Keywords
Cuminum cyminum; Murraya koenigii; Trigonella foenum-graecum; polyherbal formulation; prediabetes; glycemic regulation.

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Received:25-06-2026
Revised:28-07-2026
Accepted:05-08-2026
Doi:10.1922/ejprd.v34i7s.1696

Effect of a Polyherbal Formulation of Cuminum cyminum, Murraya koenigii, and Trigonella foenum-graecum on Glycemic Control and Metabolic Health in Prediabetic Adults: An Experimental Study

Abstract
Prediabetes is a high-risk metabolic condition that frequently progresses to type 2 diabetes and requires effective early interventions to improve glycemic regulation and metabolic health. This study aimed to prepare and evaluate a standardized polyherbal blend of Cuminum cyminum, Murraya koenigii, and Trigonella foenum-graecum through laboratory, preclinical, and clinical investigations. An experimental translational study was conducted involving standardized extraction, formulation, phytochemical screening, preclinical evaluation in streptozotocin-induced diabetic rats, and clinical evaluation in 60 adults with prediabetes. Participants received either the polyherbal blend combined with exercise or an exercise comparator. Hydroalcoholic Soxhlet extraction produced the highest extraction yields and a phytochemically rich formulation. In the preclinical phase, the polyherbal blend significantly reduced fasting blood glucose and improved antioxidant and biochemical markers. In the clinical phase, participants receiving the polyherbal formulation demonstrated greater improvements in Blood pressure, waist circumference, body weight, body mass index, fasting blood glucose, postprandial blood glucose, HbA1c, lipid profile and liver function biomarkers than those receiving the comparator intervention. The formulation was well tolerated, with only mild adverse events reported. Overall, the findings indicate that the standardized polyherbal blend possesses promising antihyperglycemic and metabolic benefits and may serve as a complementary method for enhancing glycemic regulation and metabolic health in adults with prediabetes. To validate its long-term efficacy and safety, more extensive randomised controlled trials with longer follow-up are needed.

INTRODUCTION

Impaired fasting glucose (IFG), impaired glucose tolerance (IGT), or raised glycated haemoglobin levels are signs of prediabetes, a dangerous metabolic condition that develops when blood glucose levels are above normal but not high enough to be classified as diabetes. The disturbances in glucose homeostasis and the growing risk of manifestation of overt diabetes with related cardiovascular complications are caused via oxidative stress, chronic low-grade inflammation, pancreatic β-cell malfunction, and increasing insulin resistance. Therefore early intervention in prediabetic phase is crucial to prevent or slow down the progression and decrease the burden of metabolic disorders in the long term. The use of complementary therapeutic strategies is encouraged due to conventional pharmacological approaches continuing to be effective although sometimes having adverse effects, high treatment costs and poor adherence to therapy (Kumar et al., 2021; Yilmaz et al., 2017).

Given this, herbal medicine has become more and more popular as an alternative remedy to manage diabetes due to its wide range of phytochemical composition, multitarget mechanisms of action and generally favorable safety profile. The antioxidant, anti-inflammatory, hypoglycemic, and lipid lowering effect are all the activities of traditional medicinal plants which will all contribute to metabolic regulation. Their use in the clinical practice and self-care is increasing as healthcare providers and patients gain confidence in their use, despite considerations for appropriate standardization and scientific validation (Alqathama et al., 2020; Ekor, 2020). Cuminum cyminum, Murraya koenigii and Trigonella foenum-graecum have been proven to be a potential medicinal plant for metabolic disorders. These plants are rich in bioactive compounds that are able to enhance insulin sensitivity, decrease oxidative stress, regulate carbohydrate metabolism and enhance lipid homeostasis. The experimental and clinical data suggest that fenugreek supplementation is beneficial for glycated hemoglobin, body weight, lipid profile and other metabolic parameters and cumin and curry leaves have complementary antioxidant and antidiabetic effects. Combining these botanicals into a single formulation might thus have an additive therapeutic effect due to the synergistic effects of the phytochemicals (Rao et al., 2020; Besada et al., 2025; Nyiramana Mukamurera, 2025; Ayenew et al., 2026).

Although prediabetes is a worldwide problem and herbal treatments are receiving more attention, there are still some areas of research that could be important. Current epidemiological data from all over the world show a significant rise in the population at risk of developing type 2 diabetes (T2D) from prediabetes, highlighting the importance of effective preventive measures (Saeedi et al., 2019; Duncan et al., 2026). While several medicinal plants have been studied individually, Very few research have been conducted to evaluate the therapeutic potential of Cuminum cyminum, Murraya koenigii and Trigonella foenum-graecum when used as a combination in a standardized polyherbal formulation. In addition, most studies do not include standardized extraction methods, formulations, and a full phytochemical profile, thus affecting the reproducibility and comparability of the studies (Karole et al., 2019).

Finally, another significant constraint is the lack of approaches that include laboratory standardization, preclinical pharmacological validation, and human clinical translation in the same experimental setting. While recent developments in network pharmacology and evidence synthesis have emphasized the need for scientifically validating the traditional polyherbal formulations using a standardized experimental approach, similar comprehensive study of polyherbal interventions for prediabetes and metabolic dysfunction is limited (Ingale, 2023; Brahma et al., 2024).

Considering the complimentary pharmacological characteristics of the Cuminum cyminum, Murraya koenigii and Trigonella foenum-graecum, the formulation of a standardized polyherbal formulation can render more broad therapeutic benefits than individual herbal formulations. Fenugreek has demonstrated antidiabetic effects through systematic reviews and meta-analyses that highlight its ability to improve glycemic control, insulin sensitivity, and cardiovascular risk factors, implying that adding this medicinal plant into a scientifically standardized formulation may help in the regulation of metabolism (Shakil et al., 2024; Kim et al., 2023). In addition, there has been significant research on the phytochemicals of fenugreek, highlighting several bioactive compounds with potential antioxidant, anti-inflammatory, and blood sugar-lowering properties, acting via various molecular mechanisms (Sarker et al., 2024).

The current study, therefore, was designed to develop a standardized extraction and formulation protocol for the polyherbal blend and to assess the efficacy of the formulated polyherbal blend in the laboratory, in preclinical trials, and in human clinical trials. This holistic, translational method offers robust evidence of the formulation's ability to influence glycemic control and metabolic health in prediabetic adults and points to the future for development as an adjunct treatment to slow the progression to type 2 diabetes (Bahmani et al., 2016; Singletary, 2024).

Research Objectives

1.To prepare and characterize a standardized polyherbal blend of Cuminum cyminum, Murraya koenigii, and Trigonella foenum-graecum.

2.To evaluate the antidiabetic efficacy of the polyherbal blend through preclinical and clinical investigations.

3.To measure the effects of the polyherbal blend on glycemic regulation and metabolic health in adults with prediabetes.

2. Methodology

2.1 Study Design

The study design was an experimental translational design consisting of three phases: laboratory preparation of the polyherbal formulation, preclinical testing using an experimentally induced model of diabetes in rats and human clinical testing in adults with prediabetes. Laboratory work consisted of collecting, authenticating, extracting, formulating, and preliminary phytochemical screening of plants, animal pharmacological screening, and clinical trial of the formulation with human subjects.

2.2 Collection and Authentication of Plant Materials

Cuminum cyminum, Murraya koenigii and Trigonella foenum-graecum were collected from their respective geographical areas and taxonomically identified by competent botanists. The plant materials were cleaned after authentication to remove any foreign matter and other impurities for extraction to ensure the quality, identity, and consistency of the herbal formulation.

2.3 Preparation of Plant Materials

The authenticated plant materials were air dried under environmental conditions which were suitable to provide good phytochemicals, and later ground to coarse powder with suitable grinding equipment. The powdered materials were kept in clean and dry sealed containers until additional extraction procedures were undertaken.

2.4 Extraction of Individual Herbal Components

The powdered materials of Cuminum cyminum, Murraya koenigii and Trigonella foenum-graecum have been separately extracted using Soxhlet extraction and maceration. For 72 hours, 250 g of each powdered plant material was macerated in 500 mL of water while being shaken periodically. The extraction was then carried out by Soxhlet apparatus with either 500 mL of water or a hydroalcoholic solvent mixture (250 mL of water and 250 mL of ethanol) for about 48 h. The extracts thus obtained were concentrated in rotary evaporator at 70°C and then evaporating the solvent over the water bath. These concentrated extracts were subsequently lyophilised and powdered and stored suitably until formulation preparation.

2.5 Preparation of the Polyherbal Blend

The dried extracts of Cuminum cyminum, Murraya koenigii and Trigonella foenum-graecum were mixed in equal ratio to get final polyherbal formulation. As per formulation protocol, 10 mg of each individual extract was thoroughly blended and made as homogenous powdered formulation and was stored till its use in experimental and clinical phase of the study in air tight containers.

2.6 Preliminary Phytochemical Screening

In order to identify the presence of important phytochemical constituents like steroids, phenolic compounds, terpenoids, alkaloids, flavonoids, tannins, saponins, and glycosides, the individual extracts and prepared polyherbal formulation underwent preliminary phytochemical screening using standard qualitative procedures. The screening gave baseline data on what was in the formulation before biological evaluation was done, in terms of phytochemical composition.

2.7 Preclinical Animal Evaluation

The formulation was prepared and evaluated in experimentally induced diabetic rats model. Streptozotocin was used to induce diabetes followed by administration of the formulation to the experimental animals as per the protocol of the study. The intervention was carried out for 3 weeks and the animals were monitored and evaluated for their antidiabetic activity by glycemic study, biochemical investigations and oxidative stress and antioxidant parameters for the pharmacological efficacy of the formulation.

2.8 Human Clinical Evaluation

The polyherbal formulation was prepared after the preclinical phase and then the formulation was given to the adults with prediabetes. The participants were then assessed to see how the three-pronged intervention affected glycemic control and metabolic health in line with the clinical study protocol.

2.9 Data Collection

Data was gathered during the laboratory, preclinical, and clinical aspects of the study. Laboratory data comprised extraction process, formulation characteristics, and phytochemical screening results, and the animal and clinical phases included systematic recording of the pharmacological observations, biochemical measurements, and clinical findings results using the standardized data collection procedures.

2.10 Data Analysis

The obtained data were entered into MS Excel. Frequencies and percentages were used to display categorical data, and mean ± standard deviation (SD) was used to display continuous data. The baseline and post-intervention scores within each study group were compared using paired samples t-tests, while continuous outcomes between study groups were compared using independent samples t-tests. Due to the small sample size, the frequency of adverse events were compared using Fisher's exact test. Statistical significance was defined as a p-value of less than 0.05.

2.11 Ethical Considerations

The study was done with respect to the principles of ethics for experimental and preclinical research. The globally recognised guidelines for the care and use of laboratory animals were followed in rat experiments. Before the study began, all participants provided written informed consent and were informed of its objectives and methodology. The confidentiality and privacy of the participants were respected during the study and no data were used for any other purpose than for research studies and in accordance with ethical standards.

3. Results

3.1 Extraction Yield and Preliminary Phytochemical Profile

Figure 1 depicts that the highest extraction yield was observed for the hydroalcoholic Soxhlet extraction for all three medicinal plants followed by the aqueous Soxhlet extraction and maceration. From these results hydroalcoholic Soxhlet extracts of Cuminum cyminum, Murraya koenigii and Trigonella foenum-graecum were chosen for preparing final polyherbal blend. Major bioactive phytochemicals, including terpenoids, alkaloids, flavonoids, phenolic compounds, tannins, saponins, glycosides, and steroids, were found in preliminary phytochemical screening, thus suggested that the formulation consisted of a wide range of phytochemicals that can be subjected to preclinical and clinical evaluation.

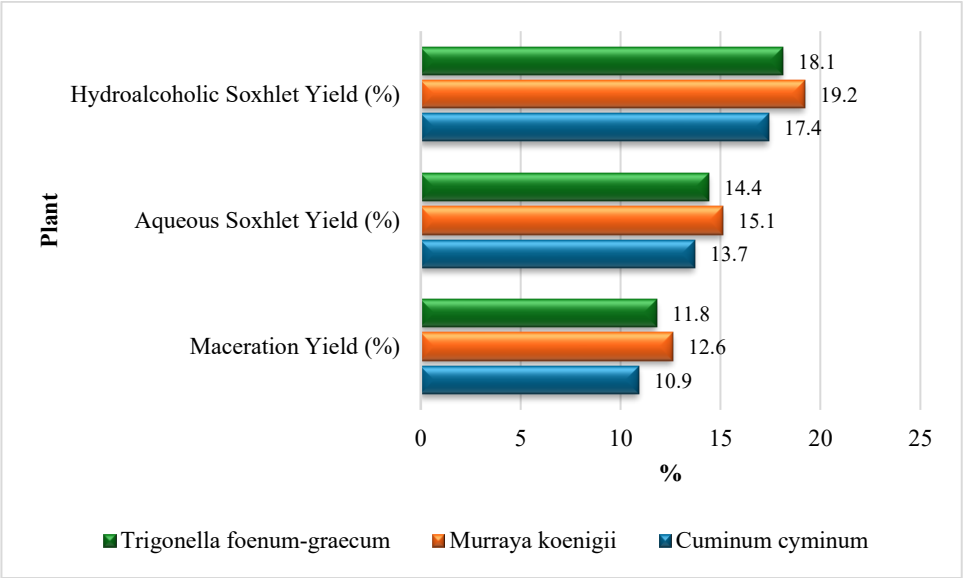

Figure 1. Extraction Yield of the Selected Medicinal Plants

The comparison of the extraction yields of the three particular medicinal plants from the three extraction techniques is given in Figure 1. Overall, the extraction efficiency of hydroalcoholic Soxhlet extraction was found to be the highest among all the plant materials followed by aqueous soxhlet extraction and maceration, thus the hydroalcoholic Soxhlet extraction was chosen for the preparation of the poly herbal formulation.

3.2 Preclinical Evaluation of the Polyherbal Blend

A total of 24 rats were randomly separated into four groups: normal control, diabetic control, standard-treatment and polyherbal-treatment. Paired-samples t-tests revealed a substantial alteration in fasting blood glucose among the diabetic-control group (increased) and the standard-treatment group (decreased) and between the diabetic-control group (increased) and the polyherbal-treatment group (decreased) after the 3-week intervention ($p < .05$). Independent-samples t-tests also showed that the week-three fasting blood glucose level was significantly lower in the polyherbal group than the diabetic-control group. The standard-treatment group showed the highest decrease in the blood glucose level (−79.23 ± 13.80 mg/dL), followed by the polyherbal group (−62.67 ± 6.73 mg/dL), which showed a remarkable antihyperglycemic effect of the formulated polyherbal formulation (Table 1).

Table 1. Changes in fasting blood glucose during the three-week experimental period

Experimental Group	Baseline FBG (mg/dL)	Week 3 FBG (mg/dL)	Mean Change (mg/dL)	Within-group p-value
Normal control (n = 6)	96.18 ± 4.06	96.92 ± 4.54	+0.73 ± 1.86	.374
Diabetic control (n = 6)	285.83 ± 17.79	314.73 ± 22.59	+28.90 ± 12.92	.003
Standard treatment (n = 6)	292.00 ± 23.19	212.77 ± 36.15	−79.23 ± 13.80	<.001
Polyherbal blend (n = 6)	274.60 ± 27.38	211.93 ± 22.27	−62.67 ± 6.73	<.001

3.3 Biochemical and Oxidative Stress Outcomes in Experimental Animals

The polyherbal mixture significantly reduced biochemical markers and markers of oxidative stress in addition to its beneficial effect on glycemic control compared to the diabetic-control group. Independent-samples t-test revealed that the serum insulin, superoxide dismutase (SOD) and catalase activities in polyherbal treated rats were significantly increased, and that thiobarbituric acid reactive substances (TBARS), alanine aminotransferase (ALT) and aspartate aminotransferase (AST) levels were significantly reduced. Although HOMA-IR values showed improvement in the polyherbal group, the alteration was not statistically substantial. In general, biochemical profile of the animals treated with polyherbal closely came up to standard treatment group, which showed that pancreatic functions, antioxidant defence, lipid peroxidation and hepatic injury were enhanced after administration of the prepared polyherbal formulation (Table 2).

Table 2. Biochemical and oxidative stress outcomes following three weeks of treatment

Parameter	Normal Control (n = 6)	Diabetic Control (n = 6)	Standard Treatment (n = 6)	Polyherbal Blend (n = 6)	p-value
Serum insulin (µIU/mL)	11.85 ± 1.04	5.48 ± 0.74	9.58 ± 1.14	8.69 ± 0.75	<.001
HOMA-IR	2.83 ± 0.25	4.27 ± 0.72	5.08 ± 1.24	4.55 ± 0.65	.497
TBARS (nmol/mg)	2.34 ± 0.29	6.28 ± 0.79	3.46 ± 0.49	3.41 ± 0.39	<.001

SOD (U/mg)	10.21 ± 0.57	3.92 ± 0.47	8.52 ± 0.63	8.17 ± 0.44	<.001
Catalase (U/mg)	51.68 ± 5.36	27.77 ± 3.34	42.69 ± 3.27	41.24 ± 3.37	<.001
ALT (U/L)	41.40 ± 12.11	86.40 ± 15.09	60.78 ± 14.69	58.95 ± 9.25	.005
AST (U/L)	69.42 ± 13.64	105.37 ± 15.49	53.40 ± 14.79	53.62 ± 12.74	<.001

3.4 Baseline Characteristics of Adults with Prediabetes

60 adults with prediabetes were recruited into clinical phase, 30 were assigned to polyherbal-plus-exercise group and 30 to the exercise-comparator group. Table 3 shows the baseline clinical parameters: anthropometric measurements, glycemic parameters, lipid profile, blood pressure and liver function biomarkers.

Table 3. Baseline Clinical Characteristics of Adults with Prediabetes

Characteristic	Polyherbal + Exercise (n = 30)	Exercise Comparator (n = 30)
Age (years)	48.83 ± 9.68	49.43 ± 9.35
Weight (kg)	83.01 ± 9.17	82.95 ± 11.84
BMI (kg/m²)	31.31 ± 4.90	31.27 ± 6.44
Waist circumference (cm)	98.82 ± 9.23	99.94 ± 10.17
Systolic BP (mmHg)	129.57 ± 9.69	127.93 ± 9.86
Diastolic BP (mmHg)	83.70 ± 8.58	83.57 ± 7.70
Fasting blood glucose (mg/dL)	113.48 ± 6.73	114.90 ± 7.95
Postprandial blood glucose (mg/dL)	168.97 ± 15.90	167.09 ± 16.20
HbA1c (%)	5.97 ± 0.18	6.09 ± 0.16
Total cholesterol (mg/dL)	208.39 ± 26.92	208.05 ± 20.94
Triglycerides (mg/dL)	153.53 ± 33.16	167.11 ± 33.47
HDL cholesterol (mg/dL)	47.87 ± 7.35	47.83 ± 7.19
LDL cholesterol (mg/dL)	129.82 ± 27.04	126.79 ± 26.26
ALT (U/L)	36.69 ± 8.31	31.45 ± 8.84
AST (U/L)	32.38 ± 8.01	31.33 ± 8.45

At baseline, the continuous variables were not significantly diverse among the two study groups, which means that the clinical characteristics before the intervention were similar. Similarly, there was a comparable distribution of categorical demographic and lifestyle characteristics between the two groups (Figure 2).

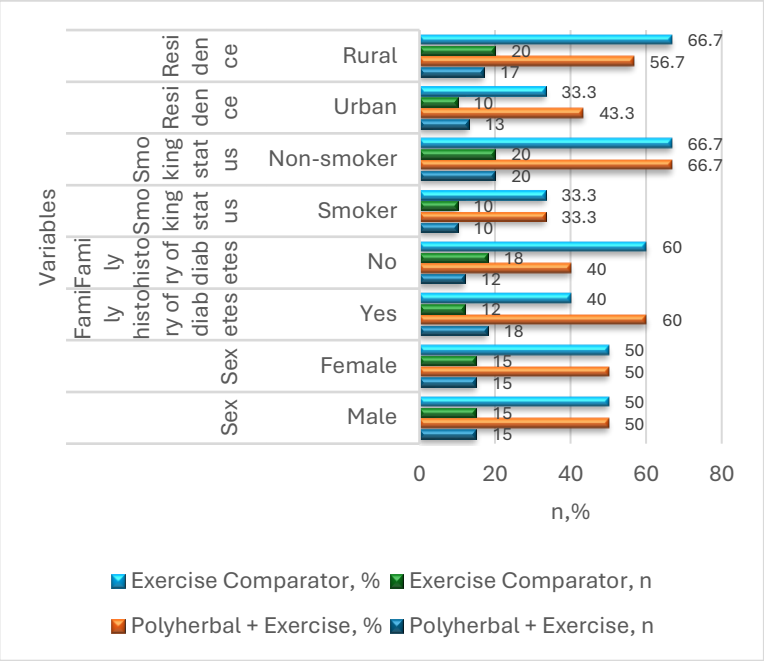

Figure 2. Baseline Demographic and Lifestyle Characteristics

Demographic and lifestyle characteristics at baseline for the polyherbal-plus-exercise and exercise-comparator groups are shown in Fig. 2. There were no substantial variances in the distribution of the categorical variables among the two groups, suggesting good baseline comparability before the intervention.

3.5 Effects of the Polyherbal Blend on Glycemic Regulation

In both groups, there was a good reduction in fasting blood glucose (FBG), postprandial blood glucose (PPBG), and HbA1c after the intervention. But the cuts were consistently higher among those who were assigned to one of the

polyherbal blends plus exercise. The polyherbal-plus-exercise group showed mean lowering of 7.69 ± 4.86 mg/dL in FBG, while the exercise-comparator group showed the mean lowering of 3.98 ± 2.77 mg/dL. Likewise, there was a drop in postprandial blood glucose of 11.05 ± 7.31 mg/dL for the intervention group and 6.23 ± 4.05 mg/dL for the comparator group. HbA1c decreased by 0.25 ± 0.16% after polyherbal supplementation, whereas it decreased by 0.11 ± 0.08% in the exercise-only group. Within group improvements were significant for all glycemic parameters (paired samples t-test) and between group improvements were also significantly greater in the intervention group (independent samples t-test) (Table 4).

Table 4. Changes in glycemic parameters following intervention

Outcome	Group	Baseline	Post-intervention	Mean Change	Within-group p	Between-group p[1]
FBG (mg/dL)	Polyherbal + Exercise	113.48 ± 6.73	105.79 ± 8.29	−7.69 ± 4.86	<.001	.001
	Exercise Comparator	114.90 ± 7.95	110.92 ± 7.93	−3.98 ± 2.77	<.001	
PPBG (mg/dL)	Polyherbal + Exercise	168.97 ± 15.90	157.92 ± 18.92	−11.05 ± 7.31	<.001	.003
	Exercise Comparator	167.09 ± 16.20	160.86 ± 17.40	−6.23 ± 4.05	<.001	
HbA1c (%)	Polyherbal + Exercise	5.97 ± 0.18	5.72 ± 0.27	−0.25 ± 0.16	<.001	<.001
	Exercise Comparator	6.09 ± 0.16	5.98 ± 0.18	−0.11 ± 0.08	<.001	

[1] Independent-samples t-test comparing the mean changes between groups

3.6 Effects of the Polyherbal Blend on Anthropometric and Cardiometabolic Outcomes

The intervention resulted in positive anthropometric and cardiometabolic changes in both groups, with those in the polyherbal group being more consistent. Body weight, BMI, waist circumference, SBP, DBP, TC, TGs, LDL, ALT, AST were all significantly reduced after treatment and HDL was significantly increased. Independent-samples t-tests presented that the mean improvement in the intervention group was meaningfully advanced for all the outcomes studied, which indicated that the combined polyherbal formulation and exercise intervention was effective in improving metabolic health in addition to exercise alone (Table 5).

Table 5. Changes in anthropometric and cardiometabolic parameters following intervention

Outcome	Polyherbal + Exercise (Mean Change)	Exercise Comparator (Mean Change)	p-value
Weight (kg)	−1.34 ± 1.02	−0.65 ± 0.58	.003
BMI (kg/m²)	−0.50 ± 0.38	−0.24 ± 0.22	.002
Waist circumference (cm)	−1.96 ± 1.16	−1.14 ± 0.74	.002
Systolic BP (mmHg)	−4.07 ± 3.48	−1.77 ± 1.63	.002
Diastolic BP (mmHg)	−2.50 ± 1.63	−1.20 ± 0.96	<.001
Total cholesterol (mg/dL)	−8.26 ± 6.23	−3.40 ± 2.81	<.001
Triglycerides (mg/dL)	−12.30 ± 7.22	−7.20 ± 4.67	.002
HDL cholesterol (mg/dL)	+1.96 ± 1.77	+0.95 ± 0.80	.007
LDL cholesterol (mg/dL)	−6.92 ± 5.19	−4.03 ± 2.87	.011
ALT (U/L)	−2.70 ± 2.09	−1.24 ± 0.98	.001
AST (U/L)	−2.48 ± 1.73	−1.21 ± 0.93	.001

3.7 Exercise Adherence and Safety Outcomes

There was substantial compliance with the exercise prescribed by the participants in the polyherbal-plus-exercise group compared to the exercise-comparator group. The intervention was generally well tolerated and most individuals were able to finish the intervention lacking adverse events. Three of the polyherbal formulation group reported mild gastrointestinal upset while one in the comparator group reported transient muscle soreness. No adverse events or treatment discontinuations were observed, which shows that the polyherbal formulation was safe for the intervention period (Table 6).

Table 6. Exercise adherence and safety outcomes

Outcome	Polyherbal + Exercise (n = 30)	Exercise Comparator (n = 30)	p-value
Exercise adherence (%)	84.48 ± 8.88	75.97 ± 9.86	<.001[1]
No adverse events, n (%)	27 (90.0)	29 (96.7)	.612[2]

Mild gastrointestinal discomfort, n (%)	3 (10.0)	0 (0.0)	
Transient muscle soreness, n (%)	0 (0.0)	1 (3.3)	
Severe adverse events, n (%)	0 (0.0)	0 (0.0)	

[1] Independent-samples t-test; [2] Fisher's exact test

4. Discussion

The current study has revealed that standardized polyherbal formulation of Cuminum cyminum, Murraya koenigii and Trigonella foenum-graecum showed beneficial effects at all three stages of investigation (laboratory, preclinical and clinical). Hydroalcoholic Soxhlet extraction was the most efficient method in terms of extraction efficiency and enabled the development of a phytochemically rich formulation which had several bioactive components. The polyherbal blend administration in preclinical evaluation effectively reduced the FBG, improved the antioxidant enzyme activities and biochemical markers of oxidative stress and hepatic functions. These results show that the formulation has an antihyperglycemic and antioxidant activity which can help to reduce the metabolic disturbance in the experimentally induced diabetic rats. The clinical stage also showed beneficial effect on blood glucose, PPBG, HbA1c, anthropometric indices, lipid profile, BP and liver enzyme levels in prediabetic adults who consumed polyherbal blend with exercise. Overall, these results indicate that the formulation may have played a role in enhancing glycemic control and metabolic well-being in addition to lifestyle modifications.

The results obtained are in line with previous studies pointing to medicinal spices/herbal preparations as potential antidiabetics. Singletary (2024) reviewed several culinary spices that contain compounds with biological activity that promote the antihyperglycemic effects observed in the present study such as cumin and fenugreek. Similarly, Merah et al., 2020, showed the high content of phenolic compounds and other phytochemicals in Cuminum cyminum, which have antioxidant properties that could help in regulating metabolism. Murraya koenigii, with its carbazole alkaloids and flavonoids, is also reported to have similar pharmacological properties that help alleviate oxidative stress and promote glucose homeostasis (Balakrishnan et al., 2020). Methodological studies that highlight the need for optimized extraction processes to maximize the recovery of biologically active components of plants also support the successful preparation of a phytochemically rich formulation using a hydroalcoholic extraction method (Srivastava, 2025; Shafodino et al., 2024). Moreover, using the streptozotocin-induced diabetic animals as a model in the present study was in line with the established experimental methods to assess antidiabetic measures and their metabolic impacts (Noshahr et al., 2020).

The outcomes of this investigation have significant inferences for prediabetes prevention and management. Standardised herbal extracts and systematic lifestyle changes could be a complementary approach to better glycemic control in the pre-diabetic phase. The translational study design with laboratory standardization, preclinical validation and human clinical evaluation also offers an integrated approach to the evaluation of herbal formulations and could be useful for the design of more evidence-based phytotherapeutic interventions. Furthermore, the concurrent improvement in lipid profile, blood pressure, and liver function parameters indicates that the positive effects of the polyherbal formulation might not be limited to glycemic control but could also impact overall metabolic health.

Although these results are promising, the study has several drawbacks. The intervention period was comparatively short so that long-term effectiveness and sustainability of the effects of the intervention observed was not possible. The clinical evaluation was limited by a small sample size, and included only adults with prediabetes, which may not provide generalizability to other groups. In addition, the study mainly assessed clinical and biochemical parameters, and did not examine the detailed molecular mechanisms which might account for the observed therapeutic effects.

Future studies are necessary to confirm the polyherbal formulation's long-term safety and effectiveness through larger multicenter randomised controlled trials with longer follow-up periods. Further studies on dose optimization, pharmacokinetic properties, molecular mechanisms and quality standardization of the formulation would be beneficial to reinforce the evidence base. The study of the effectiveness of the formulation among a variety of population and individuals with known type 2 diabetes may also help to broaden the range of therapeutic possibilities.

5. Conclusion

The present study showed that the development and preliminary evaluation of a standardized polyherbal mixture of Cuminum cyminum, Murraya koenigii, and Trigonella foenum-graecum is successful using a translational experimental approach involving laboratory preparation, preclinical evaluation, and human clinical evaluation. The highest extraction yield was obtained from hydroalcoholic Soxhlet extraction which also allowed the formulation of a phytochemically rich formulation with several bioactive constituents known for their antidiabetic activity. The polyherbal blend showed significant reductions in FBG and enhanced activities of antioxidant enzymes, along with modulation of the effect of oxidative stress and liver function indicators, suggesting its antihyperglycemic and antioxidant effects in the preclinical phase. Further clinical evaluation also revealed that, when the polyherbal formulation was given in combination with exercise, it produced more beneficial effects compared to exercise alone on FBG, blood pressure, waist circumference, body weight, body mass index, postprandial blood glucose, HbA1c, lipid profile, and liver enzymes. The formulation tolerability was also good with only a few adverse events reported, which indicated a favorable short-term safety profile. The results indicate that the combined effects of the three medicinal plants on glycemic control and general metabolic well-being in prediabetic adults may be due to the

complementary activities of their phytochemical constituents. The study as a whole is a piece of translation research that could be used as an adjunctive approach in slowing down the development of type 2 diabetes from prediabetes. However, further studies with higher number of patients and Longer follow-up times are required to confirm the formulation's long-term efficacy, safety, and clinical viability.

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