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Effect of *Bifidobacterium Breve* on Lipid Profile and Body Fat Reduction in Patients with Metabolic Syndrome: A Randomized, Double-Blind, Placebo-Controlled, Clinical Trial

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Abstract

Metabolic Syndrome (MetS) is a cluster of metabolic abnormalities, including impaired glucose tolerance and elevated triglyceride levels, that increase the risk of cardiovascular disease and diabetes. This randomized, double-blind, placebo-controlled clinical trial aimed to evaluate the efficacy of *Bifidobacterium breve* strains BR03 and B632 in reducing body fat and improving metabolic parameters in individuals with MetS. Ninety participants were randomly assigned to either a placebo group (n = 45; receiving 1.6 g of microcrystalline cellulose daily) or a treatment group (n = 45; receiving 1.6 g of microencapsulated *B. breve* BR03 and B632, 2×10^9 CFU/day). Anthropometric and biochemical parameters, including BMI, waist circumference (WC), visceral fat ratio (VFR), blood pressure, HbA1c, fasting blood sugar (FBS), total cholesterol (TC), triglycerides (TGs), LDL-C, and HDL-C, were assessed at baseline and at 1, 2, and 3 months. At 3 months, the treatment group showed significant reductions compared to the placebo group in BMI ($p = 0.001$), WC ($p < 0.01$), VFR ($p < 0.016$), HbA1c ($p = 0.001$), FBS ($p < 0.001$), TC ($p < 0.001$), TGs ($p < 0.001$), and LDL-C ($P < 0.001$), along with a modest increase in HDL-C ($p = 0.034$). No significant differences were found in systolic ($p = 0.19$) or diastolic blood pressure ($p = 0.15$). These findings suggest that *B. breve* BR03 and B632 supplementation may offer a beneficial adjunctive strategy for improving metabolic profiles in patients with metabolic syndrome.

Keywords: *Bifidobacterium breve BR03; Bifidobacterium breve B632; metabolic syndrome; probiotic*

1. Introduction

Metabolic syndrome (MetS) is a group of conditions that increase the risk of cardiovascular disease, diabetes, and stroke (Saklayen et al., 2018). These conditions include high blood pressure, high blood sugar, a large waist circumference, high blood triglycerides, and low HDL cholesterol. MetS is particularly concerning because it is a major risk factor for various cardiovascular diseases (CVD), such as coronary atherosclerosis, myocardial infarction, heart failure, microvascular dysfunction, calcification, and cardiac dysfunction (Tran et al., 2020; Tune et al., 2017). The association of obesity and the MetS has increased the incidence of chronic kidney disease (CKD) (Wahba et al., 2007).

The diagnosis of metabolic syndrome is based on criteria established by the National Cholesterol Education Program (NCEP) Adult Treatment Panel III (ATPIII), the International Diabetes Federation (IDF), and World Health Organization (WHO) (Ahmed et al., 2022; Pouragha et al., 2021; Alberti et al., 2006). According to these guidelines, a person is diagnosed with MetS if at least three out of five specific abnormalities are detected (Grundy et al., 2005).

Probiotic in Obesity and Metabolic Syndrome

Probiotics, or live microorganisms, can have a positive effect on health when present in sufficient amounts in the body (Zawistowska-Rojek et al., 2018). The most commonly used probiotics species of *Lactobacillus* and *Bifidobacterium*. The most common species include: *Lactobacillus johnsonii, Lactobacillus acidophilus, Lactobacillus gasseri, Lactobacillus casei, Lactobacillus rhamnosus, Lactobacillus plantarum, Bifidobacterium longum, Bifidobacterium breve, Bifidobacterium bifidum and Bifidobacterium infantis* which are classified as the "generally recognized as safe" (GRAS) (Ishibashi et al., 2001).

These beneficial microorganisms, especially those in the Lactobacillus family, can influence appetite, nutrient absorption, and waste excretion. Probiotics also affect hormones that regulate appetite. They enhance the secretion of GLP-1, a hormone group in the gastrointestinal tract that helps lower blood sugar and increase hormone levels that promote fat burning by stimulating proteins such as angiopoietin-like 1 (ANGPTL1), (Kaji et al., 2014), which help reduce fat storage. This mechanism contributes to better weight management. Therefore, the use of probiotics represents an effective strategy for managing body weight and reducing both hyperglycemia and hyper-lipidemia.

Several studies have demonstrated the potential of probiotic supplementation in improving metabolic parameters among individuals with metabolic syndrome (MetS). For instance, *Lactobacillus plantarum* has been shown to significantly reduce blood glucose levels. In a randomized trial, postmenopausal women with MetS were divided into a control group ($n = 12$) and a probiotic group ($n = 12$) that consumed 80 mL of fermented milk with *L. plantarum* (10^7 CFU/g) daily for 12 weeks. The probiotic group experienced a significant reduction in glucose levels compared to the control group ($p = 0.037$ and $p = 0.019$, respectively) (Barreto et al., 2014).

In another 12-week study involving women with abdominal obesity, a multi-strain probiotic formulation including *Bifidobacterium bifidum* W23, *B. lactis* W51 and W52, *Lactobacillus acidophilus* W37, *L. brevis* W63, *L. casei* W56, *L. salivarius* W24, and *Lactococcus lactis* W19 and W58 was evaluated. Participants were assigned to a control group ($n = 58$), a low-dose group (2.5×10^9 CFU/day; $n = 56$), or a high-dose group (1×10^{10} CFU/day; $n = 55$). The high-dose group exhibited a significant reduction in blood glucose levels compared to both the control (-0.61 mg/dL, $p = 0.0272$) and low-dose groups (-0.72 mg/dL, $p = 0.0043$) (Szulińska et al., 2018). Further evidence supports the metabolic benefits of *Bifidobacterium lactis* HN019. In a 6-week clinical trial involving 51 MetS patients (control group; $n = 25$ and a probiotic group; $n = 26$), daily consumption of probiotic milk (80 mL/day, 2.72×10^{10} CFU/mL) resulted in significantly greater improvements in BMI, triglycerides, and LDL-C compared to the control group. Specifically, BMI decreased by 1.3 kg/m² versus 0.3 kg/m² in controls ($p = 0.017$); total cholesterol levels declined by 15 mg/dL vs. 6 mg/dL ($p = 0.009$); and LDL-C was reduced by 17.5 mg/dL vs. 2 mg/dL ($p = 0.008$) (Bernini et al., 2016).

In a randomized trial, 180 individuals with abdominal overweight were divided into three groups: a placebo group ($n = 60$), a probiotic group receiving *Limosilactobacillus fermentum* strains K7-Lb1, K8-Lb1, and K11-Lb3 ($n = 60$), and a probiotic plus acacia gum group receiving 10 g daily ($n = 60$) for 12 weeks. Body fat mass (BFM; kg) was significantly reduced in the probiotic group (-0.61 ± 1.94) compared to the placebo group ($+0.13 \pm 1.64$) ($p = 0.039$). However, no significant reduction in BFM was observed in the probiotic plus acacia gum group ($p = 0.730$) (Laue et al., 2023).

Despite growing interest in the role of probiotics in managing metabolic disorders, there remains limited clinical evidence evaluating the effects of specific *Bifidobacterium breve* strains particularly BR03 and B632 on lipid profiles and body fat in patients with metabolic syndrome. Most existing studies have focused on other probiotic strains or combinations, often in non-Asian populations. Moreover, the Thai population, which presents distinct dietary patterns, gut microbiota profiles, and genetic predispositions, remains underrepresented in probiotic research. This study addresses this gap by assessing the efficacy of *B. breve* BR03 and B632 in improving metabolic parameters among Thai adults with MetS in a controlled clinical setting.

2. Objective

To study the efficacy of *Bifidobacterium breve* strain BR03 and *Bifidobacterium breve* strain B632 to control and reduce weight and biochemical parameters in MetS.

3. Methods

This study was designed as a randomized, double-blind, placebo-controlled clinical trial conducted between October and December 2023 at Dhurakij Pundit University, Bangkok, Thailand. Participants were recruited from university staff based on routine

health check-up data and evaluated according to metabolic syndrome (MetS) criteria. A total of 90 participants diagnosed with MetS provided written informed consent and were randomly assigned to either the placebo group (n = 45) or the probiotic treatment group (n = 45). The random allocation sequence was generated using block randomization (block size of 10) via an online randomization tool (https://www.randomizer.org/), managed by an independent consultant. Allocation concealment was maintained by assigning each participant a unique code. Investigators, participants, and staff involved in product administration were blinded to group allocation to preserve study integrity.

Participants in the placebo group received 1.6 g of microcrystalline cellulose daily. Those in the probiotic group received a daily sachet containing 1.6 g of microencapsulated *Bifidobacterium breve* strains BR03 and B632, providing a total daily dose of 2×10^9 colony-forming units (CFU) equally divided between both strains. The probiotic and placebo sachets were identical in appearance, size, and color to ensure blinding. All participants were provided standardized lifestyle guidance, including a prebiotic-rich diet, carbohydrate moderation, and structured exercise. Anthropometric and biochemical measurements were recorded at baseline (M0) and after 1 (M1), 2 (M2), and 3 months (M3) of intervention. Physical parameters included body weight, height, waist circumference (WC), and visceral fat ratio (VFR), from which body mass index (BMI, kg/m²) was calculated. Blood pressure measurements included systolic (SBP), diastolic (DBP), and pulse pressure (PP). Biochemical assessments were performed after a 12-hour overnight fast and included hemoglobin A1c (HbA1c), fasting blood sugar (FBS), total cholesterol (TC), triglycerides (TGs), low-density lipoprotein cholesterol (LDL-C), and high-density lipoprotein cholesterol (HDL-C). All participants received standardized nutritional education from a certified dietitian. They were advised to avoid high-sugar foods, processed foods, fast food, high-sodium meals, and alcohol, and to increase their intake of prebiotic-rich foods such as whole grains, oats, cabbage, bananas, and broccoli. In addition, participants were enrolled in a supervised exercise program conducted by a sports science professional. The regimen included cardiovascular training (at least 45 minutes) and resistance training (20–25 minutes) on a minimum of two days per week. The exercise program was tailored specifically to support individuals with metabolic syndrome.

3.1 Inclusion Criteria

Participants were eligible for inclusion if they were aged between 18 and 60 years and exhibited behaviors consistent with the development of metabolic syndrome (MetS), such as poor dietary habits and physical inactivity. Diagnosis of MetS was based on harmonized criteria from NCEP ATP III (2007), IDF (2023), WHO criteria (1999) (Ahmed et al., 2022), requiring the presence of at least three out of the following five abnormalities: (1) central obesity, defined as a waist circumference >90 cm for men and >80 cm for women (Southeast Asian cutoffs) or a body mass index (BMI) >27.5 kg/m² for Asian populations; (2) elevated blood pressure, with systolic BP >130 mmHg or diastolic BP >85 mmHg, or current use of antihypertensive medications; (3) elevated triglycerides, defined as serum triglyceride levels >150 mg/dL or treatment for this lipid abnormality; (4) reduced HDL cholesterol, defined as <40 mg/dL in men and <50 mg/dL in women, or treatment for this condition; and (5) elevated fasting plasma glucose >100 mg/dL or a previous diagnosis of type 2 diabetes mellitus.

3.2 Exclusion Criteria

Exclusion criteria included pregnancy, the presence of chronic illnesses, or the use of medications or supplements that could interfere with metabolic parameters. Specifically, individuals were excluded if they were taking anti-diabetic agents, lipid-lowering drugs, antibiotics, anti-inflammatory medications, or any form of vitamin, mineral, or probiotic supplements within the last 30 days. Participants with known gastrointestinal disorders, immune-compromised status, or a history of recent hospitalization were also excluded.

3.3 Ethical Approval

The study protocol was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and was approved by the Dhurakij Pundit University Human Research Ethics Committee (DPUHREC), Bangkok, Thailand. Ethical approval was granted under protocol number COA No. 007/66, following a Full Board Review. Participant recruitment occurred between October 2023 and January 2024. All participants provided written informed consent prior to enrollment.

3.4 Statistics Analysis

Descriptive statistics were used to summarize baseline demographic and clinical characteristics,

including mean, standard deviation, and percentage distributions. The Mann–Whitney U test was employed for between-group comparisons of continuous variables due to non-parametric distribution, while the exact probability test was used for categorical data. Intra-group comparisons across time points were conducted using repeated-measures analysis of variance (ANOVA) or equivalent non-parametric tests. The percentage change from baseline (M0) to 3 months (M3) was calculated for all variables. A two-tailed p-value of <0.05 was considered statistically significant.

4. Results

A total of 90 participants diagnosed with metabolic syndrome were enrolled and randomly assigned in equal numbers to either the placebo group (n = 45) or the probiotic treatment group (n = 45). Baseline demographic and clinical characteristics, including age, sex, BMI, waist circumference (WC), visceral fat ratio (VFR), blood pressure (systolic and diastolic), hemoglobin A1c (HbA1c), fasting blood sugar (FBS), total cholesterol (TC), triglycerides (TGs), low-density lipoprotein cholesterol (LDL-C), and high-density lipoprotein cholesterol (HDL-C), were comparable between groups (Table 1).

Following the 3-month intervention, within-group analysis showed a statistically significant increase in BMI (p = 0.042), WC (p = 0.040), VFR (p = 0.048), and blood pressure (SBP p = 0.022; DBP p = 0.037) in the placebo group. In contrast, participants in the probiotic group demonstrated significant reductions in BMI (p = 0.035), WC (p = 0.036), and VFR (p = 0.037), while changes in SBP (p = 0.12) and DBP (p = 0.22) were not significant. Between-group comparisons from baseline (M0) to 3 months (M3) showed significantly greater reductions in BMI (p = 0.001), WC (p < 0.01), and VFR (p = 0.016) in the treatment group compared to the placebo group (Table 2 and Figures 1(a-c)).

Table 1 Demographic and Clinical Characteristics at Baseline (n = 90)

Data		Mean ± SD (n= 45), Placebo group	Mean ± SD (n= 45), Treatment group
Age (Years)		44.17± 6.33	42.42 (range: 25.00-43.00)
Gender	Male	14 (31.08), n (%)	12 (26.64), n (%)
	Female	31 (68.82), n (%)	33 (73.26), n (%)
BMI(Kg/m^2)		30.56 ± 19.22	31.66 ± 28.09
WC (inch)		36.66 ± 24.00	37.47± 25.50
VFR (%)		13.66 ± 16.11	13.84 ± 15.19
Blood pressure (mmHg)	SBP	132.69 ± 90.16	135.70 ± 92.25
	DBP	83.05 ± 75.01	84.55 ± 62.08
HbA1c (%)		5.65 ± 4.30	5.90 ±:4.55
FBS (mg/dL)		109.10 ± 75.00	111.56 ± 77.66
TC (mg/dL)		245.66 ± 80.23	246.11 ± 79.26
TGs (mg/dL)		190.30 ± 55.62	194.33 ± 45.06
LDL-C (mg/dL)		142.22 ± 75.99	150.22 ± 78.66
HDL-C (mg/dL)		51.45 ± 28.62	57.45 ± 23.56

Note: BMI, body mass index; VFR, visceral fat ratio; WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; HbA1c, hemoglobin A1c; FBS, fasting blood sugar; TC, total cholesterol; TGs, triglycerides; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol. Values are presented as mean ± standard deviation (SD), unless otherwise specified.

Table 2 Changes in Anthropometric and Biochemical Parameters Over 3 Months: Comparison Between Placebo and Probiotic Groups

Parameters	Group	M0	M1	M2	M3	P1	P2
		(mean ± SD)	(mean ± SD)	(mean ± SD)	(mean ± SD)	**(p < 0.05)**	**(p < 0.05)**
BMI	Placebo group	30.56 ± 19.22	31.56 ± 20.00	32.99 ± 21.00	34.65 ± 22.01	0.042*	0.001*t
(kg/m^2)	Treatment group	31.66 ± 18.50	31.38 ± 18.00	29.01 ± 17.50	28.19 ± 17.10	0.035*	
WC	Placebo group	36.66 ± 24.00	37.55 ± 24.50	39.04 ± 26.00	39.99 ± 27.50	0.040*	0.014*
(inch)*	Treatment group	37.47 ± 25.50	36.96 ± 25.00	35.73 ± 25.00	34.62 ± 25.00	0.036*	
VFR	Placebo group	13.66 ± 1.20	14.05 ± 3.08	15.09 ± 4.82	15.69 ± 4.98	0.048*	0.016*
(%)	Treatment group	13.84 ± 1.80	13.03 ± 1.50	12.65 ± 1.45	11.85 ± 1.20	0.037*	
SBP	Placebo group	132.69 ± 90.00	140.66 ± 95.00	145.21± 98.00	156.94 ± 102.00	0.022*	0.19
(mmHg)	Treatment group	135.7 ± 92.00	132.83 ± 91.00	134.66 ± 92.00	135.94 ± 89.00	0.12	
DBP	Placebo group	83.05 ± 75.00	95.66 ± 90.00	98.62 ± 92.00	102 ± 96.00	0.037*	0.15
(mmHg)	Treatment group	84.55 ± 62.00	86.28 ± 60.00	87.91 ± 64.00	84.05 ± 65.00	0.22	
HbA1c (%)*	Placebo group	5.65 ± 13.22	Not measurement	Not measurement	6.85 ± 15.10	0.011*	0.001*t
	Treatment group	5.9 ± 13.10	Not measurement	Not measurement	5.08 ± 10.20	0.030*	
FBS	Placebo group	109.1 ± 75.00	132.8 ± 90.00	121 ± 85.00	134.66 ± 102.00	0.028*	0.000*t
(mg/dL)	Treatment group	111.56 ± 77.00	103.37 ± 72.00	93.08 ± 49.00	87.35 ± 48.00	0.003*	
TC	Placebo group	245.66 ± 165.00	252.96 ± 175.00	269.32 ± 182.00	284.11 ±195.00	0.002*	0.000*t
(mg/dL)*	Treatment group	246.11 ± 167.00	226.82 ±143.00	215.07 ± 81.00	199.65 ± 75.00	0.001*	
TGs (mg/dL)	Placebo group	190.3 ± 55.00	212.56 ± 75.00	251.3 ± 89.00	289 ± 90.00	0.003*	0.000*t
	Treatment group	194.33 ± 45.00	158.37 ± 1.00	147.6 ± 47.00	132 ± 39.00	0.001*	
LDL-C	Placebo group	142.22 ± 75.00	146.45 ± 85.00	150.16 ± 87.00	162.22 ± 89.00	0.001*	0.000*t
(mg/dL)*	Treatment group	150.08 ± 80.00	140.56 ± 75.10	132.59 ± 68.30	112.03 ± 56.04	0.001*	
HDL-C	Placebo group	51.45 ± 28.00	50.22 ± 26.00	52.26 ±29.00	53.01 ± 28.00	0.008*	0.004*t
(mg/dL)*	Treatment group	57.45 ± 23.00	56.48 ± 24.00	55.73 ± 28.00	57.45 ± 29.00	0.010*	

Note: BMI, body mass index; VFR, visceral fat ratio; WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; HbA1c, hemoglobin A1c; FBS, fasting blood sugar; TC, total cholesterol; TGs, triglycerides; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol.

HbA1c was measured only at baseline (M0) and at 3 months (M3), as it reflects average blood glucose over the preceding 8–12 weeks.

M0 = baseline (pre-intervention); M1 = 1 month; M2 = 2 months; M3 = 3 months.

Statistical analysis was performed using ANOVA for repeated measures and Mann–Whitney U test for between-group comparisons. $p < 0.05$ was considered statistically significant.

*: Statistically significant within-group differences from baseline (M0)

t: Statistically significant percentage change from baseline

P1: Within-group comparison from M0 to M3

P2: Between-group comparison from M0 to M3 (placebo vs. treatment)

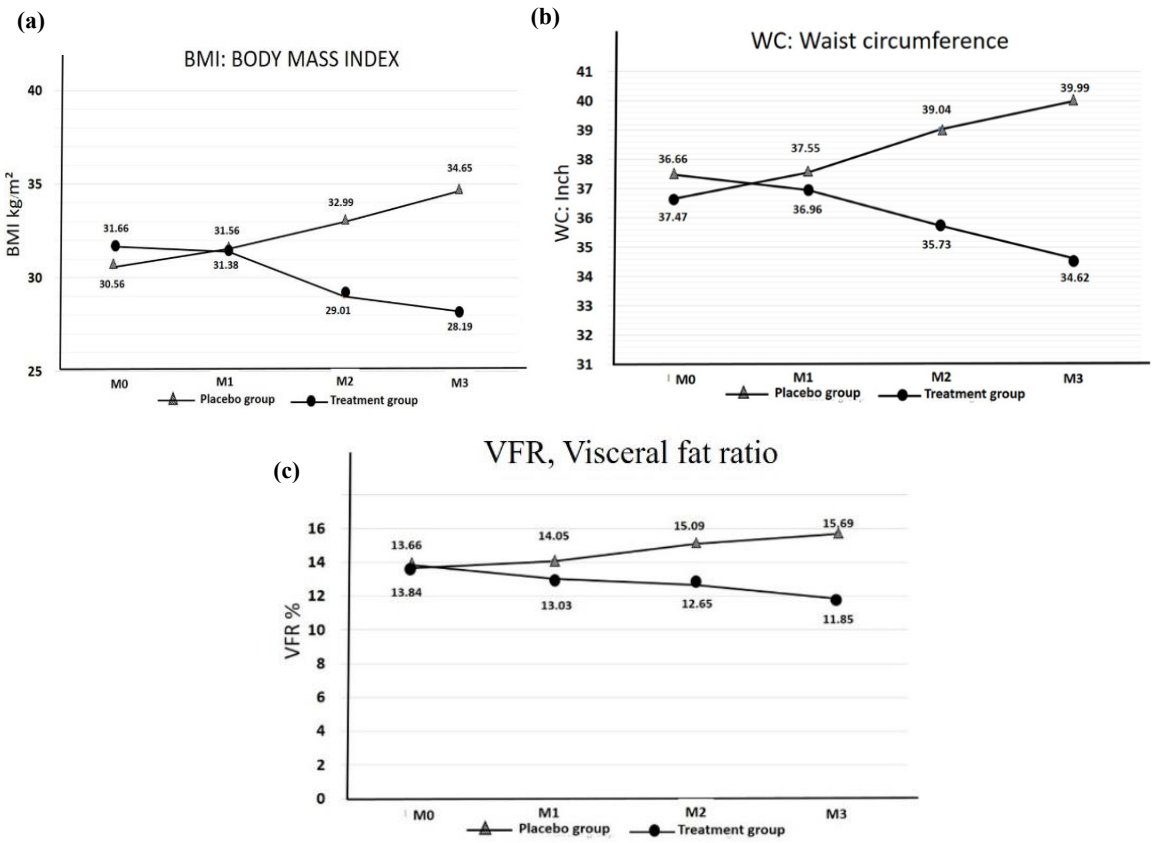

Figure 1 Changes in anthropometric parameters over 3 months in placebo and probiotic groups. (a) BMI; (b) waist circumference; (c) visceral fat ratio

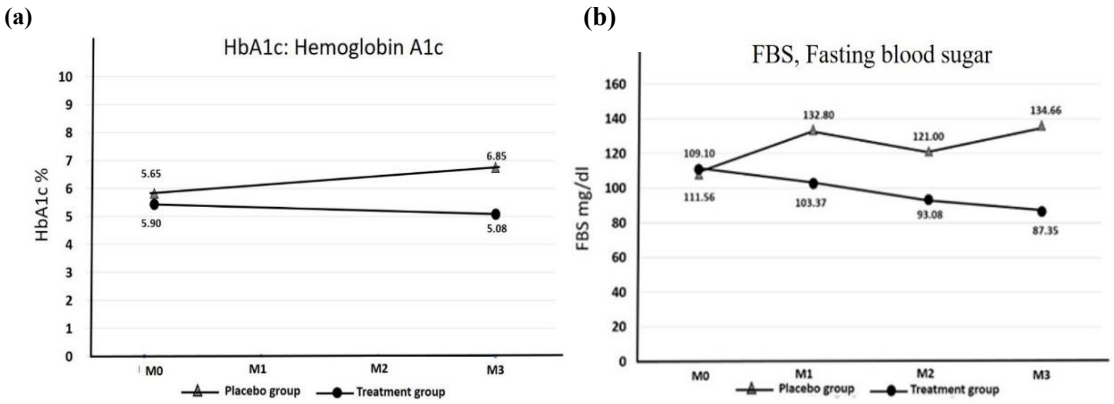

Figure 2 Changes in glycemic markers over 3 months in placebo and probiotic groups. (a) HbA1c (b) FBS

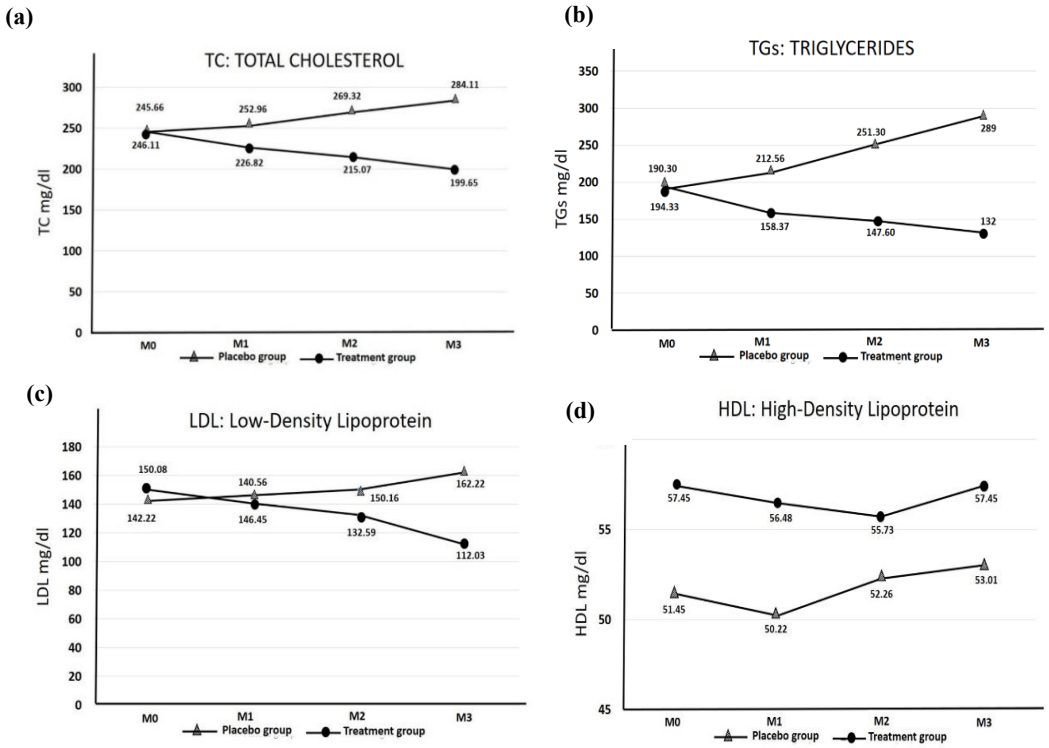

Figure 3 Changes in lipid profile over 3 months in placebo and probiotic groups. (a) Total cholesterol; (b) triglycerides; (c) LDL-C; (d) HDL-C

No significant differences in blood pressure were observed between groups (SBP p = 0.19; DBP p = 0.15). Regarding biochemical outcomes, the placebo group exhibited significant increases in HbA1c (p = 0.011), FBS (p = 0.028), TC (p = 0.002), TGs (p = 0.003), LDL-C (p = 0.001), and HDL-C (p = 0.008) from baseline to month 3. Conversely, the probiotic group demonstrated significant reductions in HbA1c (p = 0.030), FBS (p = 0.003), TC (p = 0.001), TGs (p = 0.001), LDL-C (p = 0.001), and HDL-C (p = 0.010) over the same period. Between-group analysis revealed statistically significant improvements favoring the treatment group for all key metabolic parameters, including HbA1c (p = 0.001), FBS (p < 0.001), TC (p < 0.001), TGs (p < 0.001), LDL-C (p < 0.001), and HDL-C (p = 0.004) (Table 2, Figure 2(a-b) and Figure 3(a-d)).

5. Discussion

This randomized, double-blind, placebo-controlled clinical trial demonstrated that daily supplementation with *Bifidobacterium breve* strains BR03 and B632 for three months resulted in significant improvements in key anthropometric and metabolic parameters among patients with metabolic syndrome. Notably, the probiotic group experienced reductions in BMI, waist circumference, visceral fat ratio, fasting blood glucose, HbA1c, total cholesterol, triglycerides, and LDL-C, along with an increase in HDL-C, compared to the placebo group. These findings support the hypothesis that specific probiotic strains can positively influence glucose and lipid metabolism in adults with MetS.

The observed metabolic improvements are consistent with prior studies reporting similar benefits of probiotic interventions. For example, *Bifidobacterium lactis* HN019 has been shown to significantly reduce triglyceride and LDL-C levels and improve BMI in patients with metabolic syndrome (Bernini et al., 2016). Similarly, *Lactobacillus plantarum* was associated with improved glycemic control in postmenopausal women with MetS (Barreto et al., 2014), while multi-strain probiotic formulations have demonstrated dose-dependent effects on plasma glucose reduction (Szulińska et al., 2018).

The mechanism underlying the metabolic benefits observed in this study may involve the production of short-chain fatty acids (SCFAs) such as acetate, propionate, and butyrate at a ratio 3:1:1 (Høverstad et al., 1984), which are known to enhance

insulin sensitivity and modulate hepatic lipid metabolism. SCFAs also regulate gut hormone secretion, including glucagon-like peptide-1 (GLP-1), thereby contributing to improved glycemic control (Zhang et al., 2021). SCFAs induce secretion of the glucagon like peptide (GLP)-1 by expression of the SCFA receptors such as ffar2 (grp43) and ffar3 (gpr41) in GLP-1 by L cells in the distal small intestine and colon which enhance insulin secretion as antidiabetic effect (Tolhurst et al., 2012). Moreover, *Bifidobacterium breve* has been shown in prior studies to reduce body fat accumulation and improve insulin sensitivity, possibly through modulation of the gut microbiota and suppression of inflammation (Miglioranza Scavuzzi et al., 2015; Chaiyasut et al., 2023).

In contrast to these metabolic improvements, our study did not observe significant changes in blood pressure, which may reflect the short duration of intervention or the multifactorial etiology of hypertension in MetS. This aligns with previous literature indicating that probiotics have more pronounced effects on lipid and glucose profiles than on blood pressure regulation (Greany et al., 2008; Guo et al., 2011).

One of the strengths of this study is its rigorous design-randomization, double-blinding, and the use of well-characterized probiotic strains. Additionally, both groups received equivalent dietary and exercise guidance, helping to isolate the probiotic effect. However, there are limitations. The sample size was modest, and the intervention duration was relatively short. Furthermore, the study population consisted of university personnel in a specific geographic area, limiting generalizability. Microbiome composition was not assessed, which would have helped clarify host-microbe interactions.

6. Conclusion

Three months of supplementation with *Bifidobacterium breve* strains BR03 and B632 significantly improved BMI, waist circumference, visceral fat ratio, fasting blood glucose, HbA1c, total cholesterol, triglycerides, and LDL-C, along with an increase in HDL-C in individuals with metabolic syndrome. These metabolic improvements may be attributed to the modulation of gut microbiota, enhanced short-chain fatty acid (SCFA) production, and improved insulin sensitivity. While no significant effect was observed on blood pressure, the overall findings support the use of targeted probiotic therapy as a safe and effective adjunct in managing metabolic syndrome. Future studies with longer follow-up periods, diverse populations, and microbiota analysis are warranted to validate and expand upon these findings.

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