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Original Article

Pharmacology Section

Efficacy of *Bacillus Coagulans* Supplementation on Metabolic Parameters and Inflammation in Prediabetic Obese South Indian Adults: A Double-blinded, Placebo-controlled, Randomised Clinical Trial

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ABSTRACT

Introduction: Prediabetes and obesity are major public health concerns contributing to the growing global burden of Type 2 Diabetes Mellitus (T2DM) and cardiometabolic disorders. Metabolic inflammation and gut microbiota dysbiosis are key mechanisms linking these conditions, highlighting the potential therapeutic role of probiotics. While probiotic supplementation has been studied for glycaemic control and metabolic inflammation, data on its efficacy in prediabetic obese populations, particularly in the Indian context, remain limited.

Aim: To evaluate the effect of *Bacillus coagulans* supplementation on glycaemic parameters and metabolic inflammation in prediabetic obese patients compared to placebo.

Materials and Methods: This was a prospective, double-blinded, placebo-controlled, randomised clinical trial conducted at the General Medicine and Diabetology Outpatient Department of SRM Medical College Hospital and Research Centre (SRM MCH&RC), Kattankulathur, Chengalpattu District, Tamil Nadu, India, a tertiary care hospital in South India the period of 10 months (July 2024 to April 2025). A total of 72 prediabetic obese individuals aged 18-65 years were randomly assigned to two groups: Group-I (n=36, 50%) received *Bacillus coagulans*, commercially available as Lactic Acid Bacillus (120 million spores) once daily for 12 weeks, while Group-II (n=36, 50%) received an identical placebo. Glycaemic parameters Glycated haemoglobin (HbA1c), Fasting Plasma Glucose (FPG), Postprandial Blood Glucose (PPBG), insulin resistance markers {Triglyceride-Glucose (TyG) index, TG/High-Density Lipoprotein Cholesterol (HDL-C) ratio}, anthropometric measures {Body Mass Index (BMI)}, metabolic inflammation markers, Tumour Necrosis Factor-alpha (TNF-α) and oxidative stress marker, Malondialdehyde (MDA) were measured at baseline and after 12 weeks. Data were analysed using IBM Statistical Package for the Social Sciences (SPSS) Statistics version 29.0.

Results: A significant reduction in FPG ($p<0.05$) and HbA1c ($p<0.05$) was observed in the probiotic group n=36 (50%) compared to the placebo group n=36 (50%). TNF-α levels significantly decreased ($p<0.05$) in Group-I, suggesting reduced metabolic inflammation. The TyG index showed a significant reduction, suggesting improved insulin sensitivity, while TG/HDL-C ratio remained unchanged. Among lipid parameters, total cholesterol and Low-Density Lipoprotein Cholesterol (LDL-C) showed significant reductions. No significant changes were observed in oxidative stress markers (MDA levels). The probiotic supplementation was well-tolerated, with only minor gastrointestinal symptoms reported.

Conclusion: Probiotic supplementation with *Bacillus coagulans* significantly improved glycaemic control, reduced metabolic inflammation and enhanced lipid metabolism in prediabetic obese individuals. Favourable effects were also observed in insulin resistance (TyG index), while oxidative stress markers were unchanged. While probiotics offer a promising adjunctive approach, integrating them with lifestyle and dietary modifications is crucial for optimal metabolic health. Further long-term studies with diverse probiotic strains and extended follow-up periods are recommended to validate these findings.

Keywords: Glycaemic control, Insulin resistance, Metabolic inflammation, Obesity, Prediabetes, Probiotics

INTRODUCTION

Prediabetes and obesity have emerged as major public health challenges worldwide, often coexisting and significantly increasing the risk of developing T2DM and associated cardiometabolic disorders. Their rising prevalence is largely attributed to urbanisation, sedentary lifestyles and dietary transitions [1]. Current estimates suggest nearly one-third of adults exhibit early signs of impaired glucose regulation, highlighting the urgent need for early identification and intervention [2].

Prediabetes is an intermediate state of dysglycaemia characterised by elevated blood glucose levels below the diagnostic threshold for T2DM [3]. In India, the prevalence of prediabetes demonstrates considerable variability, affecting approximately 5.57% of the general population according to recent meta-analyses, with certain demographic subgroups reporting prevalence rates as high as 15.3% [4,5]. Urban populations are disproportionately affected due to lifestyle-related risk factors; prevalence among lower socioeconomic groups is reported to be around 6.06%, compared to 4.93-5.48% in higher-income segments. The American Diabetes Association (ADA) 2024 defines prediabetes as FPG-100-125 mg/dL, 2-hour plasma glucose during an Oral Glucose Tolerance Test (OGTT) between 140-199 mg/dL, or Glycated Haemoglobin (HbA1c) 5.7-6.4% [6,7].

Obesity, defined by the World Health Organisation (WHO) as a Body Mass Index (BMI) $\geq$30 kg/m^2, results from a complex interplay of genetic predisposition, behavioural patterns and environmental factors [8,9]. Globally, obesity rates have tripled since 1975 and by 2025, projections estimate it will affect 18% of men and over 21% of women [10]. Recent Indian data reveal that 28.6% of the population meets BMI criteria for obesity, while 39.5% exhibit

central adiposity patterns [4]. The coexistence of prediabetes and obesity synergistically heightens the risk of insulin resistance and cardiometabolic risk, underscoring the need for early detection [11]. Central to their pathogenesis is insulin resistance, characterised by diminished biological responsiveness to insulin in peripheral tissues, commonly associated with chronic low-grade inflammation in obese individuals [12,13].

This inflammatory response, termed metabolic inflammation or meta-inflammation, originates largely from visceral adipose tissue and is characterised by elevated levels of proinflammatory cytokines including TNF-α and Interleukin-6 (IL-6). These inflammatory mediators disrupt insulin signalling pathways and impair glucose homeostasis [14]. The chronic inflammatory state also promotes oxidative stress imbalance, as evidenced by elevated levels of MDA, a validated biomarker of lipid peroxidation and Reactive Oxygen Species (ROS) production [15,16].

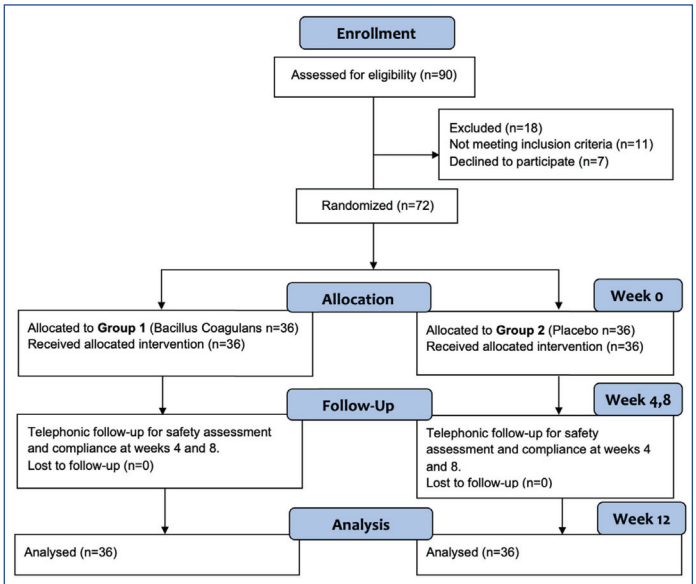
Bacillus coagulans, commercially available as lactic acid bacillus was selected for the present study due to its spore-forming nature, which enhances stability during storage and enables survival through gastric acidity and bile, ensuring high viability in the intestine [17]. A recent network meta-analysis ranked B. coagulans among the most effective probiotic strains for improving glycaemic control in type 2 diabetes [18], while clinical trials have demonstrated significant reductions in fasting insulin, Homeostatic Model Assessment for Insulin Resistance (HOMA-IR) and inflammatory markers with B. coagulans-containing formulations [19]. The widespread availability, affordability and established safety profile of this strain in India made it a pragmatic choice for this population.

Recent advances in metabolic research have identified the gut microbiome as a key player in metabolic health. Dysbiosis, an imbalance in gut microbial composition, is frequently observed in obese and prediabetic individuals and is associated with increased gut permeability. This enhanced permeability facilitates the systemic translocation of bacterial endotoxins such as Lipopolysaccharides (LPS), which further propagate chronic inflammation and insulin resistance [20,21]. Emerging evidence suggests that probiotic supplementation may beneficially modulate gut microbiota composition, reduce inflammatory cytokine levels and improve glycaemic parameters [22].

While multiple studies from Western populations have explored the therapeutic potential of probiotics in metabolic disorders, data from Indian populations, particularly South Indian cohorts, remain limited. Given the ethnic, dietary and microbiome differences between populations, contextualised studies are essential to establish therapeutic efficacy and safety profiles. The present study was conducted to evaluate the effects of probiotic supplementation on inflammatory markers and metabolic parameters in South Indian individuals with coexistent prediabetes and obesity. The present study assessed quality of life using the SF-36 questionnaire as a secondary outcome; those findings will be reported separately.

MATERIALS AND METHODS

The present study was a prospective, interventional, double-blinded, placebo-controlled, randomised clinical trial, in which participants and investigators were blinded to treatment allocation. It was conducted from July 2024 to April 2025, over a period of 10 months, in the General Medicine and Diabetology Outpatient Department of SRM Medical College Hospital and Research Centre (SRM MCH&RC), Kattankulathur, Chengalpattu District, Tamil Nadu, India. Approval was obtained from the Institutional Ethics Committee (Approval No. SRMIEC-ST1123-808) and the trial was registered with the Clinical Trials Registry of India (CTRI/2024/07/071576). The study complied with International Council for Harmonisation - Good Clinical Practice (ICH-GCP), Indian Council of Medical Research (ICMR) guidelines and followed Consolidated Standards of Reporting Trials (CONSORT) reporting standards [Table/Fig-1]. Adequate institutional resources and facilities were available for conducting the study. The authors declare no conflict of interest. The study was self-funded.



[Table/Fig-1]: CONSORT flow diagram depicting the study participants.

Sample size calculation: The sample size was calculated using FPG as the primary outcome. Baseline FPG standard deviations were obtained from a previous randomised controlled trial of probiotic supplementation in adults with prediabetes [23], reported in mmol/L (1.5 in the probiotic group, 0.95 in the placebo group) and converted to mg/dL (×18.02) as 27.0 and 17.1, respectively. Assuming 95% confidence level (α=0.05) and 80% power, the standard formula for two independent means gave a minimum of 30 participants per group. Allowing for 20% attrition, the final sample size was 36 participants per group, resulting in a total of 72 participants.

Inclusion criteria: Males or females aged 18-65 years diagnosed with prediabetes (FPG 100-125 mg/dL, PPBG 140-199 mg/dL and/or HbA1c 5.7-6.4%) based on ADA 2024 criteria [7] and obesity defined by BMI ≥30 kg/m² based on WHO criteria [8] were included. Patients with or without comorbid hypertension or dyslipidaemia were also eligible for enrolment.

Exclusion criteria: Patients with a history of gastrointestinal malabsorption or chronic diarrhoea, antibiotic use or intestinal infection within the past three months, current pharmacological treatment for obesity or prediabetes, pregnant or lactating women, psychiatric illness and those unwilling to provide informed consent were excluded from the study.

Randomisation of patients into two groups was carried out using simple randomisation with a computer-generated randomisation sequence.

Study Procedure

A total of 90 patients were screened for eligibility at the Outpatient Department. After evaluation, 72 patients who met the inclusion and exclusion criteria were enrolled in the study [Table/Fig-1]. All 72 patients allocated for the study provided written informed consent before enrolment. There was no attrition during the study period, all 72 participants completed the study and were included in the final analysis.

Group-I (treatment group) received Capsule Vizylac (Lactic Acid Bacillus, not less than 120 million spores; manufactured by Torrent Pharmaceuticals Ltd., Ahmedabad, India) once daily in the morning after food for 12 weeks. This licensed commercial dose reflects a widely available, affordable and accessible intervention representative of real-world clinical use. Patients in Group-II (control group) received an identical-appearing placebo once daily in the

morning after food for 12 weeks. Both the groups were asked to continue the diet and lifestyle modifications.

Participants visited the study site at baseline and at the end of the intervention period. A 12-week duration was selected based on prior studies demonstrating significant glycaemic improvements with probiotic supplementation within this timeframe [22,24,25] and to align with the HbA1c turnover cycle of 8-12 weeks. At baseline, comprehensive assessment including physical examination and laboratory investigations was performed. Compliance and adverse effects were monitored through telephonic follow-up at weeks four and eight. All baseline measurements were repeated at the conclusion of the study.

Data collection: Data were collected using structured proformas at baseline and at 12 weeks. Demographic and clinical information including age, sex, residence, past medical history, family history and medication history were recorded. Anthropometric measurements comprising height, weight and BMI were obtained. For biochemical assessment, 6 mL of venous blood was collected from each participant at both time points. Fasting samples were analysed for FPG, HbA1c, Fasting Lipid Profile (FLP), TNF-α and MDA, while postprandial samples collected two hours after a meal were used for PPBG estimation.

Reference ranges for baseline parameters were based on the ADA 2024 criteria [7] and the National Cholesterol Education Program (NCEP) Adult Treatment Panel III (ATP III) guidelines [26], FPG (prediabetes: 100-125 mg/dL), PPBG (prediabetes: 140-199 mg/dL), HbA1c (prediabetes: 5.7-6.4%), total cholesterol (desirable: <200 mg/dL), LDL-C (optimal: <100 mg/dL), HDL-C (normal: ≥40 mg/dL) and triglycerides (normal: <150 mg/dL).

Biochemical investigations: The FPG and PPBG were analysed using the hexokinase method, while HbA1c was determined by High-Performance Liquid Chromatography (HPLC). The lipid profile included total cholesterol and triglycerides measured by Cholesterol Oxidase and Peroxidase (CHOD-POD) and Glycerol Phosphate Oxidase and Peroxidase (GPO-POD) methods, respectively, with HDL-C and LDL-C quantified using direct antibody inhibition method. TNF-α was assessed by Enzyme-Linked Immunosorbent Assay (ELISA) (DeQuanto™ Human TNF alpha ELISA Kit, Cat# QT4001, Denovo Biolabs Pvt., Ltd., Bengaluru, India) and MDA was quantified using colorimetric assay (Malondialdehyde Colorimetric Assay Kit, Cat# EEA015, Invitrogen™, Thermo Fisher Scientific, USA).

Outcomes: The primary outcome was the change in glycaemic parameters including FPG, PPBG and glycated haemoglobin (HbA1c) from baseline to 12 weeks. Secondary outcomes included changes in insulin resistance markers, namely the Triglyceride-Glucose (TyG) index (a surrogate marker of insulin resistance calculated using triglyceride and fasting glucose levels) and the TG/HDL-C ratio, BMI and changes in the inflammatory marker TNF-α and oxidative stress marker MDA were assessed.

STATISTICAL ANALYSIS

Data were entered using Microsoft Excel 2016 and analysed using IBM SPSS Statistics for Windows, Version 29.0 (Armonk, NY: IBM Corp). Descriptive statistics were expressed as mean±SD for continuous variables. Group comparisons for continuous variables were performed using the independent samples t-test and within-group comparisons (baseline vs 12 weeks) using the paired t-test. A p-value <0.05 was considered statistically significant.

RESULTS

There were a total of 72 patients recruited for the study. The treatment group (Group-I) received *Bacillus coagulans* once daily, while the control group (Group-II) received placebo once daily for 12 weeks. There were no statistically significant differences found in the baseline demographic and clinical parameters of the study groups [Table/Fig-2].

At the end of the 12-week period, the treatment group exhibited a significant reduction in HbA1c levels compared to the placebo group (p=0.008), reflecting improved glycaemic control. FPG levels also showed a notable decline in the treatment group at 12 weeks, with mean values significantly lower than those in the placebo group (p=0.001). In contrast, PPBG levels did not show any statistically significant change between the groups over the study period (p=0.758) [Table/Fig-3].

In terms of lipid profile, there was a statistically significant reduction in total cholesterol (p=0.002) and LDL-C levels (p=0.003) in the treatment group compared to placebo at 12 weeks. However, no significant changes were observed in HDL-C (p=0.604), VLDL-C (p=0.682), or triglyceride levels (p=0.228) between the groups.

Characteristic	Group-I (n=36)	Group-II (n=36)	p-value
Age (years)	52.1±7.6	50.4±7.9	0.36
Sex (M/F)	18/18	17/19	0.81
Weight (kg)	95.9±9.7	95.7±9.6	0.94

[Table/Fig-2]: Baseline demographic characteristics of study participants.
Data are presented as Mean ± Standard Deviation. Statistical comparisons between groups were performed using independent samples t-test. *A p-value < 0.05 was considered statistically significant

Parameters	Group	Baseline (Mean±SD)	12 Weeks (Mean±SD)	Mean change (Δ)	Within-group p-value[1]	Between-group p-value[2]
HbA1c (%)	Group-I	6.06±0.18	5.70±0.17	-0.36	<0.001*	0.008*
	Group-II	6.04±0.16	5.96±0.17	-0.08	0.048*	
Fasting Plasma Glucose (FPG) (mg/dL)	Group-I	117.69±4.98	104.80±4.60	-12.89	<0.001*	0.001*
	Group-II	116.50±4.51	112.90±4.60	-3.60	0.041*	
Postprandial Blood Glucose (PPBG) (mg/dL)	Group-I	167.58±9.88	164.80±9.40	-2.78	0.062	0.758
	Group-II	166.31±8.58	165.20±8.50	-1.11	0.412	
BMI (kg/m²)	Group-I	35.49±0.97	35.05±0.98	-0.44	0.002*	0.054
	Group-II	35.33±1.03	35.20±1.05	-0.13	0.089	
TyG Index	Group-I	9.14±0.05	9.03±0.05	-0.11	<0.001*	0.006*
	Group-II	9.00±0.04	9.07±0.04	+0.07	0.031*	
TG/HDL-C Ratio	Group-I	3.93±0.29	3.85±0.28	-0.08	0.212	0.590
	Group-II	3.81±0.26	3.79±0.29	-0.02	0.318	

[Table/Fig-3]: Effect of *Bacillus coagulans* on glycaemic, anthropometric and insulin resistance parameters.
Group-I =*Bacillus coagulans*; Group-II =Placebo. Data expressed as Mean±Standard Deviation. Δ=mean change from baseline to 12 weeks (negative value indicates reduction). [1]Within-group comparison (baseline vs 12 weeks) by paired t-test.
[2]Between-group comparison of change from baseline by independent-samples t-test. *Statistically significant at p<0.05. HbA1c: Glycated Haemoglobin; FPG: Fasting plasma glucose; PPBG: Postprandial blood glucose; TC: Total cholesterol; LDL-C: Low-density lipoprotein cholesterol; HDL-C: High-density lipoprotein cholesterol; VLDL-C: Very-low-density lipoprotein cholesterol; TG: Triglycerides; BMI: Body mass index.

Markers of insulin resistance demonstrated improvement in the intervention group. The TyG index was significantly lower in the treatment group at 12 weeks compared to placebo (p=0.006), suggesting enhanced insulin sensitivity. However, no significant intergroup difference was observed in the TG/HDL-C ratio at the end of the study.

With respect to inflammatory and oxidative stress markers, the treatment group exhibited a highly significant reduction in Tumour Necrosis Factor-alpha (TNF-α) levels at 12 weeks compared to the placebo group (p=0.002), indicating an anti-inflammatory benefit. In contrast, there was no significant change in MDA levels between the two groups, implying that the intervention did not notably affect oxidative stress status [Table/Fig-4] [27,28].

Parameters	Group	Baseline (Mean±SD)	12 Weeks (Mean±SD)	Mean change (Δ)	Within-group p-value[1]	Between-group p-value[2]
Total cholesterol (mg/dL)	Group-I	214.69±3.08	208.90±2.90	-5.79	<0.001*	0.002*
	Group-II	215.58±3.34	213.90±3.30	-1.68	0.072	
LDL-C (mg/dL)	Group-I	133.00±3.28	128.90±2.60	-4.10	<0.001*	0.003*
	Group-II	134.21±3.15	132.90±3.10	-1.31	0.058	
HDL-C (mg/dL)	Group-I	41.43±2.78	41.90±2.70	+0.47	0.118	0.604
	Group-II	42.60±2.62	41.80±2.60	-0.80	0.221	
VLDL-C (mg/dL)	Group-I	33.67±2.04	33.10±1.90	-0.57	0.094	0.682
	Group-II	33.65±2.03	33.30±1.95	-0.35	0.276	
Triglycerides (mg/dL)	Group-I	159.22±1.69	156.80±1.60	-2.42	0.072	0.228
	Group-II	160.40±1.20	158.90±1.30	-1.50	0.164	
MDA (nmol/mL)	Group-I	4.11±0.21	3.95±0.18	-0.16	<0.001*	0.158
	Group-II	3.97±0.19	3.94±0.18	-0.03	0.212	
TNF-α (pg/mL)	Group-I	8.31±0.28	6.95±0.30	-1.36	<0.001*	0.002*
	Group-II	8.27±0.23	7.95±0.25	-0.32	0.028*	

[Table/Fig-4]: Effect of *Bacillus coagulans* on lipid profile, oxidative stress and inflammatory markers [27,28].
Group-I =*Bacillus coagulans*; Group-II =Placebo. Data expressed as Mean±Standard Deviation. Δ=mean change from baseline to 12 weeks (negative value indicates reduction; positive value indicates increase). [1]Within-group comparison (baseline vs 12 weeks) by paired t-test. [2]Between-group comparison of change from baseline by independent-samples t-test. *Statistically significant at p<0.05. LDL-C: Low-density lipoprotein cholesterol; HDL-C: High-density lipoprotein cholesterol; VLDL-C: Very-low-density lipoprotein; MDA: Malondialdehyde; TNF-α: Tumour necrosis factor-alpha; Reference ranges: TNF-α ≤8.1 pg/mL [27], TyG index: 8.5-8.8, with values <8.5 indicating insulin sensitivity and >8.8 suggesting insulin resistance [28], MDA: 1-10 nmol/mL [16]

Bacillus coagulans supplementation was well tolerated. Mild, self-limiting gastrointestinal symptoms (bloating, flatulence, constipation) were reported in Group-I, which resolved with continued use. No serious adverse events occurred and no participants withdrew from the study. The placebo group reported no adverse effects. All adverse events were reported to the Pharmacovigilance Programme of India.

DISCUSSION

The present randomised, double-blinded, placebo-controlled trial demonstrated that 12 weeks of *Bacillus coagulans* supplementation significantly improved selected glycaemic parameters, lipid profile, insulin sensitivity markers and reduced systemic inflammation in prediabetic obese South Indian adults.

Statistically significant reductions in FPG and Glycated Haemoglobin (HbA1c) were observed in the probiotic group compared to placebo (p=0.001 and p=0.008, respectively). These findings align with recent meta-analyses by Li G et al., involving 1,827 type 2 diabetes patients {Standardised Mean Difference (SMD)=-0.331 for FPG, p<0.001} [29] and Baroni I et al., comprising 41 Randomised Controlled Trials (RCTs) (SMD=-0.282 for HbA1c, p<0.001) [24]. Similar improvements were reported in Indian populations by Rajkumar H et al., and in prediabetes trials by Kassaian N et al., [30,31].

The clinical significance of these glycaemic improvements is noteworthy. Epidemiological studies suggest that modest reductions in fasting glucose and HbA1c are associated with a lower risk of progression to type 2 diabetes and improved long-term metabolic outcomes [32,33]. The reductions observed in the study (FPG: 12.89 mg/dL; HbA1c: 0.36%) therefore represent clinically relevant improvements that may delay or prevent diabetes onset in this high-risk population. The similarity of baseline parameters between groups confirms effective randomisation and the greater metabolic improvements observed in the probiotic arm reflect a clinically meaningful benefit in prediabetes.

No significant changes were observed in PPBG levels (p=0.758), consistent with findings by Stefanaki C et al., suggesting probiotics may preferentially influence fasting glucose metabolism [25]. Modest glycaemic improvements in the placebo arm likely reflect behavioural adjustments during study participation, a recognised non specific effect in metabolic trials. Accordingly, although several parameters reached statistical significance on within-group analysis in the placebo arm, the magnitude of change was consistently small (e.g., HbA1c -0.08% and FPG -3.60 mg/dL) and substantially lower than in the probiotic arm (HbA1c -0.36%; FPG -12.89 mg/dL). The between-group comparison of change from baseline, which controls for these non specific effects, therefore represents the more appropriate test of efficacy and confirmed a significant treatment advantage for *Bacillus coagulans*. However, the greater reductions observed in the probiotic Group-Indicate an independent treatment effect.

The observed metabolic improvements may be explained by several mechanisms: enhancement of intestinal barrier integrity through upregulation of tight junction proteins (occludin, ZO-1), reducing LPS translocation [34,35]; modulation of incretin secretion, particularly Glucagon-like Peptide-1 (GLP-1); production of short-chain fatty acids (butyrate, propionate) that improve insulin sensitivity [36]; and attenuation of chronic low-grade inflammation [35]. Takeuchi T et al., demonstrated that gut microbial carbohydrate metabolism directly contributes to insulin resistance [20], while Balakumar M et al., showed that Indian-origin probiotic strains improved glucose tolerance and reduced inflammatory markers in experimental models [37].

A highly significant reduction in TNF-α was observed in the probiotic group (p<0.001), consistent with meta-analyses by Naseri K et al., [38] and network meta-analysis by Allam AR et al., [18] confirming Bacillus species among the most effective strains for TNF-α reduction. This finding is clinically relevant as TNF-α impairs insulin receptor signaling through JNK and IKKβ-mediated serine phosphorylation of Insulin Receptor Substrate 1 (IRS-1). Reduction in TNF-α may contribute to improved insulin signaling and

peripheral glucose uptake, providing a mechanistic basis for the observed glycaemic improvements. The minor reduction in TNF-α noted in the placebo arm (-0.32 pg/mL) was of limited biological magnitude relative to that in the probiotic arm (-1.36 pg/mL) and the significant between-group difference (p=0.002) supports a strain-specific anti-inflammatory effect. No significant changes in MDA levels were observed (p=0.158). Meta-analytic evidence suggests MDA reduction typically requires intervention durations exceeding 12 weeks [38] and this represents a potential area for extended investigation rather than a limitation of probiotic efficacy.

A significant reduction in total cholesterol (p=0.002) and LDL-cholesterol (p=0.003) were observed in the probiotic group, while HDL-C, VLDL-C and triglyceride levels remained unchanged. These selective improvements are consistent with strain-specific lipid-lowering mechanisms, including bile salt hydrolase activity and cholesterol assimilation [39,40]. Even modest reductions in LDL-C are associated with meaningful reductions in cardiovascular risk, suggesting that the lipid changes observed in this metabolically vulnerable population may have clinically relevant benefits.

The TyG index showed significant reduction in the probiotic group (p=0.006). This finding is potentially meaningful as elevated TyG index independently predicts adverse cardiometabolic outcomes. The TyG index correlates well with hyperinsulinemic-euglycaemic clamp measurements and offers a practical, cost-effective alternative for insulin resistance assessment [23,41]. The TG/HDL-C ratio showed non significant reduction, reflecting stable triglyceride and HDL-C levels individually. BMI showed a modest within-group reduction in the probiotic arm (-0.44 kg/m²; p=0.002), though the between-group difference was not significant (p=0.054). This trend aligns with evidence that probiotics may benefit body composition [42-44] and warrants longer, adequately powered studies to confirm any anthropometric effect.

The present study demonstrated significant reductions in FPG, HbA1c, total cholesterol, LDL-C, TyG index and TNF-α following 12 weeks of *Bacillus coagulans* supplementation in prediabetic obese adults. These findings are particularly relevant to South Indian adults, characterised by high prediabetes prevalence (15.3% per ICMR-INDIAB data), central adiposity at lower BMI thresholds and elevated metabolic inflammation [4]. Given limited accessibility of intensive interventions in resource-constrained settings, probiotics represent a culturally acceptable, cost-effective adjunctive strategy for early metabolic risk management.

Limitation(s)

Study limitations include the 12-week duration, single probiotic strain, surrogate insulin resistance markers, absence of microbiota profiling and single-centre design. Future studies should evaluate multi-strain formulations over longer durations with direct insulin sensitivity measurements and microbiome analyses.

CONCLUSION(S)

Twelve weeks of *Bacillus coagulans* supplementation significantly improved glycaemic parameters (FPG, HbA1c), reduced systemic inflammation (TNF-α) and improved lipid parameters (total cholesterol and LDL-C) in prediabetic obese South Indian adults. The intervention was safe and well-tolerated with no serious adverse events. These findings support the potential role of probiotics as a cost-effective adjunctive strategy for early metabolic risk management in prediabetic individuals.

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