Advances in Bioresearch
Adv. Biores., Vol 16 (4) July 2025: 85-96

Print ISSN 0976-4585; Online ISSN 2277-1573
Journal's URL:http://www.soeagra.com/abr.html
CODEN: ABRDC3
DOI: 10.15515/abr.0976-4585.16.4.8596

Advances in Bioresearch

ORIGINAL ARTICLE

Prevalence and Correlates of Prediabetes in Rural and Urban Populations of Panchkula, India: A Cross-Sectional Study with Intervention Outcomes

Reema Goyal[1], Rakesh Sharma[3], Shiv Kumar[3], Rekha Kaushik[3], Sukriti Singh[2*]
[1-3]Department of Food Science and Technology, MMICT & BM (HM), MM(DU), Mullana, Ambala, Haryana, North India
*Corresponding author

ABSTRACT
Prediabetes represents a significant and growing public health concern globally and in India, with urban-rural disparities often observed. Understanding these differences is crucial for targeted interventions. The main focus of this study is to determine the prevalence of prediabetes and compare demographic, anthropometric, biochemical, clinical, and lifestyle characteristics among prediabetic adults (25–60 years) in rural and urban Panchkula. Secondary objectives included assessing the impact of nutrition education and a high-fiber diet intervention. A cross-sectional study was conducted, screening 1145 individuals, from whom 422 prediabetic participants were identified. Data were collected on demographics, anthropometry (Body Mass Index (BMI), waist circumference), biochemical parameters (Fasting Plasma Glucose (FPG), 2-hour Oral Glucose Tolerance Test (OGTT), Hemoglobin A1c (HbA1c)), clinical symptoms, physical activity, and dietary intake. Prediabetes was diagnosed using American Diabetes Association (ADA)/World Health Organization (WHO) criteria. Statistical analyses included t-tests and Chi-square tests. Prediabetes was more prevalent among individuals residing in urban areas (65.9%) compared to rural areas (34.1%). The mean age of prediabetic participants was 49.82±8.04 years, and 55.2% were female. No statistically significant differences were found in mean age (p=0.522), gender distribution (p=0.758), or BMI categories (p=0.466) between urban and rural prediabetic participants. Overall, 37% of prediabetic individuals were overweight or obese, and 13% exhibited central obesity, with no significant urban-rural differences within this prediabetic cohort. All participants (100%) had HbA1c levels in the prediabetic range (5.7%–6.4%). Commonly reported symptoms included extreme thirst (56.4%), extreme hunger (55.0%), and anxiety/depression (56.9%). Only 47.9% of participants were aware of their prediabetic condition. Physical activity levels were low (mean 115.6 minutes/week), and sedentary time was high. A nutrition education intervention significantly improved knowledge scores (p<0.001). A one-month high-fiber diet intervention in a subgroup (n=48) led to significant reductions in weight, BMI, waist circumference, and fasting glucose (all p<0.001). Prediabetes prevalence is high in Panchkula, particularly in urban areas. However, among those already prediabetic, key measured risk profiles were similar across urban and rural settings. The findings underscore the low awareness of prediabetes and the potential of lifestyle interventions to improve metabolic health and knowledge.
Keywords: *Prediabetes; Prevalence; Urban Population; Rural Population; Risk Factors; Anthropometry; Glycemic Control; Lifestyle; India.*

Received 20.05.2025 Revised 22.06.2025 Accepted 11.7.2025

How to cite this article:
Reema G, Rakesh S, Shiv K, Rekha K, Sukriti S. Prevalence and Correlates of Prediabetes in Rural and Urban Populations of Panchkula, India: A Cross-Sectional Study with Intervention Outcomes. Adv. Biores. Vol 16 [4] July 2025.85-96

INTRODUCTION
Prediabetes is a critical metabolic state characterized by glycemic levels that are higher than normal but do not meet the threshold for a diagnosis of type 2 diabetes mellitus (T2DM). Typically, this includes an impaired fasting glucose (FPG) ranging from 100 to 125 mg/dL, impaired glucose tolerance (IGT) with 2-hour post-load glucose values between 140 and 199 mg/dL following a 75g oral glucose load, or a glycated hemoglobin (HbA1c) level between 5.7% and 6.4% [4]. This condition serves as a crucial

window for preventive interventions, as a considerable proportion of individuals with prediabetes will progress to overt T2DM without lifestyle modification.

The global burden of prediabetes and diabetes is immense and continues to escalate. The International Diabetes Federation (IDF) estimated that in 2024, 589 million adults aged 20–79 years were living with diabetes, a figure projected to reach 853 million by 2050. Alarmingly, an additional 1.1 billion adults worldwide had impaired glucose tolerance or impaired fasting glycemia, predisposing them **to** an increased risk of developing T2DM [11].The IDF Diabetes Atlas 10th Edition (2021) had previously estimated that 541 million people had impaired glucose tolerance [10]. This escalating prevalence poses a substantial public health challenge, placing a significant burden on individuals, families, and healthcare systems globally. India, in particular, faces a burgeoning epidemic of diabetes and prediabetes, with a high number of individuals affected and a notable rate of conversion from prediabetes to T2DM. The economic consequences are profound, encompassing direct medical costs and indirect costs due to lost productivity. For instance, in the United States, the economic cost attributed to prediabetes was estimated at $43.4 billion in 2017 [8].

The pathophysiology of prediabetes typically involves a combination of insulin resistance, where cells in muscles, fat, and the liver do not respond effectively to insulin, and/or impaired pancreatic beta-cell function, leading to insufficient insulin secretion to overcome this resistance [15]. Several well-established risk factors contribute to the development of prediabetes. These include increasing age, a family history of diabetes mellitus, overweight or obesity as indicated by a high Body Mass Index (BMI), and central obesity characterized by an increased waist circumference. Furthermore, lifestyle factors such as physical inactivity and the adoption of unhealthy dietary patterns are strongly implicated [5].

Urbanization has been identified as a key driver of the T2DM and prediabetes epidemic. Studies conducted in various parts of India, including the state of Haryana where Panchkula is situated, have consistently reported a higher prevalence of diabetes and prediabetes in urban populations in comparison to their rural counterparts. These disparities are often attributed to significant lifestyle changes, including shifts towards more sedentary behaviors, increased consumption of energy-dense processed foods, and higher stress levels prevalent in urban environments. Kalra et al. [12] specifically documented a higher prevalence of diabetes in the urban Haryana.

A significant challenge in addressing prediabetes is its often asymptomatic nature, which contributes to a large proportion of undiagnosed cases. It is estimated that approximately 90% of adults with prediabetes are unaware of their condition [6]. This lack of awareness underscores the critical importance of early detection through systematic screening programs. Identifying individuals with prediabetes is paramount because lifestyle interventions, primarily focusing on dietary modifications and increased physical activity, have been proven effective in delaying or even preventing the progression to T2DM and its associated cardiovascular complications.

Despite the growing body of evidence on prediabetes, region-specific data, particularly from districts like Panchkula, detailing the prevalence and characteristics of prediabetic individuals across different settings (urban versus rural), remain limited. Understanding these local nuances is essential for developing targeted and effective public health strategies. The objectives of this study are as under:

1. To determine the prevalence of prediabetes among adults aged 25–60 years screened in the Panchkula district.
2. To compare the demographic, anthropometric, biochemical, clinical symptom profiles, physical activity levels, and dietary patterns of prediabetic individuals residing in rural and urban areas of Panchkula.
3. To evaluate the impact of a structured nutrition education program on knowledge regarding prediabetes management among the study participants.
4. To assess the effect of a one-month high-fiber dietary supplement on anthropometric and biochemical parameters in a subset of prediabetic participants who volunteered for this intervention.

MATERIAL AND METHODS

Study Design and Setting

A cross-sectional study design was executed to assess the prevalence and correlates of prediabetes. The study was conducted in various rural and urban areas within the Panchkula district, located in the state of Haryana, India.

Study Population and Sampling

A total of 1145 individuals aged between 25 and 60 years were initially screened from the general population of Panchkula district. From this screened population, 422 participants who were identified as having prediabetes were enrolled for this study. Inclusion criteria for the study were adults aged 25–60 years diagnosed with prediabetes based on the American Diabetes Association (ADA) or World Health Organization (WHO) criteria: a Fasting Plasma Glucose (FPG) level between 100 mg/dL and 125 mg/dL, or a 2-hour plasma glucose level between 140 mg/dL and 199 mg/dL during an Oral Glucose Tolerance Test (OGTT) with a 75g glucose load, or a Glycated Hemoglobin (HbA1c) level between 5.7% and 6.4%. Exclusion criteria include individuals with previously diagnosed diabetes, Co morbid Situation, Non Responding patients.

Ethical Considerations

The study protocol was approved by PGI, Rohtak, Haryana, India and informed consent was taken from all participants before including them for the study.

Data Collection Procedures

A series of assessments were conducted to gather comprehensive data from the 422 prediabetic participants.

Demographic Data Information regarding age, gender, area of residence (classified as rural or urban), self-reported knowledge of prediabetes (assessed as 'Yes' or 'No' via a questionnaire), and family history of diabetes (reported as 'Yes' or 'No') was collected using a pre-designed structured questionnaire.

Anthropometric Assessment Standardized procedures were used for all anthropometric measurements ie weight, Height, BMI, Weight Circumference

Biochemical Profile Venous blood samples were collected for biochemical analyses. Glycemic Markers includes Fasting Plasma Glucose (FPG), 2-hour post-load glucose from an OGTT (after administration of a 75g oral glucose load), HbA1c, and Random Plasma Glucose (RPG) levels were assessed. Hemoglobin (Hb) levels were also measured.

Clinical Symptoms Participants were systematically queried about the presence or absence of a range of clinical symptoms commonly associated with dysglycemia or diabetes. This was likely done using a standardized checklist or questionnaire, covering symptoms such as extreme thirst, extreme hunger, fatigue, anxiety/depression, frequent urination, vision problems, tingling or numbness, digestive issues, high or low blood pressure, and skin problems.

Physical Activity Assessment Physical activity levels over the preceding seven days were evaluated using a questionnaire (IPAQ). This assessment captured the frequency (days per week) and duration (minutes per day) of engagement in walking, moderate-intensity activities, and vigorous-intensity activities. Additionally, the average time spent sitting on a typical weekday (in minutes per day) was recorded to assess sedentary behaviour.

Dietary Intake Assessment Habitual dietary intake was assessed using a Food Frequency Questionnaire (FFQ). This tool was used to calculate mean frequency scores for the consumption of various food groups, including green leafy vegetables, roots and tubers, cereals, pulses, fruits, milk and milk products, animal products, beverages (such as tea, coffee, soft drinks), and miscellaneous items (like snacks and nuts). The frequency scores ranged from 0 (indicating never consumed) to 4 (indicating occasional consumption, though the exact scale interpretation for intermediate scores was not fully detailed beyond "frequently," "moderately," etc.).

Intervention Procedures

Two distinct interventions were implemented for the prediabetic participants.

Nutrition Education Intervention All 422 participants identified with prediabetes received a structured nutrition education session. This session was designed to enhance their understanding of balanced diets, the role of macronutrients, and specific dietary guidelines relevant to the management of prediabetes. To evaluate the effectiveness of this educational input, participants' knowledge levels were assessed using a validated questionnaire administered immediately before the session (pre-test) and again immediately after its conclusion (post-test). Knowledge scores were recorded for comparison.

Diet Modification Following the nutrition education component, participants were offered the opportunity to volunteer for a one-month dietary intervention involves consumption of Seed Powder (5-10g/Day). Fifty-eight participants initially volunteered for this part of the study. Out of these, 48 participants successfully completed the one-month intervention and returned for follow-up assessments. For this subgroup, key anthropometric parameters (Weight, BMI, WC) and biochemical markers (hemoglobin, fasting glucose) were measured at baseline (pre-intervention, before starting the supplement) and again after the one-month intervention period (post-intervention).

2.6. Statistical Analysis

All collected data were entered and analyzed using a SPSS-21. Descriptive statistics were calculated to summarize the characteristics of the study participants. Continuous variables (e.g., age, BMI, biochemical values) were presented as mean ± standard deviation (SD), while categorical variables (e.g., gender, area of residence, and presence of symptoms) were presented as frequencies (n) and percentages (%). Inferential statistical tests were employed to make comparisons between groups and to assess changes over time:

- **Independent Samples t-tests:** Used to compare the mean values of continuous variables (such as age and knowledge gain scores) between two independent groups (e.g., rural versus urban participants, male versus female participants).
- **Chi-square ($\chi 2$) tests:** Used to compare the proportions of categorical variables between different groups (e.g., gender distribution, BMI classification distribution, and waist circumference risk classification between rural and urban participants). Fisher's Exact Test was reported for 2x2 tables where appropriate.
- **Paired t-tests:** Used to compare mean values of continuous variables measured at two time points for the same individuals. This was applied to assess the change in knowledge scores (pre-test versus post-test) following the nutrition education intervention for all 422 participants, and to evaluate changes in anthropometric and biochemical parameters (baseline versus post-intervention) for the 48 participants who completed the diet modification. For all statistical tests, a p-value of less than 0.05 was considered to indicate statistical significance.

RESULTS

Participant Screening and Prediabetes Prevalence

From an initial screening of 1145 adults aged 25–60 years in the Panchkula district, 422 individuals (36.8%) were identified as having prediabetes based on the diagnostic criteria. These 422 participants constituted the cohort for the present study.

Socio demographic Characteristics of Prediabetic Participants (N=422)

The overall demographic profile of the 422 prediabetic participants is presented in Table 1. The mean age of the participants was 49.82±8.04 years. A majority of the participants were female (55.2%, n=233), while 44.8% (n=189) were male. Regarding their area of residence, 65.9% (n=278) resided in urban areas of Panchkula, and 34.1% (n=144) were from rural areas. Awareness of their prediabetic status was relatively low; only 47.9% (n=202) reported having prior knowledge of prediabetes, while 52.1% (n=220) were unaware. A family history of diabetes mellitus was reported by 39.1% (n=165) of the participants, whereas 60.9% (n=257) had no such history.

Table 1: Demographic Profile of Prediabetic Participants (N=422)

Variable	Category	n	%
Gender	Male	189	44.80%
	Female	233	55.20%
Area of Residence	Rural	144	34.10%
	Urban	278	65.90%
Knowledge of Prediabetes	Yes	202	47.90%
	No	220	52.10%
Family History of Diabetes	Yes	165	39.10%
	No	257	60.90%

Urban-Rural Comparisons of Demographic Characteristics

Age: The table 2 indicates the comparison of mean age of prediabetic participants from rural and urban areas. It was obtained by using independent samples t-test. As per results of the test, there was no statistically significant difference in the mean age between rural (50.17±8.06 years) and urban (49.64±8.04 years) participants (t(420)=0.640, p=0.522). This indicates a comparable age distribution across the two residential groups within this prediabetic cohort.

Table 2: Comparison of Age between Rural and Urban Prediabetic Participants (N=422)

Group Statistics & Independent T Test					
	Area of residence	N	Mean	Std. Deviation	Std. Error Mean
Age (in years)	Rural	144	50.17	8.060	.672
	Urban	278	49.64	8.043	.482
Mean Difference = 0.530					
p-value (Sig. 2-tailed) = 0.522					

Gender Distribution: The distribution of gender among prediabetic participants in rural and urban areas was compared using a Chi-square test (Table 3). In rural areas, 43.8% (n=63) were male and 56.3% (n=81) were female. In urban areas, 45.3% (n=126) were male and 54.7% (n=152) were female. The Chi-square test revealed no statistically significant difference in gender distribution between the rural and urban groups (χ2(1)=0.095,p=0.758). Both areas exhibited a slightly higher proportion of female participants among the prediabetic individuals.

Table 3: Gender Distribution between Rural and Urban Prediabetic Participants (N=422)

			Rural	Urban	
Gender	Male	Count	63	126	189
		% within Gender	33.3%	66.7%	100.0%
		% within Area of residence	43.8%	45.3%	44.8%
		% of Total	14.9%	29.9%	44.8%
	Female	Count	81	152	233
		% within Gender	34.8%	65.2%	100.0%
		% within Area of residence	56.3%	54.7%	55.2%
		% of Total	19.2%	36.0%	55.2%
Total		Count	144	278	422
		% within Gender	34.1%	65.9%	100.0%
		% within Area of residence	100.0%	100.0%	100.0%
		% of Total	34.1%	65.9%	100.0%

Anthropometric Profile of Prediabetic Participants (N=422)

The overall anthropometric characteristics of the prediabetic cohort are detailed in Table 4. The mean weight of the participants was 67.23±11.43 kg, and their mean height was 166.71±9.13 cm. The calculated mean BMI was 24.18±3.63 kg/m2, placing the average participant at the borderline between normal weight and the overweight category according to WHO classification. The mean waist circumference was 77.64±8.10 cm.

Table 4: Anthropometric Profile of Prediabetic Participants (N=422)

Parameter	Minimum	Maximum	Mean ± SD
Weight (kg)	41	108	67.23±11.43
Height (cm)	149	183	166.71±9.13
Body Mass Index (kg/m^2)	16	38	24.18±3.63
Waist Circumference (cm)	60	106	77.64±8.10

BMI Classification and Urban-Rural Comparison Based on WHO guidelines, 5.2% (n=22) of the prediabetic participants were classified as underweight, 57.8% (n=244) had a normal BMI, 29.9% (n=126) were overweight, and 7.1% (n=30) were obese. Cumulatively, 37.0% of the study population was either overweight or obese. Table 5 presents the BMI classification breakdown by rural and urban residence. In the rural group, 6.9% were underweight, 54.2% normal weight, 32.6% overweight and 6.3% obese. In the urban group, 4.3% were underweight, 59.7% normal weight, 28.4% overweight and 7.6% obese. A Chi-square test indicated that the distribution of BMI classification did not differ significantly between rural and urban prediabetic participants (χ2(3)=2.554,p=0.466). Although there were a slightly higher proportion of urban individuals in the normal and obese categories, these differences were not statistically meaningful.

Table 5: BMI Classification (WHO Guidelines) of Prediabetic Participants Overall and by Rural/Urban Residence (N=422)

BMI Category	Range (kg/m^2)	Overall n (%)	Rural (n=144) n (%)	Urban (n=278) n (%)	Chi-Square (p-value)
Underweight	< 18.5	22 (5.2%)	10 (6.9%)	12 (4.3%)	
Normal weight	18.5 – 24.9	244 (57.8%)	78 (54.2%)	166 (59.7%)	
Overweight	25.0 – 29.9	126 (29.9%)	47 (32.6%)	79 (28.4%)	
Obese	≥30.0	30 (7.1%)	9 (6.3%)	21 (7.6%)	
Total	—	422 (100.0%)	144 (100.0%)	278 (100.0%)	χ2(3)=2.554 (p=0.466)

Waist Circumference Risk and Urban-Rural Comparison Central obesity risk was assessed using gender-specific waist circumference thresholds (≥90 cm for males, ≥80 cm for females). Overall, 13.0% (n=55) of the prediabetic participants were classified as being at risk of central obesity. Among males, 7.4% (n=14 out of 189) were at risk, while among females, 17.6% (n=41 out of 233) were at risk. The prevalence of central obesity risk was similar when compared between rural and urban groups (Table 6). In the rural group, 12.5% (n=18) were at risk, while in the urban group, 13.3% (n=37) were at risk. A Chi-square test confirmed that this difference in waist circumference risk classification between rural and urban prediabetic participants was not statistically significant ($\chi2(1)=0.055, p=0.815$).

Table 6: Waist Circumference Risk Classification by Gender and by Area of Residence (N=422)

Classification Group	Parameter	At Risk n (%)	Not at Risk n (%)	Total n	Chi-Square (p-value)
Overall by Gender					
	Male (>90 cm)	14 (7.4%)	175 (92.6%)	189	
	Female (>80 cm)	41 (17.6%)	192 (82.4%)	233	
	Total Gender-specific	**55 (13.0%)**	**367 (87.0%)**	**422**	
By Area of Residence					
	Rural (n=144)	18 (12.5%)	126 (87.5%)	144	$\chi2(1)=0.055$ (p=0.815)
	Urban (n=278)	37 (13.3%)	241 (86.7%)	278	

Biochemical Profile of Prediabetic Participants (N=422)

The biochemical assessment confirmed the prediabetic status of the participants (Table 7). The mean FPG level was 108.61±10.87 mg/dL, with an estimated 81.0% of participants falling within the Impaired Fasting Glucose (IFG) range of 100–125 mg/dL. The mean 2-hour OGTT glucose level was 163.47±22.09 mg/dL, with an estimated 87.0% of participants categorized with Impaired Glucose Tolerance (IGT; 140–199 mg/dL). Critically, the mean HbA1c level was 5.99±0.68%, and 100% of the participants exhibited HbA1c levels within the prediabetic range of 5.7%–6.4%. The mean Random Plasma Glucose (RPG) was 129.74±6.08 mg/dL; an estimated 15% of participants had RPG values in the "borderline" range of 140–199 mg/dL as defined in the source material. The mean hemoglobin (Hb) level for the cohort was 14.22±2.34 g/dL.

Table 7: Biochemical Assessment of Prediabetic Participants (N=422)

Parameter	Mean ± SD	Prediabetic Range	% in Prediabetic Range
Fasting Plasma Glucose (mg/dL)	108.61±10.87	100–125 (IFG)	81.0% (estimated)
2-hr OGTT (mg/dL)	163.47±22.09	140–199 (IGT)	87.0% (estimated)
HbA1c (%)	5.99±0.68	5.7–6.4%	100%
Random Plasma Glucose (mg/dL)	129.74±6.08	140–199 (borderline)	~15% (estimated)
Hemoglobin (g/dL)	14.22±2.34	Gender-specific normal	Not applicable

Prevalence of Clinical Symptoms (N=422)

A variety of clinical symptoms were reported by the prediabetic participants (Table 8). The most frequently reported symptoms were extreme thirst (polydipsia), experienced by 56.4% (n=238) of individuals, and extreme hunger (polyphagia), reported by 55.0% (n=232). A notable 56.9% (n=240) of participants reported experiencing anxiety or depression. Fatigue was reported by 49.5% (n=209), and bad breath (halitosis) by 46.4% (n=196). Other symptoms were less common but still present in a significant portion of the cohort: vision problems (35.5%, n=150), digestive problems (36.5%, n=154), tingling or numbness in extremities (paresthesia) (27.5%, n=116), and high blood pressure (28.0%, n=118). Symptoms traditionally associated with more advanced glycemic dysregulation, such as frequent urination (polyuria), were reported by a smaller percentage (19.7%, n=83). Low blood pressure (10.2%, n=43) and skin problems (18.5%, n=78) were also noted.

Table 8: Frequency of Clinical Symptoms among Prediabetic Participants (N=422)

Symptom	Yes (n) (%)	No (n) (%)
Extreme Thirst	238 (56.4%)	184 (43.6%)
Extreme Hunger	232 (55.0%)	190 (45.0%)
Fatigue	209 (49.5%)	213 (50.5%)
Bad Breath	196 (46.4%)	226 (53.6%)
Anxiety/Depression	240 (56.9%)	182 (43.1%)
Frequent Urination	83 (19.7%)	339 (80.3%)
Vision Problems	150 (35.5%)	272 (64.5%)
Tingling/Numbness	116 (27.5%)	306 (72.5%)
Digestive Problems	154 (36.5%)	268 (63.5%)
High Blood Pressure	118 (28.0%)	304 (72.0%)
Low Blood Pressure	43 (10.2%)	379 (89.8%)
Skin Problems	78 (18.5%)	344 (81.5%)

Physical Activity and Sedentary Behavior Patterns (N=422)
The assessment of physical activity levels among the prediabetic participants revealed generally low engagement in exercise (Table 9). Vigorous physical activity was reported on an average of 0.35±1.13 days per week, with a mean daily duration of 3.63±11.89 minutes, culminating in a weekly total of only 13.9±49.6 minutes. Engagement in moderate-intensity activities was similarly infrequent, occurring on average 0.38±1.12 days per week for 2.84±8.84 minutes per day, resulting in a weekly total of 9.7±31.8 minutes. Walking was the most common form of physical activity, undertaken on an average of 3.11±2.49 days per week, with an average duration of 18.9±19.1 minutes per day, contributing to a weekly total of 89.9±101.8 minutes. The cumulative mean total physical activity (including walking, moderate, and vigorous exercise) was 115.6±128.8 minutes per week. This is below the World Health Organization's recommended minimum of 150 minutes of moderate-intensity physical activity per week for adults. In stark contrast, sedentary behaviour was notably high. Participants reported a mean sitting duration of 337.1±116.6 minutes per day on weekdays.

Table 9: Physical Activity Patterns of Prediabetic Participants (N=422)

Activity Type	**Days/Week (Mean ± SD)**	**Minutes/Day (Mean ± SD)**	**Total Minutes/Week (Mean ± SD)**
Vigorous Physical Activity	0.35±1.13	3.63±11.89	13.89±49.55
Moderate Physical Activity	0.38±1.12	2.84±8.84	9.69±31.83
Walking	3.11±2.49	18.93±19.15	89.93±101.82
Total Physical Activity	—	—	**115.56±128.76**
Sitting Time (Weekday)	—	337.06±116.57	—

Dietary Intake Patterns (N=422)
The dietary intake assessment, based on Food Frequency Questionnaire (FFQ) mean scores (scale 0=Never to 4=occasionally), indicated specific consumption patterns among the prediabetic participants (Table 10). Foods frequently consumed included roots and tubers (mean score 1.99±1.07) and cereals (1.95±0.64), suggesting a diet relatively high in carbohydrates. Fruits (1.85±1.01) and pulses (1.84±1.12) were consumed with moderate frequency. Conversely, intake of green leafy vegetables was infrequent (1.23±1.76), and milk and milk products were consumed at a low to moderate frequency (1.21±0.73). Animal products were rarely consumed, with a very low mean frequency score (0.54±1.08). Beverages (primarily tea/coffee/soft drinks) were consumed infrequently (0.73±0.61), and miscellaneous items like snacks and nuts were consumed occasionally (1.01±1.16).

Table 10: Mean Frequency Score of Food Group Intake among Prediabetic Participants (N=422)

Food Group	**Mean Score ± SD**	**Interpretation**
Cereals	1.95±0.64	Frequently consumed
Pulses	1.84±1.12	Moderately frequent intake
Green Leafy Vegetables	1.23±1.76	Infrequent consumption
Roots and Tubers	1.99±1.07	Fairly frequent consumption
Fruits	1.85±1.01	Moderate intake
Milk Products	1.21±0.73	Low to moderate intake
Animal Products	0.54±1.08	Rarely consumed
Beverages	0.73±0.61	Infrequent (mostly tea/coffee/soft drinks)
Miscellaneous (Snacks, Nuts)	1.01±1.16	Occasionally consumed

Scale: 0=Never to 4=Occasionally. Source:

Outcomes of Interventions
Impact of Nutrition Education on Knowledge Scores (N=422) A structured nutrition education session was administered to all 422 prediabetic participants. The intervention resulted in a statistically significant and substantial improvement in their nutrition-related knowledge scores (Table 11). The mean knowledge score increased from a baseline (pre-test) of 12.92±2.74 to 25.53±4.12 immediately following the session (post-test). This represented a mean knowledge gain of 12.61 points. A paired t-test confirmed the high statistical significance of this improvement (t- value = 54.652,p<0.001).
When analyzed by gender, male participants (n=189) exhibited a mean knowledge gain of 12.43±4.71 points, while female participants (n=233) showed a mean knowledge gain of 12.76±4.77 points. According to the results of independent samples t-test there is no statistically significant difference in the extent of knowledge improvement between males and females (p=0.489). Comparing by area of residence, rural participants (n=144) had a mean knowledge gain of 12.01±5.01 points, while urban

participants (n=278) had a mean knowledge gain of 12.92±4.57 points. Although urban participants demonstrated a slightly higher mean gain, this difference did not reach statistical significance (p=0.059), suggesting a potential trend but not a conclusive one.

Table 11: Knowledge Gain from Nutrition Education (Overall, by Gender, by Area of Residence) (N=422)

Parameter	Group	N	Pre-Test Mean ± SD	Post-Test Mean ± SD	Mean ± SD	p-value (Comparison)	t-value (Paired for Overall)
Overall	All	422	12.92±2.74	25.53±4.12	12.61±4.76*	< 0.001	-54.652
By Gender	Male	189			12.43±4.71	0.489 (M vs. F)	
	Female	233			12.76±4.77		
By Area of Residence	Rural	144			12.01±5.01	0.059 (R vs. U)	
	Urban	278			12.92±4.57		

Impact of Diet Modification on Anthropometric and Biochemical Parameters (N=48) Following the nutrition education, 48 prediabetic participants completed a one-month diet modification. This intervention led to statistically significant improvements in all measured anthropometric and biochemical parameters (Table 12).

Anthropometric Changes:

- Mean weight decreased by 1.33 kg, from 69.75±11.02 kg to 68.42±10.25 kg (p<0.001).
- Mean BMI decreased by 0.47 kg/m2, from 24.92±3.18 kg/m2 to 24.44±2.87 kg/m2 (p<0.001).
- Mean waist circumference significantly decreased by 1.10 cm, from 79.31±7.44 cm to 78.21±7.02 cm (p<0.001).

Biochemical Changes:

- Mean haemoglobin levels showed a statistically significant increase of 0.28 g/dL, rising from 14.42±2.23 g/dL to 14.69±1.88 g/dL (p=0.002).
- A highly significant and clinically relevant mean reduction in fasting glucose levels of 16.94 mg/dL was recorded. Levels dropped from a pre-intervention mean of 113.46±6.43 mg/dL to 96.52±6.07 mg/dL post-intervention (p<0.001).

Table 12: Changes in Anthropometric and Biochemical Parameters After One-Month High-Fiber Diet Intervention (n=48)

Parameter	Pre-Intervention Mean ± SD	Post-Intervention Mean ± SD	Mean Difference	p-value
Weight (kg)	69.75±11.02	68.42±10.25	1.33↓	< 0.001
BMI (kg/m^2)	24.92±3.18	24.44±2.87	0.47↓	< 0.001
Waist Circumference (cm)	79.31±7.44	78.21±7.02	1.10↓	< 0.001
Haemoglobin (g/dL)	14.42±2.23	14.69±1.88	0.28↑	0.002
Fasting Glucose (mg/dL)	113.46±6.43	96.52±6.07	16.94↓	< 0.001

DISCUSSION

The present study provides valuable insights into the prevalence of prediabetes and its associated characteristics among adults in the Panchkula district of Haryana, India, with a specific focus on urban-rural comparisons. Furthermore, it evaluates the impact of targeted nutrition education and dietary intervention on this at-risk population. The principal findings indicate a substantial prevalence of prediabetes (36.8% of those screened), with a higher proportion of prediabetic individuals residing in urban areas (65.9%) compared to rural areas (34.1%). Within this cohort of 422 prediabetic individuals, there were no statistically significant differences in mean age, gender distribution, BMI classifications, or central obesity risk between those from urban and rural settings. The study also highlights a concerning anthropometric profile, with 37% being overweight or obese, a significant clinical symptom burden including high rates of anxiety/depression, low levels of physical activity, specific dietary patterns, and notably low awareness of prediabetes. Both the nutrition education and diet interventions demonstrated positive outcomes.

Prevalence and Demographic Profile: Urban-Rural

The higher proportion of prediabetic individuals identified in urban areas of Panchkula aligns with broader epidemiological trends observed in India and other developing countries, where urbanization is often associated with non-communicable diseases like diabetes and prediabetes. Kalra *et al.* (2024) [12], in a study covering Haryana, also reported a higher prevalence of diabetes in urban areas compared to rural areas. This urban predominance is generally attributed to lifestyle transitions, including changes in

dietary habits towards processed foods, reduced physical activity, and increased psychosocial stress associated with urban living.
However, a key finding of this study is the lack of significant differences in mean age, gender distribution, BMI categories, and central obesity risk between the urban and rural *prediabetic* participants. This suggests that once individuals in Panchkula develop prediabetes, the measured demographic and adiposity-related risk factors are quite similar, regardless of their urban or rural residence. This observation might imply that the factors driving the higher overall prevalence of prediabetes in urban areas could be related to a greater proportion of the general urban population transitioning into prediabetes due to higher exposure to environment that promotes obesity or different lifestyle patterns *before* the onset of prediabetes. Alternatively, higher screening rates or awareness in urban areas could contribute to greater detection. The current study did note that awareness of diabetes was high (52.10% - this figure seems to refer to awareness of diabetes in general among rural population, not prediabetes awareness among urban prediabetics, which was 47.9% yes) and that higher knowledge levels in urban Panchkula could be due to better access to information and healthcare. If urban populations are more readily screened, a higher number of prediabetics would be identified, even if their individual risk factor profiles, once prediabetic, are similar to their rural counterparts. The mean age of the prediabetic cohort (approximately 50 years) is consistent with age being a significant risk factor for developing prediabetes and diabetes.
The level of awareness of prediabetes is low ie 52.1% were unaware they had the condition which is a critical public health concern. This aligns with national and international data, where a vast majority of individuals with prediabetes remain undiagnosed. Alvarez *et al.* [3] reported that about 90% of American adults with prediabetes are unaware of their condition. This "silent" nature of prediabetes significantly hampers efforts for early intervention and prevention of progression to T2DM. The finding that nearly 61% of participants had no family history of diabetes suggests that while family history is a known risk factor, a substantial proportion of prediabetes cases in this population may be attributable to other modifiable lifestyle and environmental factors.
Anthropometric and Biochemical Status
The mean BMI of the prediabetic cohort (24.18 kg/m2) was at the upper limit of the normal range, yet a significant 37% were classified as overweight or obese. This is consistent with findings by Chaudhary and Das (2019) [7], who also observed a strong association between higher BMI and prediabetes in an Indian population. The prevalence of central obesity, defined by increased waist circumference, was 13.0% overall, with females showing a higher risk (17.6%) than males (7.4%) using gender-specific cut-offs. Waist circumference is often considered a more sensitive indicator of metabolic risk than BMI, particularly in South Asian populations who may exhibit the "Asian Indian Phenotype" – characterized by higher body fat percentage and greater visceral adiposity at lower BMIs. Studies by Sathish *et al.* (2017; 2020) [13, 14] have emphasized the importance of waist circumference in predicting diabetes risk in Indian populations. The lack of significant difference in BMI categories and WC risk between urban and rural prediabetics in this Panchkula cohort further supports the notion that once prediabetes is established, these particular adiposity markers may not strongly differentiate between residential settings within this specific risk group. This could mean that the threshold for developing prediabetes related to adiposity is reached similarly in both groups, or that other unmeasured factors related to body composition or fat distribution play a role.
The biochemical profile conclusively confirmed the prediabetic status of all 422 participants, with 100% having HbA1c levels within the 5.7%–6.4% range. This highlights the utility of HbA1c as a reliable diagnostic tool in this population, reflecting average glycemic exposure over the preceding 2-3 months and not requiring fasting. High proportions also met FPG (81.0%) and OGTT (87.0%) criteria for prediabetes, underscoring the widespread glucose dysregulation. The OGTT is often considered more sensitive in detecting early disturbances in glucose metabolism. The mean FPG of 108.61 mg/dL and 2-hour OGTT of 163.47 mg/dL firmly place the cohort within established prediabetic ranges.
Clinical Symptoms
The clinical symptom profile revealed that extreme thirst (56.4%), extreme hunger (55.0%), and fatigue (49.5%) were commonly reported among prediabetic individuals in Panchkula. These symptoms, frequently linked with overt diabetes, may also occur in cases of prediabetes, attributable to variable glucose levels and the development of insulin resistance. The relatively lower reporting of frequent urination (19.7%) might reflect the earlier stage of glycemic dysregulation in prediabetes compared to established diabetes.
A particularly striking finding was the high prevalence of anxiety/depression, reported by 56.9% of the participants. This aligns with growing evidence linking prediabetes and mental health issues. A meta-

analysis by Yu and Wan (2024) [16] found that prediabetes was associated with a higher prevalence of depression. Potential mechanisms include chronic stress responses, hypothalamic-pituitary-adrenal (HPA) axis dysregulation, systemic inflammation, and associated lifestyle factors common to both conditions. This high comorbidity underscores the need for integrated care approaches that address both metabolic and mental health in individuals with prediabetes. The observation of bad breath (46.4%) could be linked to dry mouth (xerostomia) or changes in oral microbiome composition due to hyperglycemia. The presence of other symptoms like vision problems, digestive issues, and tingling/numbness, even if less frequent, points to the systemic nature of metabolic disturbances even in the prediabetic stage.

Lifestyle Factors: Physical Activity and Dietary Intake

The assessment of physical activity revealed alarmingly low levels among the prediabetic participants. The mean total physical activity was only 115.6±128.8 minutes per week, falling short of the WHO and ADA recommendation of at least 150 minutes of moderate-intensity activity per week. This low activity level, coupled with high reported weekday sitting time (337.1±116.6 minutes per day), indicates a predominantly sedentary lifestyle, which is a major modifiable risk factor for insulin resistance and progression to T2DM.

Dietary intake patterns also raised concerns. The diet appeared to be heavily reliant on carbohydrate-rich staples like cereals and roots/tubers, with relatively infrequent consumption of nutrient-dense foods such as green leafy vegetables and animal products. Low intake of fruits and milk products was also noted. Such dietary patterns, characterized by high intake of refined carbohydrates and low variety of essential micronutrients, are associated with increased insulin resistance and poorer glycemic control [2]. These findings highlight critical areas for lifestyle interventions focusing on increasing physical activity and promoting a balanced, nutrient-rich diet.

Impact of Nutrition Education and High-Fiber Diet Interventions

The nutrition education intervention proved highly effective in enhancing knowledge about prediabetes and its management. The mean knowledge score nearly doubled post-intervention, with a highly significant mean gain of 12.61 points ($p<0.001$). This substantial improvement suggests that the educational content and delivery method were appropriate for this population and that participants were receptive to learning. The effectiveness was comparable across genders, and while urban participants showed a slightly higher, non-significant trend in knowledge gain ($p=0.059$), the program demonstrated broad applicability. This aligns with literature supporting nutrition education as a cornerstone of diabetes self-management and prevention programs.

The one-month diet modification undertaken by a subset of 48 participants yielded significant and clinically meaningful improvements in both anthropometric and biochemical parameters. The observed mean reductions in weight (1.33 kg), BMI (0.47 kg/m2), and waist circumference (1.10 cm) are particularly important, as even modest weight loss can improve insulin sensitivity and reduce T2DM risk. The most notable biochemical change was the substantial mean reduction in fasting glucose by 16.94 mg/dL ($p<0.001$), shifting many participants towards normoglycemia. These benefits are well-supported by research demonstrating the positive effects of increased dietary fiber on glycemic control, body weight, and other metabolic markers in individuals with prediabetes or diabetes.

An intriguing finding was the statistically significant increase in hemoglobin levels (0.28 g/dL, $p=0.002$) in the high-fiber diet group. While high phytate content in some fiber sources can inhibit non-heme iron absorption, several mechanisms could explain this positive outcome. The "high-fiber food supplements" might have been fortified with iron or other hematinics. Certain prebiotic fibers (e.g., inulin, FOS, GOS) can enhance iron absorption by promoting a healthier gut microbiome and increasing short-chain fatty acid production, which lowers colonic pH and upregulates iron transporters [1]. An overall improvement in gut health due to increased fiber could also lead to better absorption of various nutrients, including iron, from the diet. Furthermore, high-fiber diets are associated with reduced systemic inflammation, and since chronic inflammation can impair erythropoiesis, its reduction could improve iron utilization [9]. The nutrition education might also have encouraged overall dietary improvements. Without details on the supplement's composition, the exact mechanism remains speculative but warrants further investigation.

The relatively low uptake for the dietary intervention (only 58 of 422, or 13.7%, volunteered, with 48 completing), despite significant knowledge gains from education, highlights the well-documented gap between acquiring knowledge and translating it into sustained behavioral action. This suggests that factors beyond knowledge, such as perceived difficulty, cost, taste, or lack of ongoing support, act as barriers, emphasizing the need for comprehensive behavioral change strategies in addition to education.

CONCLUSION

Prediabetes is highly prevalent among adults aged 25-60 years in Panchkula district, with a notably larger proportion of affected individuals residing in urban areas. This aligns with general trends of increasing NCD burdens in urbanized settings. However, within the cohort of individuals already diagnosed with prediabetes, key measured risk factors such as mean age, gender distribution, and adiposity levels (BMI categories and central obesity risk) were found to be similar between those from rural and urban backgrounds. This suggests that while factors leading to the *development* of prediabetes may differ or be more intense in urban settings (or detection rates are higher), the characteristics of individuals once they enter the prediabetic state appear comparable in this population based on the parameters assessed.

The study highlights a significant lack of awareness regarding prediabetes, with over half of the participants being unaware of their condition. Concerning lifestyle patterns, including low physical activity, high sedentary time, and dietary habits skewed towards carbohydrate staples with insufficient intake of nutrient-rich foods, are common among these prediabetic individuals and represent key targets for public health interventions.

The findings demonstrate the potential of structured nutrition education to significantly improve knowledge related to prediabetes management across different demographic subgroups. Furthermore, a short-term high-fiber dietary intervention showed promising results in improving anthropometric measures and, critically, fasting glucose levels in a subset of motivated participants. The observed increase in hemoglobin with this intervention is an interesting ancillary finding requiring further exploration.

Overall, this study underscores the urgent need for targeted public health strategies focusing on early detection through screening, raising awareness, and implementing effective lifestyle modification programs to address the growing challenge of prediabetes in Panchkula and similar settings in India. Addressing the knowledge-action gap by incorporating behavioral support strategies alongside education will be crucial for achieving sustained health improvements.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to all the participants who volunteered their time and cooperation for this study.

Conflict of Interest Statement: nil

REFERENCES

1. Ahmad, A., Amir, R. M., & Arshad, H. (2021). Effect of iron fortification and prebiotics on iron biomarkers in anemic rats. *Brazilian Journal of Biology*, ***82***, e253500.
2. Alaradi, H., Al-Hooti, S., Al-Aamri, M., Al-Hamad, N., & Al-Muhannadi, F. (2021). Association between Dietary Pattern, Weight Loss, and Diabetes among Adults with a History of Bariatric Surgery: Results from the Qatar Biobank Study. *Nutrients*, *16*(14), 2194.
3. Alvarez, M. I. T., Abdullah, A. A. A., & Ahmad, I. (2023). Assessing the Awareness of Prediabetes and Its Risk Factors among medical students. *Journal of Pharmaceutical Negative Results*, 2521-2527.
4. American Diabetes Association Professional Practice Committee; Summary of Revisions: Standards of Care in Diabetes—2025. ***Diabetes Care*** 1 January 2025; 48 (Supplement_1): S6–S13. https://doi.org/10.2337/dc25-SREV
5. Bansal, N. (2015). Prediabetes diagnosis and treatment: A review. *World Journal of Diabetes*, ***6***(2), 296–303.
6. Centers for Disease Control and Prevention. (2023). *National Diabetes Statistics Report* (May 2023)
7. Chaudhary, N., & Das, S. (2019). Prediabetes in children and adolescents: A ticking bomb! *World Journal of Diabetes*, ***10***(10), 509–516.
8. Dall, T. M., Yang, W., Halder, P., Pang, B., Massi-Benedetti, M., & Wintfeld, N. (2019). The Economic Burden of Elevated Blood Glucose Levels in 2017: Diagnosed and Undiagnosed Diabetes, Gestational Diabetes Mellitus, and Prediabetes. *Diabetes Care*, ***42***(9), 1661–1668.
9. Husmann, A., Theurl, I., & Weiss, G. (2022). Inflammation and erythropoiesis. *Best Practice & Research Clinical Haematology*, ***35***(3), 101378.
10. International Diabetes Federation. (2021). *IDF Diabetes Atlas* (10th ed.).
11. International Diabetes Federation. (2024). *Facts & figures*.
12. Kalra, B., Sharma, U. K., Pujani, M., & Anuradha, J. (2024). Prevalence and Risk of Type 2 Diabetes Mellitus and Dyslipidaemia in Urban-Rural Younger, Middle-Aged, and Elderly Indians. *Chettinad Health City Medical Journal*, *14*(1), 79-87.
13. Sathish, T., et al. (2017). Obesity indicators that best predict type 2 diabetes in an Indian population: insights from the Kerala Diabetes Prevention Program. *British Journal of Nutrition*, ***117***(12), 1731-1738.

14. Sathish, T., et al. (2020). Risk assessment of type 2 diabetes among the adult population using Indian Diabetes Risk Score: a community-based cross-sectional study in Central India. *International Journal of Community Medicine and Public Health*, ***7***(12), 4825.
15. Tabák, A. G., Herder, C., Rathmann, W., Brunner, E. J., & Kivimäki, M. (2012). Prediabetes: a high-risk state for diabetes development. *The Lancet*, *379*(9833), 2279–2290.
16. Yu, Y., & Wan, W. (2024). Association between prediabetes and depression: A meta-analysis. *PLOS ONE*, ***19***(8), e0307428.