

A CASE-CONTROL STUDY ON DIETARY PATTERNS AND RISK OF TYPE 2 DIABETES IN PAKISTANI ADULTS

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ABSTRACT

Although type 2 Diabetes Mellitus is a rapidly expanding public health concern in Pakistan, little is known about how dietary patterns affect the risk of the disease on this population. A culturally modified food frequency questionnaire was used in this case-control study to measure dietary intake in 225 newly diagnosed T2DM cases and 225 Matched controls. Three main nutritional patterns were found using principal component analysis. A substantially reduced incidence of type 2 diabetes was linked to a diet high in plant proteins, calcium, potassium, vitamins A, C, B2 and dietary fibre. Poor glycaemic control in people with diabetes was found to be independently associated with excessive sugar intake, low fibre consumption, and irregular meal frequency.

Keywords: Type 2 diabetes mellitus, Dietary patterns, Nutrient patterns, Glycemic control, Pakistani adults, Case-control study.

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INTRODUCTION

Type 2 diabetes mellitus ranks among the most pressing health challenges we face today. This metabolic condition develops when the body becomes resistant to insulin and the pancreatic beta cells that produce insulin gradually fail, leading to persistently high blood sugar and complications affecting multiple organ systems. The International Diabetes Federation estimated that in 2019, roughly 463 million adults aged 20 to 79 worldwide—about 9.3% of this age group—had diabetes. Their projections suggest this number will climb to 578 million by 2030 and possibly reach 700 million by 2045 [1].

Countries with developing economies bear an unfair share of this burden, accounting for roughly 80% of all people with T2DM globally. Pakistan holds a particularly worrying position, ranking third worldwide in diabetes prevalence after China and India. With about 19 million adults affected, Pakistan faces enormous challenges in both preventing new cases and caring for those already diagnosed. The World Health Organization has

identified diabetes as the seventh leading cause of death worldwide, underscoring just how urgent this problem has become [2].

Many factors drive the rising diabetes rates, including rapid urbanization, economic development, aging populations, and shifting dietary habits. Over recent decades, Pakistan has undergone dramatic lifestyle changes. People now eat far more processed foods, refined carbohydrates, and calorie-dense meals while moving their bodies less. These changes have played a major role in the growing diabetes crisis in the region.

What we eat matters enormously for both preventing and managing T2DM. While Western populations have been studied extensively regarding how different dietary patterns relate to diabetes—looking at both individual nutrients and overall eating habits—nutritional science has increasingly moved away from analysing single nutrients. Instead, researchers now examine whole dietary patterns, which gives us a more complete picture of how combinations of foods and nutrients work together to influence

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disease risk. Individual nutrients might have small effects that become much clearer when we look at the bigger dietary picture [3].

Strong evidence links specific ways of eating to T2DM risk. Healthy dietary patterns—think plenty of vegetables, fruits, whole grains, legumes, nuts, and lean proteins—consistently show protective effects against diabetes. Meanwhile, Western-style diets heavy in red meat, processed meats, refined grains, sugary drinks, and fried foods tend to increase diabetes risk.

Recent research suggests that analysing nutrient patterns might reveal insights that traditional dietary pattern methods miss. Studies examining how specific nutrient combinations relate to metabolic problems have found particular groupings associated with disease risk. For example, nutrient patterns featuring vitamins A, C, B6, potassium, and dietary fibre have been linked to better insulin function and lower risk of insulin resistance [4].

However, most dietary pattern research has focused on Western populations, leaving us with limited evidence from South Asian countries like Pakistan. Pakistani dietary traditions differ substantially from Western eating patterns, with staples like rice, wheat flatbreads (roti), lentils (Dal), and vegetable curries forming the foundation of most meals. As Pakistan becomes more urbanized and affluent, traditional foods are increasingly supplemented—or replaced—by processed items, sweetened beverages, and fast food. How these changing dietary patterns influence T2DM risk in Pakistani populations remains poorly understood, limiting our ability to develop effective prevention strategies tailored to local contexts.

Beyond broad dietary patterns, specific nutrients have shown promise in preventing or managing T2DM. Dietary fibre, especially soluble fiber, helps slow glucose absorption, keeping blood sugar more stable. Studies consistently show that people who eat more fibre face lower diabetes risk. Complex carbohydrates from whole grains offer similar benefits compared to refined carbohydrates that cause rapid blood sugar spikes.

Plant-based proteins appear to offer advantages over animal proteins for blood sugar management. Research comparing the two suggests that replacing animal protein with plant protein improves glycaemic control in people with diabetes. This benefit might stem from plant proteins' effects on insulin sensitivity and their association with healthier overall dietary patterns [5].

Various vitamins and minerals also contribute to diabetes prevention. Vitamin C acts as a powerful antioxidant that might protect pancreatic beta cells from damage, potentially helping prevent. Vitamin A plays a role in insulin secretion and glucose metabolism, with deficiency linked to worse metabolic control. B vitamins, particularly B1, B2, and B6, participate in carbohydrate metabolism and

energy production, influencing how the body handles glucose. Minerals including magnesium, potassium, and calcium have been associated with better insulin sensitivity and reduced diabetes risk.

While we know individual nutrients matter, they don't work in isolation. The concept of nutrient patterns acknowledges that people consume foods containing multiple nutrients that interact in complex ways. This approach may better capture the biological reality of how diet influences health compared to studying single nutrients. Yet despite growing interest in nutrient patterns, few studies have examined them in Pakistani populations or other South Asian contexts, where dietary habits differ markedly from Western patterns [6].

Most existing research on dietary patterns and T2DM comes from Western or East Asian populations. Pakistani dietary habits reflect a unique blend of cultural traditions, regional variations, and recent changes driven by urbanization and globalization. Traditional Pakistani diets typically emphasize grains, legumes, and vegetables, with moderate amounts of dairy and meat. However, economic development has brought increased consumption of processed foods, refined carbohydrates, and sugar-sweetened beverages, particularly in urban areas [7].

We know relatively little about how these evolving dietary patterns relate to diabetes risk among Pakistanis. The few existing studies have used methods that may not fully capture the complexity of Pakistani eating habits or have been limited by small sample sizes. Additionally, most previous research has examined either individual nutrients or broad food groups, rather than looking at nutrient patterns that might reveal important combinations. Understanding these relationships matters enormously for public health. Pakistan faces a rapidly growing diabetes burden that threatens to overwhelm its healthcare system. Evidence-based dietary interventions could help prevent new cases and improve management of existing ones, but such interventions must be grounded in local dietary patterns and food availability. Generic Western dietary recommendations may not translate effectively to Pakistani contexts where food choices, meal structures, and cultural food practices differ substantially.

This study aims to address these knowledge gaps by examining nutrient patterns among Pakistani adults and their relationship to T2DM risk. By using principal component analysis to identify prevalent nutrient patterns in the Pakistani diet and then examining their association with diabetes, we hope to provide evidence that can inform culturally appropriate prevention strategies. We hypothesize that nutrient patterns rich in fibre, plant proteins, and protective vitamins and minerals will be associated with reduced T2DM risk, while patterns high in sugar and refined carbohydrates will show increased

risk. Additionally, we examine how specific dietary behaviours—including meal frequency, sugar intake, and fibre consumption—relate to glycaemic control among people already diagnosed with diabetes [8].

METHODS

Study Design and Participants

We conducted this case-control study between January and December 2024 at major tertiary care hospitals across Pakistan. We recruited 450 participants total: 225 newly diagnosed T2DM cases and 225 matched controls without diabetes [9]. Participants ranged from 25 to 80 years old. Cases included adults recently diagnosed with T2DM (within the past 6 months) based on standard criteria: fasting plasma glucose ≥ 126 mg/dL or 2-hour glucose ≥ 200 mg/dL during oral glucose tolerance testing, or HbA1c $\geq 6.5\%$. For each case, we selected one control matched by age (± 5 years), sex, and geographic region who had normal glucose tolerance confirmed by HbA1c $< 5.7\%$.

We excluded people with type 1 diabetes, gestational diabetes, or diabetes secondary to other conditions. We also excluded those with severe kidney or liver disease, cancer, or conditions requiring special diets, as well as pregnant or breastfeeding women. All participants provided written informed consent, and the institutional ethics committee approved this study according to the Declaration of Helsinki.

Dietary Assessment

To capture dietary intake, we used a semi-quantitative food frequency questionnaire containing 168 items specifically adapted for Pakistani foods and eating patterns. This FFQ includes commonly consumed foods across different regions of Pakistan, with portion sizes based on local measurements and household units. Trained nutritionists conducted face-to-face interviews, asking participants about their usual frequency of consumption for each food item over the past year. Response options ranged from "never or less than once per month" to "multiple times per day."

We converted frequency responses to daily intake amounts and calculated nutrient content using Pakistani food composition tables supplemented by international databases where local data were unavailable. For each participant, we computed total daily intake of 25 nutrients including macronutrients (proteins, fats, carbohydrates, fibre), vitamins (A, C, D, E, B1, B2, B3, B6, B12, folate, pantothenic acid), and minerals (calcium, phosphorus, iron, zinc, magnesium, potassium, sodium, copper).

We also collected information about specific dietary behaviours relevant to diabetes risk, including typical number of meals per day, frequency of sugar consumption (added sugar, sweets, sugar-sweetened beverages), and intake of fruits and vegetables. These questions used simple categories that

participants could easily answer without extensive nutritional knowledge.

Biochemical Measurements

We measured HbA1c for all participants using standardized high-performance liquid chromatography methods. Blood samples were collected after an overnight fast and processed within 2 hours. HbA1c reflects average blood glucose levels over the previous 2-3 months, making it a reliable indicator of glycaemic control. We defined good glycaemic control as HbA1c $< 7\%$, consistent with international guidelines. For participants with diabetes, we also recorded fasting blood glucose and, when available, postprandial glucose levels to provide additional context about glycaemic management [10].

Assessment of Covariates

We collected demographic information including age, sex, education level, occupation, and monthly household income through structured interviews. We measured height and weight using calibrated equipment and calculated body mass index (BMI) as weight in kilograms divided by height in meters squared. We categorized participants as normal weight (BMI < 25 kg/m²), overweight (25-29.9 kg/m²), or obese (≥ 30 kg/m²) based on standard cutoffs.

Physical activity was assessed using the International Physical Activity Questionnaire short form (IPAQ Research Committee, 2005), which asks about time spent in vigorous and moderate-intensity activity and walking during the past week. We classified participants as having low, moderate, or high physical activity levels based on IPAQ scoring protocols. We recorded smoking status as never, former, or current smoker, and asked about family history of diabetes in first-degree relatives. For participants with diabetes, we documented disease duration, current medications, and presence of diabetes-related complications through medical record review and patient interview. This information helped us account for disease severity and treatment intensity when examining dietary associations with glycaemic control.

RESULTS

Participant Characteristics

Our final analysis included 450 participants: 225 cases with newly diagnosed T2DM and 225 matched controls. Table 1 shows their baseline characteristics. Mean age was 52.4 ± 11.3 years, with 54% female participants. As expected, cases had significantly higher BMI than controls (28.7 ± 4.2 vs. 24.9 ± 3.6 kg/m², $p < 0.001$) and were more likely to be obese (48% vs. 18%, $p < 0.001$). Cases also reported lower physical activity levels and were more likely to have a family history of diabetes (62% vs. 35%, $p < 0.001$).

Educational levels varied, with about 40% of participants having completed secondary education or higher. Most participants (65%) lived in urban

areas, reflecting recruitment from major cities. Monthly household income ranged widely, though most families fell into middle-income brackets based on Pakistani economic data. Smoking prevalence was relatively low (18% overall), with current smoking more common among men than women[11].

Identified Nutrient Patterns

Principal component analysis identified three distinct nutrient patterns that together explained 47.2% of the variance in nutrient intake (Table 2). Nutrient Pattern 1 (explaining 18.3% of variance) was characterized by high loadings for sucrose, animal proteins, vitamins E, B1, and B12, along with calcium, phosphorus, zinc, and potassium. This pattern generally reflected diets higher in animal products, processed foods, and added sugars[12].

Nutrient Pattern 2 (explaining 15.8% of variance) featured dietary fibre, plant proteins, vitamin D, riboflavin (B2), pantothenic acid, copper, and magnesium. This pattern was associated with legumes, dairy products, and fortified foods. Nutrient Pattern 3 (explaining 13.1% of variance) combined dietary Fiber and plant proteins with vitamins A, C, and B2, plus calcium and potassium. This pattern primarily reflected diets rich in fruits, vegetables, and plant-based foods.

When we examined how these patterns correlated with actual food consumption, Pattern 1 scores were higher among people who ate more meat, fried foods, sweets, and processed snacks. Pattern 2 associated with consumption of dairy products, lentils, beans, and fortified cereals. Pattern 3 showed the strongest correlation with fruit and vegetable intake, whole grains, and traditional Pakistani vegetable dishes.

Nutrient Patterns and T2DM Risk

Table 3 presents associations between nutrient pattern tertiles and T2DM risk. After adjusting for age, sex, BMI, physical activity, smoking, and family history of diabetes, Nutrient Pattern 3 showed a significant inverse association with T2DM. Participants in the highest tertile (those whose diets most closely matched this plant-rich pattern) had 48% lower odds of having diabetes compared to the lowest tertile (OR: 0.52, 95% CI: 0.30-0.89, P for trend = 0.039). This protective effect remained significant even after full adjustment for confounders.

We found no significant associations between Nutrient Pattern 1 or Pattern 2 and T2DM risk in fully adjusted models. While Pattern 1 showed a suggestive trend toward increased risk in age- and sex-adjusted analyses (OR for highest vs. lowest tertile: 1.42, 95% CI: 0.89-2.26), this association weakened and lost statistical significance after adjusting for BMI and other confounders (OR: 1.18, 95% CI: 0.70-1.99). This suggests that any apparent effect of Pattern 1 on diabetes risk might be

mediated through obesity rather than representing an independent dietary effect [13].

When we examined individual nutrients that loaded heavily on Pattern 3—vitamins A, C, and B2, fiber, plant protein, calcium, and potassium—in sensitivity analyses, most showed inverse associations with T2DM in the expected direction, though not all reached statistical significance individually. This supports the idea that these nutrients work together as a pattern rather than through isolated effects [14].

Dietary Behaviours and Glycemic Control

Among the 225 participants with T2DM, we had complete dietary and HbA1c data for 177 individuals (mean age 54.0 ± 10.6 years, 55% female). Average HbA1c was $8.1 \pm 1.6\%$, with 66.7% showing poor glycaemic control (HbA1c $\geq 7\%$). We found striking relationships between specific dietary behaviours and blood sugar management.

Sugar consumption showed a clear dose-response relationship with HbA1c (Table 4). Participants consuming more than 2 servings daily of sugary foods and beverages had average HbA1c of $8.6 \pm 1.7\%$, significantly higher than those consuming less than 1 serving daily ($7.5 \pm 1.1\%$, $p = 0.011$) (Khawar Rahman et al., 2025). This relationship remained significant even after adjusting for diabetes duration, medication use, BMI, and physical activity. Translated into clinical terms, high sugar consumers were 2.67 times more likely to have poor glycaemic control (AOR = 2.67, 95% CI: 1.39-5.12, $p = 0.003$). Fiber intake showed an inverse pattern. People eating fewer than 5 servings of fibre-rich foods (fruits, vegetables, whole grains, legumes) daily had worse glycaemic control (HbA1c $8.3 \pm 1.5\%$) than those consuming more than 10 servings ($7.4 \pm 1.2\%$, $p = 0.004$). Low fibre intake was independently associated with 2.45-fold higher odds of poor control (AOR = 2.45, 95% CI: 1.19-5.02, $p = 0.015$). The median fibre intake in our sample was only 18 grams daily, well below the recommended 25-30 grams, suggesting widespread inadequate fibre consumption.

Meal frequency also mattered. People eating 2 or fewer meals daily—often skipping breakfast or combining meals—had significantly worse glycaemic control than those eating 3-4 regular meals (HbA1c $8.4 \pm 1.6\%$ vs. $7.6 \pm 1.3\%$, $p = 0.006$). Irregular eating patterns were associated with 2.21-fold higher odds of poor control (AOR = 2.21, 95% CI: 1.02-4.79, $p = 0.045$) after adjusting for confounders including total caloric intake, suggesting an effect beyond simply how much people ate.

Subgroup Analyses

We examined whether the protective association of Nutrient Pattern 3 varied across subgroups defined by age, sex, BMI, and physical activity. The inverse association appeared strongest among participants

under 55 years (OR for highest vs. lowest tertile: 0.38, 95% CI: 0.18-0.82) compared to older adults (OR: 0.68, 95% CI: 0.32-1.43), though the interaction term did not reach statistical significance (p for interaction = 0.18).

The protective effect seemed slightly more pronounced among women (OR: 0.44, 95% CI: 0.21-0.91) than men (OR: 0.61, 95% CI: 0.29-1.31), but again without significant statistical interaction (p = 0.47). When we stratified by BMI, the association remained significant among overweight and obese participants (OR: 0.48, 95% CI: 0.26-0.88) but not among normal-weight individuals (OR: 0.73, 95% CI: 0.24-2.21), possibly reflecting the smaller sample size in the normal-weight group.

Physical activity did not appear to modify the nutrient pattern association. Both active and sedentary participants showed similar protective effects for Pattern 3, suggesting that diet and exercise contribute independently to diabetes risk rather than one substituting for the other [12].

DISCUSSION

This case-control study examined how nutrient patterns relate to T2DM risk in Pakistani adults—a population facing a rapidly growing diabetes burden yet remaining understudied regarding dietary influences. We identified three distinct nutrient patterns through principal component analysis and found that the pattern characterized by plant proteins, dietary fibre, vitamins A, C, and B2, along with calcium and potassium (Pattern 3) was associated with nearly 50% lower diabetes risk. Among people already diagnosed with diabetes, we found that excessive sugar intake, insufficient fibre consumption, and irregular meal timing independently predicted poor glycaemic control.

These findings carry important implications for diabetes prevention and management in Pakistan, where dietary interventions must be culturally appropriate and economically feasible. The protective pattern we identified aligns with traditional Pakistani dietary practices emphasizing vegetables, lentils, and whole grains, suggesting that promoting these traditional foods might offer a more effective prevention strategy than importing Western dietary guidelines [15].

Our finding that Nutrient Pattern 3 protects against T2DM aligns with previous research showing benefits of plant-based diets, though most prior studies focused on food groups rather than nutrient patterns. A case-control study in Lebanon similarly found that patterns emphasizing fruits, vegetables, and whole grains reduced diabetes risk. Research from Iran examining nutrient patterns and metabolic syndrome reported comparable results, with patterns high in vitamins A and C and fibre showing protective effects.

The biological mechanisms behind this protective pattern likely involve multiple pathways. Dietary fibre slows carbohydrate absorption, leading to more

gradual rises in blood glucose and reduced insulin demand. This gives pancreatic beta cells a break from constantly producing high insulin levels, potentially preserving their function over time. Plant proteins, compared to animal proteins, may improve insulin sensitivity through effects on amino acid composition, gut hormone secretion, and the gut microbiome.

The specific vitamins and minerals that loaded on Pattern 3 each contribute to glucose metabolism in distinct ways. Vitamin C functions as a powerful antioxidant, potentially protecting beta cells from oxidative damage caused by chronic hyperglycaemia. Vitamin A influences insulin gene expression and secretion. Vitamin B2 (riboflavin) participates in energy metabolism and might influence insulin sensitivity. Potassium and calcium both play roles in insulin secretion and action at the cellular level [7].

What makes nutrient pattern analysis valuable is that it captures these combined effects, recognizing that people eat meals containing multiple nutrients simultaneously. The whole may be greater than the sum of its parts—combinations of nutrients might work synergistically in ways that studying individual nutrients misses. For example, vitamin C enhances iron absorption from plant foods, while fibre modifies the glycaemic response to carbohydrates consumed in the same meal.

Among participants with diabetes, we found strong associations between specific dietary behaviours and blood sugar management. The detrimental effect of high sugar consumption on glycaemic control is well established, but our findings quantify this relationship in a Pakistani context where sugar consumption patterns differ from Western populations. Many Pakistani traditional sweets and beverages contain substantial added sugar, and increasing consumption of sugary soft drinks accompanies urbanization [16].

The 1.1% difference in HbA1c between high and low sugar consumers that we observed translates to clinically meaningful differences in diabetes complications risk. Each 1% increase in HbA1c is associated with roughly 20-30% higher risk of microvascular complications and significant increases in cardiovascular risk. Our finding that high sugar intake nearly tripled the odds of poor glycaemic control (AOR = 2.67) emphasizes the importance of reducing added sugar as a key component of diabetes management.

The strong inverse association between fibre intake and glycaemic control supports previous meta-analyses showing that increased dietary fibre improves HbA1c in people with diabetes. What is concerning is how few participants met adequate fibre intake levels—median intake was only 18 grams daily, far below recommendations. This deficit likely reflects low fruit and vegetable consumption combined with preference for refined

grains over whole grains. Unlike some dietary interventions that require expensive foods or major cooking changes, increasing fibre intake could be achieved through relatively simple modifications like choosing whole wheat roti over refined versions, eating more vegetables with meals, and including fruit as snacks.

The finding that meal frequency matters for glycaemic control is particularly interesting and has practical implications. Many working adults in Pakistan, especially men, skip breakfast or eat irregularly due to work schedules. Our results suggest that eating regular meals throughout the day helps maintain more stable blood sugar levels. This might work through several mechanisms: regular eating patterns help synchronize the body's circadian rhythms with food intake, prevent excessive hunger that leads to overeating, and distribute glucose load more evenly across the day rather than overwhelming the system with large meals (. Even if total daily calories remain constant, how those calories are distributed across meals appears to matter[12].

Implications for Diabetes Prevention and Management

Our findings suggest several practical strategies for diabetes prevention and management in Pakistani populations that could be incorporated into public health programs and clinical practice. First, dietary guidance should emphasize increasing consumption of vegetables, fruits, legumes, and whole grains—foods that contribute to the protective Nutrient Pattern 3[17]. These foods are generally affordable and culturally acceptable, unlike some Western health foods that may be expensive or unfamiliar[18].

Traditional Pakistani cuisine offers many options that fit this pattern: vegetable curries (sabzi), lentil dishes (Dal), chickpea preparations, and mixed vegetable sides. The challenge lies not in introducing foreign foods but in reversing the trend away from these traditional items toward processed foods and refined carbohydrates. Public health messaging could frame diabetes prevention not as adopting a "diet" but as maintaining traditional eating patterns while limiting newer processed foods. For people already diagnosed with diabetes, our findings point to three specific behavioural targets: reducing added sugar, increasing fibre intake, and establishing regular meal patterns. These recommendations are straightforward to communicate and monitor. Healthcare providers could assess these behaviours through simple questions and track changes over time. Unlike complex dietary interventions requiring extensive counselling and follow-up, these focused targets might be more achievable in resource-constrained healthcare settings.

The association between meal regularity and glycaemic control suggests that diabetes education

programs should address eating schedules, not just what people eat. For working adults, this might involve practical strategies like preparing breakfast the night before, packing healthy snacks for work, and planning dinner timing. Such behavioural interventions could complement medication management and potentially reduce the medication burden over time as glycaemic control improves.

Strengths and Limitations

This study has several strengths. We used a culturally adapted food frequency questionnaire specifically designed for Pakistani foods, improving the accuracy of dietary assessment compared to using generic FAQs. Our sample size was adequate for detecting meaningful associations, and we carefully matched cases and controls to reduce confounding[19]. The use of principal component analysis to identify nutrient patterns represents a more sophisticated approach than simply examining individual nutrients or broad food groups, potentially revealing combinations that have biological significance.

However, important limitations must be acknowledged. The case-control design means we cannot determine causality—we can show associations but not prove that dietary patterns caused or prevented diabetes. Dietary assessment always carries risk of measurement error and recalls bias, even with validated questionnaires. People may report eating healthier than they actually do, especially after a diabetes diagnosis. While we adjusted for many potential confounders, residual confounding remains possible; unmeasured factors might explain some of the associations we observed. Our study recruited participants from tertiary care hospitals in major cities, potentially limiting generalizability to rural populations whose dietary patterns and diabetes risk factors may differ. Urban Pakistanis generally have higher incomes, better healthcare access, and different food environments than rural residents. The protective dietary pattern we identified might not be as feasible or relevant in rural areas where food availability and economic constraints differ [20].

We relied on single measurements of HbA1c to assess glycaemic control, which may not fully capture long-term management patterns. Ideally, multiple measurements over time would provide a more complete picture. Additionally, we did not collect detailed information about specific diabetes medications, making it difficult to determine whether medication differences across participants might partly explain glycaemic control variations. Similarly, we lacked data on diabetes complications, which would have provided additional context about disease severity. The nutrient patterns we identified using principal component analysis represent data-driven patterns specific to our sample. Different populations might show different nutrient clustering patterns based on their unique food cultures. This

means the specific patterns we identified may not replicate exactly in other populations, though the underlying principles about which nutrients protect against diabetes likely apply more broadly.

CONCLUSION

This case-control study provides evidence that nutrient patterns emphasizing plant proteins, dietary fibre, vitamins A, C, and B2, along with potassium and calcium, are associated with substantially lower T2DM risk among Pakistani adults. This protective pattern aligns with traditional Pakistani dietary practices emphasizing vegetables, legumes, and whole grains, suggesting that promoting these traditional foods rather than importing Western dietary recommendations might offer an effective and culturally appropriate prevention strategy.

Among people already living with diabetes, we found that three modifiable dietary behaviours—excessive sugar consumption, insufficient fibre intake, and irregular meal timing—independently predict poor glycaemic control. These findings point to specific, actionable targets for diabetes management that could be implemented even in resource-limited healthcare settings. Reducing added sugar, increasing fibre-rich foods, and establishing regular meal patterns represent straightforward recommendations that don't require expensive foods or dramatic lifestyle upheaval.

As Pakistan faces a rapidly growing diabetes burden that threatens to overwhelm its healthcare system, these findings underscore the urgent need for

culturally sensitive dietary interventions. Such interventions should emphasize returning to traditional plant-based foods, limiting processed items and added sugars, and maintaining regular eating patterns. Public health programs, healthcare providers, and community organizations all have roles to play in promoting these dietary changes.

The fight against diabetes in Pakistan will require multiple approaches—from healthcare system strengthening to medication access to community education. But diet represents a modifiable risk factor where individual and community action can make a real difference. By grounding dietary recommendations in evidence from Pakistani populations and respecting local food cultures, we can develop prevention and management strategies that people can actually follow long-term. This study contributes to that evidence base, though much more research is needed to fully understand how diet influences diabetes in Pakistani and broader South Asian contexts.

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