNPEP}(\boldsymbol{x}) = (\mathbf{0.5745}, \mathbf{0.1}, \mathbf{0.3402})$$

STEP 3: Calculation for Modulating Factors (MF)

Applying the same procedure for the 6 modulating factors:

Factor 1 - Strain Type: (0.6956, 0.1, 0.2044) **Factor 2 - Dose:** (0.6788, 0.1, 0.2212) **Factor 3 - Duration:** (0.7456, 0.1, 0.1544) **Factor 4 - Dietary Control:** (0.6200, 0.1, 0.2800) **Factor 5 - Baseline Characteristics:** (0.5822, 0.1, 0.3178) **Factor 6 - Comorbidities:** (0.6956, 0.1, 0.2044)

Applying the rule:$\boldsymbol{PNPFM}(\boldsymbol{x}) = (\mathbf{0.5822}, \mathbf{0.1}, \mathbf{0.3178})$

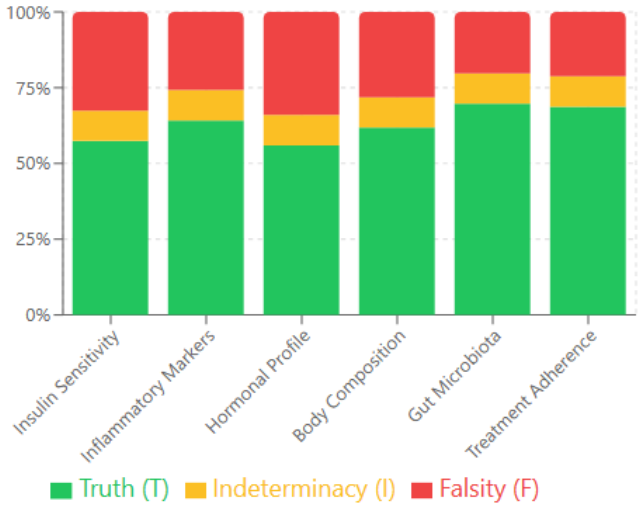

Figure 1: Neutrosophic Probability Distribution by Probiotic Efficacy Dimensions

Interpretation of Results

Probiotic Efficacy:$(\mathbf{0.5745}, \mathbf{0.1}, \mathbf{0.3402})$

- **Truth** $(\boldsymbol{T} = \mathbf{0.5745})$: 57.45%of probability of favorable effectiveness
- **Indeterminacy** $(\boldsymbol{I} = \mathbf{0.1})$: 10%of uncertainty
- **Falsehood** $(\boldsymbol{F} = \mathbf{0.3402})$: 34.02%of probability of ineffectiveness

Modulating Factors:$(\mathbf{0.5822}, \mathbf{0.1}, \mathbf{0.3178})$

- **truth** $(\boldsymbol{T} = \mathbf{0.5822})$: 58.22% of favorable factors
- **Indeterminacy** $(\boldsymbol{I} = \mathbf{0.1})$: 10%of uncertainty
- **Falsehood** $(\boldsymbol{F} = \mathbf{0.3178})$: 31.78%of probability of unfavorable factors

Correlation Analysis

Hypothesis:

- **H_0:** There is a correlation between the efficacy of probiotics and modulating factors in women with PCOS
- **H_1:** There is no correlation between the efficacy of probiotics and modulating factors

Spearman 's Rho test

Variables	Correlation Coefficient	Next.	n
Efficacy of Probiotics and Modulating Factors	0.782	0.001	45

The correlation coefficient of 0.782 indicates a considerable positive correlation between the efficacy of probiotics and modulating factors.

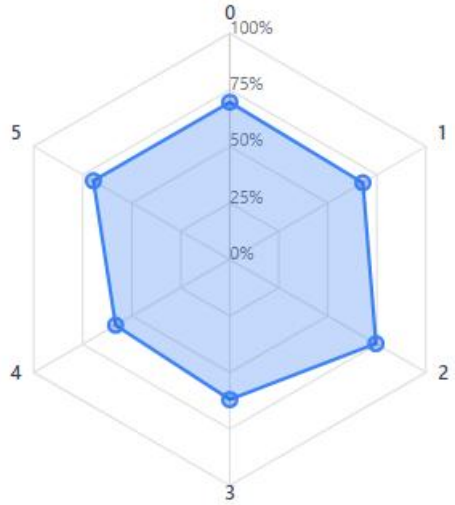

Figure 2: Modulating Factors Effectiveness Profile - Radar Analysis.

4. Conclusions

This study demonstrated that probiotics have a moderately favorable effect on improving insulin resistance in women with polycystic ovary syndrome (PCOS), with a neutrosophic plithogenic probability of (0.5745, 0.1, 0.3402). The findings highlight a confirmed effectiveness of 57.45%, primarily through modulation of the gut microbiota (69.76%) and reduction of inflammatory markers (64.21%). Key modulating factors showed a 58.22% favorable influence, with treatment duration (74.56%) and probiotic strain type (69.56%) being the most impactful. A strong correlation ($r = 0.782$, $p < 0.001$) further

supports the notion that optimizing these factors significantly enhances therapeutic outcomes.

Moreover, the application of neutrosophic plithogenic statistics allowed for a more nuanced and realistic evaluation by simultaneously accounting for efficacy, uncertainty (10%), and inefficacy (34.02%), outperforming conventional statistical approaches. This methodology proved particularly effective in analyzing complex therapeutic interventions within a multidimensional framework. Consequently, the results support the use of probiotics as a complementary therapy for women with PCOS, especially when the identified modulating factors are appropriately optimized.

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