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Evaluation of anti - diabetic activity of palmyrah (palm jaggery and palm honey) (*Borassus flabellifer* L.) against streptozotocin - nicotinamide induced diabetic wistar rats

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Abstract

Value-added products derived from palmyrah (*Borassus flabellifer* L.), such as palm jaggery and palm honey, serve as alternative source of table sugar with a low glycemic index. During 2022-23, an experiment was to evaluate their anti-diabetic activity. The efficacy of palm jaggery and palm honey was assessed in diabetic rats at a dose of 200 mg/kg and their effects were compared to those of oral glimepiride in a 28-days randomized control study. Biochemical estimations and histopathological analyses revealed that palm jaggery and palm honey possess anti -diabetic, antioxidant, anti-hyperglycemic and insulinogenic properties. These palmyrah products significantly enhanced insulin secretion by pancreatic β-cells, leading to a marked reduction in blood glucose levels, serum uric acid, creatinine and lipid peroxidise activity. Furthermore, the restoration of normal metabolic pathways reduced oxidative stress-induced mechanisms in diabetic rats treated with palmyrah jaggery and honey. Hence, palm products could be used as an adjuvant in the treatment of diabetes mellitus.

Keywords

diabetes mellitus; diabetic rats; insulin; nicotinamide; palmyrah honey; palmyrah jaggery; streptozotocin

Introduction

Diabetes mellitus (DM) is an insulin-dependent disorder that significantly impact human metabolism. Insulin, is an important anabolic hormone that plays a major role in carbohydrate, lipid and protein metabolism in humans. A lack or impairment in insulin action leads to the onset of diabetes mellitus (1). The primary causes of DM include inadequate insulin production and a reduced capacity to process insulin within the body (2). Additionally, limited access to a healthy lifestyle and nutritious food has been associated with the rising prevalence of DM. According to the International Diabetes Federation (IDF), low- and middle-income countries are expected to host the majority of the diabetic population by 2030, driven by factors such as urbanization and dietary changes. DM also reduces life expectancy by contributing to complications such as coronary heart disease, peripheral nerve damage, peptic ulcers and delayed wound healing (3). Patients with DM often need to reduce or eliminate sugar intake and rely on lifelong medication to maintain stable glucose levels.

Studies conducted on rats have shown that streptozotocin selectively damages pancreatic β-cells, resulting in insufficient insulin production and leading to type 1 DM (4). However, nitric oxide-mediated mechanisms provide partial protection and preservation of β-cells through the action of nicotinamide. Consequently, a combination of nicotinamide and streptozotocin induces type 2 DM in experimental

rats (5). Type 1 DM is less common than type 2 DM and patients with type 1 DM require insulin injections to maintain appropriate blood glucose levels (6). The effective management of DM has drawn significant attention from the medical community due to the adverse effects associated with many currently available drugs, including metformin, sodium-glucose transport protein 2 (SGLT2) inhibitors, meglitinides, sulfonylureas, thiazolidinediones, alpha-glucosidase inhibitors, bile acid sequestrants, dopamine agonists and dipeptidyl peptidase 4 inhibitors (DPP-4 inhibitors) (7). Side effects, such as hypoglycemia, have prompted researchers to explore alternative treatments that are easy to produce, widely accessible and have minimal or no side effects (8). Plant-based medicines have emerged as a promising area of research, as they have been traditionally used to manage various diseases, including DM, across different parts of the world. For instance, plants such as Mexican spinach (*Cnidoscolus chayamansa*) are believed to exhibit significant medicinal properties, including anti-diabetic, antioxidant, hepatoprotective, cardioprotective, antitumoral, gastroprotective and hypocholesterolemic effects (9). However, traditional plant-based medicines are often overlooked in scientific studies due to a lack of clarity regarding their mechanisms of action and preparation methods. To address this gap, scientists are rigorously evaluating the efficacy of these medicines through stringent scientific methodologies (10, 11).

While conventional medicines have been widely used to treat DM (12-14), their adoption is hindered by several challenges. These include adverse effects such as toxicity and drug resistance, lack of regulation of practitioners in many countries and the high cost of treatment. Additionally, conventional medicines may not completely reverse diabetes complications and glucose-lowering drugs are not suitable for all diabetic patients. Such limitations further highlight the need for alternative therapeutic approaches.

Palmyrah (*Borassus flabellifer* Linn.), a member of the Arecaceae family, is popularly referred to as the "Tree of Life" due to its numerous economic benefits (15-17). Native to India, palmyrah boasts over 125 million standing trees, with 60% of them concentrated in Tamil Nadu, where it is designated as the state tree (18, 19). Botanically, palmyrah is a single-stemmed, tall -growing, dioecious perennial capable of living for over a century. It is characterized by its large, fan-shaped leaves. In regions where it is cultivated, the tree's fruits are traditionally used to treat various ailments (20). The fruit pulp is reported to possess antioxidant and antimicrobial properties (21-23). Traditional preparations using palm fruits have also been employed to manage DM (24, 25). The sugary sap extracted from the inflorescences of palmyrah palms, known as "neera," is rich in nutrients. Per 100 cc, neera contains moisture (86.6 g), protein (350 g), ash (0.53 mg), calcium (143 mg), phosphorus (10 mg), iron (0.30 mg), ascorbic acid (15.74 mg), thiamine (82.3 mg), riboflavin (44.4 mg), niacin (674.4 mg) and reducing sugar (998 mg). Although neera has a short shelf life, it can be processed into value-added products such as jaggery (palm sugar) and honey (Fig. 1 and 2). These byproducts, which have a similar nutrient composition-carbohydrates (90.6%), minerals (0.74%), protein (0.35%) and fat (0.17%) can be stored for extended periods. Palm jaggery, in particular, is recommended as a treatment for diabetic acidosis and as a substitute for regular sugar due to its high nutritional value.

Fig. 1. Prepared palm jaggery.

Fig. 2. Prepared palm honey.

Despite the traditional use of palmyrah products in DM management, their anti-diabetic properties have not been extensively studied. This research aims to bridge that gap by evaluating the anti-diabetic potential of palmyrah jaggery and honey in diabetic rats induced by streptozotocin and nicotinamide.

Materials and Methods

The experiment was conducted by the Department of Horticulture, VOC Agricultural College and Research Institute, Killikulam, located in the Thoothukudi district of Tamil Nadu, India, during the year 2022-23. The products of palmyrah viz., palm Jaggery and palm honey were prepared from the fresh sap of the inflorescence (neera) extracted from the existing palmyrah trees in the College orchard. The samples of palm jaggery and palm honey was subsequently sent to M/s. K.M. College of Pharmacy, Madurai, for standardization.

Animals used in this study

Male Wistar rats, each weighing between 190 and 200 g, were obtained from the central animal house at K.M. College of Pharmacy, Madurai. The animals were housed in ventilated cages and maintained under standard laboratory conditions with a consistent supply of pellet diet and water available at all times. The Institutional Ethical Committee of K.M. College of Pharmacy validated and approved the experimental protocol vide ethical approval number IAEC/SURYA.R/SRF/TNAU/KMCP/183/2022-23 of the IAEC.

Induction of experimental diabetes

DM was induced in rats weighing between 180 to 200 g after overnight fasting periods. Nicotinamide (NA), dissolved in saline at a dose of 110 mg/kg body weight, was administered intraperitoneally. This was followed, after 15 minutes, by the intraperitoneal administration of streptozotocin (STZ), dissolved in 0.1 M citrate buffer at a dose of 65 mg/kg body weight (pH 4.5). Blood glucose levels were measured 48 hours after induction to confirm hyperglycemia through blood sample analysis. Rats with blood glucose levels exceeding 220 mg/dL were deemed diabetic and included in the study.

Experimental design

The diabetic rat was randomly divided into six groups, each consisting of five animals per group:

Group I: (Normal control)

Rats in this group received 0.9% sodium chloride (NaCl) at a dose of 10 mL/kg body weight orally for 28 days.

Group II: (Diabetic control)

Rats in this group were intraperitoneally administered nicotinamide (110 mg/kg body weight), followed 15 minutes later by streptozotocin (65 mg/kg body weight, dissolved in 0.1 M citrate buffer, pH 4.5). This treatment was carried out for the 28-day duration of the experiment.

Group III: (Standard control)

The diabetic rats in this group were orally administered glimepiride at a dose of 10mg/kg body weight for 28 days.

Group IV: (Treatment control)

Diabetic rats in this group were orally administered palm jaggery, a value-added product of palmyrah, at a dose of 200mg/kg body weight for 28 days.

Group V: (Test group)

Diabetic rats in this group were orally administered palm honey, another value-added product of palmyrah,) at a dose of 200mg/kg body weight for 28 days.

For oral administration, palmyrah products and glimepiride were suspended in 0.9% NaCl in warm water as the vehicle solution.

Biochemical estimations

On the 0^{th} and 14^{th} days after treatment, fasting blood glucose levels in rats was measured using a commercial kit. On 0^{th} and 28^{th} day after treatment, the body weight of the rats and the insulin levels in blood plasma were measured using the EZRMI Rat/Mouse Insulin Enzyme-Linked Immunosorbent Assay (ELISA) kit.

At the end of the treatment period (28 days), the rats were subjected to a 16-hours fasting period before cervical decapitation. Immediately after decapitation, blood samples were collected in tubes containing anticoagulants (sodium fluoride and potassium oxalate). The following blood parameters were analyzed using standard procedures: total haemoglobin (26), HbA1c (27) and total protein (28). HbA1c was estimated from the total haemoglobin using colorimetric assay and was expressed in mmol/mol or % HbA1c. Protein concentration was estimated using bovine serum albumin as a standard (29).

The hepatic function of diabetic rats was assessed by quantifying alanine transaminase (ALT), aspartate transaminase (AST) and alkaline phosphatase (ALP). Comparably, urea and creatinine levels were measured to evaluate renal function. The lipid profile of the rats was analysed by estimating the levels of total cholesterol, triglycerides and high-density lipoprotein (HDL).

Oxidative stress induced in the diabetic rats was evaluated by measuring enzymatic antioxidants such as catalase (CAT), superoxide dismutase (SOD) and glutathione peroxidase (GPX), as well as non-enzymatic antioxidants such as reduced glutathione (GSH). Lipid peroxidation levels were also estimated and expressed as malondialdehyde (MDA) following standard procedures (30).

Histopathological analysis

A small portion of pancreatic tissue was dissected from the sacrificed rats, carefully processed to remove excess blood, fat, or connective tissue. To preserve cellular structure, the tissues were immediately fixed in 10% buffered neutral formal saline solution. After fixation, the tissues were prepared for microtomy and photomicrography by embedding them in paraffin wax and slicing them into 5 µm sections using a microtome. The tissue sections were stained with hematoxylin and eosin to enhance visibility and examined under a light microscope to study different cellular components and identify abnormalities in the size or shape of pancreatic tissues (30). Photomicrographs were taken for documentation and future references (31).

Statistical analysis

The data were expressed as mean ± standard error (SE) for all the observations. Analysis of variance (ANOVA) was computed and tested using Newman-Keuls multiple range test in GraphPad instat 3.0 statistical software. A significance level of $p < 0.01$ was considered to identify significant differences between groups.

The process for accepting or rejecting the null hypotheses involved arranging the sample means in ascending or descending order to create an ordered range (p). The largest and smallest means were compared first. If the largest range included four means ($p = 4$), as determined by the Newman-Keuls method, the null hypothesis was rejected. Subsequently, comparisons were made stepwise with progressively smaller ranges (e.g., $p = 3$), continuing until the smallest range of just two means was analysed. Null hypotheses within a specific range were accepted if the detected difference between two sample means were non-significant, making further comparisons within smaller range unnecessary.

Results

Differences in body weight and blood parameters between normal and treated rats are shown in Table 1, 2 & 3. In diabetic rats, elevated HbA1c levels and reduced body weight were observed alongside a decline in blood parameters such as plasma insulin and total haemoglobin. However, these diabetic effects were effectively restored to near-normal levels following the administration of glimepiride (Group III), palm jaggery (Group IV) and palm honey (Group V) at a dose of 200mg/kg body weight.

Diabetic rats in group II exhibited elevated levels of urea and creatinine and decreased levels of total protein (Tables 3 and 4). These abnormal levels were significantly reversed to near-normal values after treatment with glimepiride (Group III) and palmyrah products (Group IV and V).

Table 3 and 4 also revealed that consecutive oral administration of palm jaggery and palm honey (Group IV and V) at the specified dose for 28 days resulted in a significant increase in HDL levels and a significant ($p < 0.05$) reduction in ALT, AST, ALP and triglycerides when compared to the diabetic control groups.

The parenchymal cells of the liver in diabetic rats exhibited a significant ($p < 0.05$) increase in MDA levels and a notable decrease in measured antioxidants (Table 5). Comparatively, oral administration of palmyrah products (Groups IV and V) significantly mitigated these changes in a dose-dependent manner, restoring the levels to near-normal values at the highest dose.

Histological examination of pancreatic tissues in normal rats (Group I) revealed an intact pancreatic structure, with islets of Langerhans appropriately distributed in the same lobule (Fig. 3). Each islet was organized into well-expanded cellular plates, separated by reticular membranes from the surrounding acini. In contrast, the diabetic control group (Group II) displayed peripheral widening between the islets of Langerhans and the pancreatic acini (Fig. 4).

In the glimepiride-treated group (Group III), the absence of inflammatory cells and the dense packing of Langerhans cells with minimal spacing were noted. However, some degree of architectural disorder was evident in the pancreas compared to the normal group (Fig. 5). In diabetic rats treated with palmyrah products (Groups IV and V), minimal architectural changes were observed in the pancreatic tissue. Slight peripheral widening of

Table 1. Effect of palmyrah products (palm jaggery and palm honey) on bodyweight in rats induced with streptozotocin and nicotinamide type-2 diabetes

Groups	Treatment	Body weight		
		0 day	14 day	28 day
G1	Normal control	210±4.3	220±4.9	235±5.2
G2	Diabetic control	222±5.0	190±3.8*a	175±3.2*a
G3	Standard control	224±5.1	242±5.9	253±6.3
G4	Test group	218±4.9	236±5.3	248±6.0
G5	Treatment control	215±4.7	234±5.4	245±5.8

Values are expressed as Mean±SE; *significant difference from normal control

Table 2. Effect of palmyrah products (palm jaggery and palm honey) on blood glucoseand plasma insulin in rats induced with streptozotocin and nicotinamide type-2 diabetes

Groups	Treatment	Blood glucose (mg/dL)			Plasma insulin (micro litre/ml) 28 day
		0 day	14 day	28 day	
G1	Normal control	96.8±2.5	94.9±2.3	97.9±2.8	18.40±0.90
G2	Diabetic control	245.7±5.9	266.7±6.2*a	272.2±6.7*a	5.82±0.40*a
G3	Standard control	253.1±6.3	145.6±4.8*b	130.2±4.1*b	16.70±0.82*b
G4	Test group	244.6±5.6	157.3±5.5*b	140.3±4.8*b	15.90±0.74*b
G5	Treatment control	250.2±5.9	153.4±5.2*b	135.6±4.4*b	16.10±0.77*b

Values are expressed as Mean±SE; *a-significant difference from normal control; *b-significant difference from diabetic control

Table 3. Effect of palmyrah products (palm jaggery and palm honey) on different bio-chemical parameters in rats induced with streptozotocin and nicotinamide type-2 diabetes

Groups	Haemoglobin (mg/dl)	HbA1c (%)	Total proteins (g/dl)	Total cholesterol (mg/dl)	TG (mg/dL)	HDL (mg/dl)
G1	13.3±1.20	6.30±0.70	8.40±0.85	148±3.22	85.3±2.45	46.30±2.20
G2	8.3±0.60*a	11.45±1.95*a	4.72±0.40*a	245±5.48*a	170.3±4.30*a	23.40±1.65*a
G3	12.8±1.04*b	6.70±0.82*b	7.58±0.73*b	167±4.45*b	90.2±2.70*b	41.20±2.05*b
G4	12.3±0.80*b	7.10±0.78*b	7.05±0.60*b	179±4.95*b	99.6±2.89*b	37.75±1.75*b
G5	12.5±0.88*b	6.90±0.87*b	7.32±0.67*b	170±4.60*b	93.2±2.76*b	39.10±1.90*b

Values are expressed as Mean±SE; *a-significant difference from normal control; *b-significant difference from diabetic control

Table 4. Effect of palmyrah products (palm jaggery and palm honey) on different biochemical parameters in rats incited with streptozotocin and nicotinamide type-2 diabetes

Groups	ALT (U/L)	AST (U/L)	ALP (U/L)	Urea (mg/dl)	Creatinine (mg/dl)
G1	30.7±2.24	48.4±2.55	134.7±3.60	32.8±3.22	1.14±0.30
G2	59.4±3.46*a	94.3±3.35*a	234.2±5.20*a	85.8±3.55*a	3.04±0.68*a
G3	33.8±2.63*b	52.8±2.70*b	145.3±3.85*b	38.2±1.87*b	1.21±0.39*b
G4	39.2±2.84*b	58.4±2.92*b	153.6±4.20*b	45.7±2.10*b	1.32±0.45*b
G5	36.7±2.72*b	54.3±2.84*b	150.1±4.05*b	41.9±1.96*b	1.26±0.42*b

Values are expressed as Mean±SE; *a-significant difference from normal control; *b-significant difference from diabetic control

Table 5. Effect of palmyrah products (palm jaggery and palm honey) on hepatic oxidant-antioxidant parameters in rats induced with streptozotocin and nicotinamide type-2 diabetes

Groups	SOD unit/mg protein	CAT Mmol/min/mg protein	GPx Mmol/min/mg protein	GSH Mm/100mg tissue	MDA Mmol/100mg tissue
G1	8.78±0.92	95.3±3.40	10.90±0.95	60.30±3.30	1.32±0.35
G2	4.60±0.40*a	40.4±2.35*a	5.30±0.40*a	23.25±1.20*a	2.46±0.65*a
G3	8.30±0.72*b	83.8±3.10*b	10.20±0.83*b	54.10±3.02*b	1.43±0.41*b
G4	7.55±0.64*b	77.1±2.75*b	9.75±0.74*b	50.70±2.90*b	1.52±0.47*b
G5	7.80±0.68*b	80.6±2.90*b	9.90±0.79*b	48.90±2.80*b	1.48±0.44*b

Values are expressed as Mean±SE; *a-significant difference from normal control; *b-significant difference from diabetic control

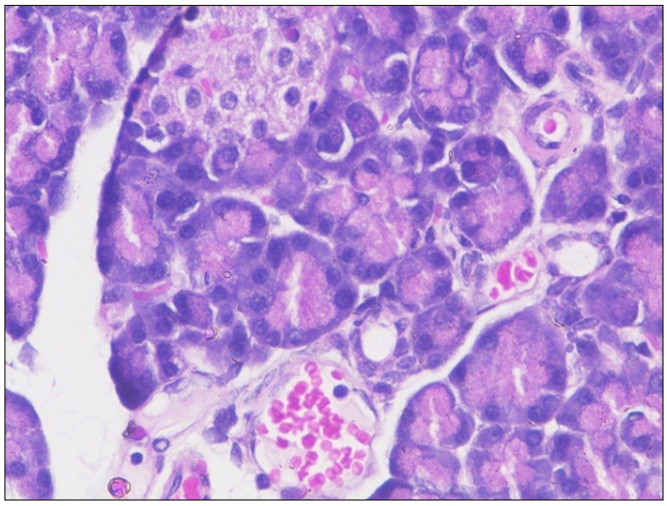

Fig. 3. Normal control photomicrograph of a pancreatic tissue section showing the exocrine region and islets of Langerhans, with scattered β-cells and red blood cells visible in the vicinity.

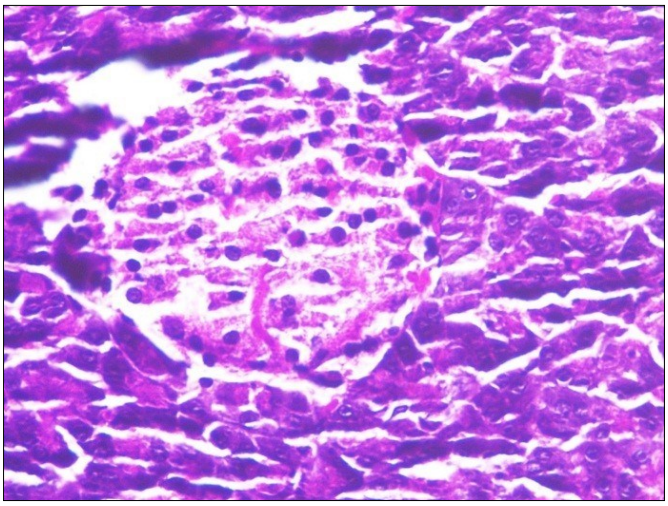

Fig. 4. Photomicrograph of pancreatic tissue of diabetic rats induced with STZ+NA. It shows the exocrine region and islets of Langerhans with damaged β-cells due to necrosis and a decreased number of β-cells.

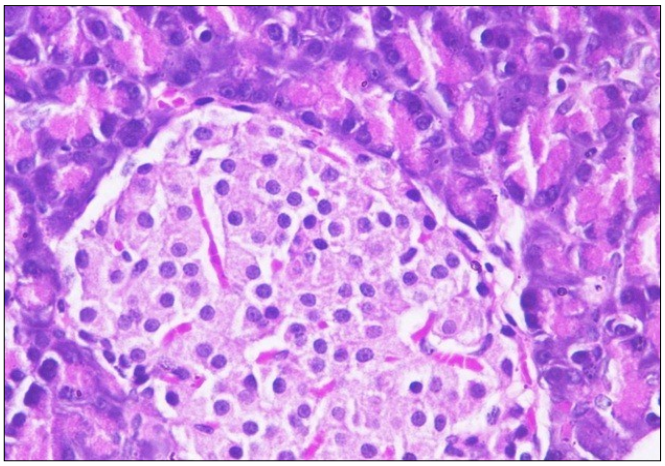

Fig. 5. Restoration of general architecture of β-cells in standard control diabetic rats upon glimepiride treatment. The treatment increased the number of β-cells and are evenly distributed.

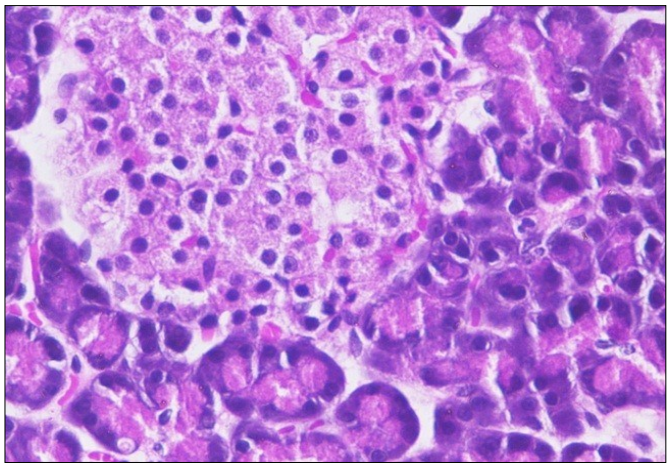

Fig.6. Rats administered with palm jaggery at a dose of 200 mg/kg palm jaggery treatment dose reverted back to near normal levels.

acini and islets of Langerhans was noted, but the structural integrity was better preserved compared to untreated diabetic rats (Fig. 6 and 7). Overall, minimal histopathological alterations were recorded in these groups, with partial regeneration of β-cells observed following palmyrah product administration.

Discussion

Ayurveda and Unani are traditional systems of alternative medicine that have played a crucial role in maintaining human health for thousands of years. These systems document numerous crude herbal drug preparations to manage prevalent diseases, including diabetes (32). Various plant species have been integral to natural medicine across different traditions and are widely used globally to treat DM (33). Although many anti-

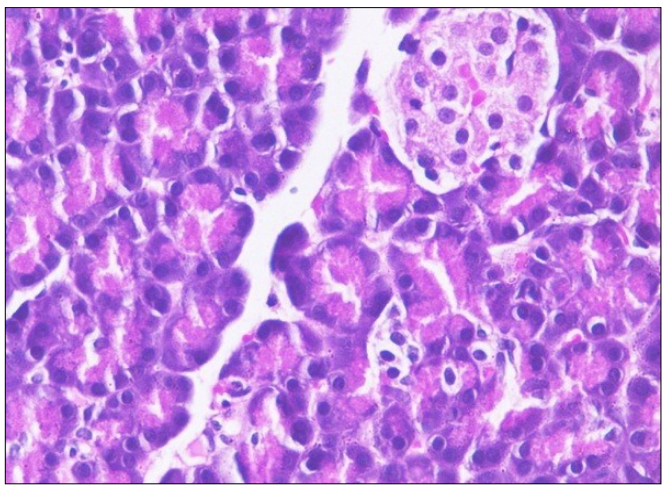

Fig.7. Treatment control diabetic rats treated with palmyrah (palm honey) at a dose of 200 mg/kg showing evenly distributed β-cells and an increased number of β-cells.

diabetic drugs are available both orally and systemically, there is an increasing demand for natural anti-diabetic products as complementary adjuvants (34, 35).

Studies have shown that type 2 DM can be induced in nicotinamide/streptozotocin-treated rats, while type 1 DM can be induced in streptozotocin-only treated rats. In type 1 DM, the body's immune system attacks the insulin-producing β-cells in the pancreas, leading to a complete lack of insulin production, which is considered an autoimmune condition. Conversely, in type 2 DM, the pancreas produces insufficient insulin, or the insulin produced is ineffective due to insulin resistance (4, 5, 36, 37). Streptozotocin selectively destroys pancreatic β-cells, creating a diabetic state and generating reactive oxygen species (ROS) as a result. The destruction of β-cells leads to insufficient insulin production, which, in turn, causes hyperglycemia and promotes ROS production (38).

Nicotinamide offers partial protection to pancreatic β-cells from streptozotocin by inhibiting poly (ADP-ribose) polymerase-1 activity and acting as a precursor to nicotinamide adenine dinucleotide (39). Despite this protection, diabetic rats often exhibit various oxidative stress-induced complications (40).

In the current study, fasting diabetic rats administered with palm products demonstrated a notable reduction in plasma insulin levels, consistent with previous findings (41). However, the results also indicated increased insulin concentration and a significant reduction in fasting glucose levels in diabetic rats treated with palm jaggery and palm honey as adjuvants.

The free radicals generated during the Fenton reaction in alloxan metabolism destroy pancreatic β-cells, leading to elevated blood glucose levels in rats. This study observed increased blood glucose levels in diabetic rats treated with standard drugs like glibenclamide and glimepiride. The increase in insulin production due to Na^+ ion channel activation (depolarization) and the decrease in insulin production due to K^+ ion channel activity (repolarization) was noted. Oral administration of glibenclamide inhibited K^+ ion channels, resulting in increased insulin production, albeit with associated side effects (42). Similarly, palm products effectively decreased blood glucose levels by protecting pancreatic β-cells.

The hypoglycemic effects of palm products restored the structure and function of the plasma membrane (responsible for glucose transport), which is primarily regulated by insulin (43). Additionally, the antioxidant properties of palm products protected pancreatic β-cells from oxidative stress-induced injury, contributing to increased insulin levels (44). The study demonstrated that palm products significantly reduced elevated blood glucose levels in diabetic rats after 28 days of treatment. This effect can be attributed to enhanced insulin release from pancreatic β-cells, highlighting the anti-diabetic potential of palm products. Similar findings have been reported in other studies (45). Administration of palm products also elevated plasma insulin levels, showcasing their insulinogenic and anti-hyperglycemic activities. These products stimulated insulin secretion from pre-existing β-cells and promoted their regeneration, leading to increased plasma insulin levels.

DM is often associated with body weight loss due to imbalances in metabolic pathways. In this study, rats treated with palm products gained body weight, likely due to the restoration of normal glycogenolysis and gluconeogenesis processes (46). One potential mechanism linking hyperglycemia to vascular complications in diabetes is increased non-enzymatic glycosylation. In diabetic conditions, excess glucose reacts with hemoglobin to form HbA1c (47). Compared to normal rats, diabetic rats in this study exhibited elevated HbA1c levels. However, palm products significantly reduced HbA1c levels and increased total hemoglobin levels, indicating improved glucose metabolism. Elevated liver enzymes are often associated with glycemic dysregulation in type 2 DM (48). In this study, diabetic rats exhibited higher levels of ALT, AST and ALP, likely due to increased diabetic ketogenesis and gluconeogenesis (49). Conversely, reduced transaminase activity was observed in diabetic rats treated with palm products, indicating their hepatoprotective potential. Diabetic hyperglycemia also leads to renal dysfunction, evidenced by elevated serum urea and creatinine levels due to impaired kidney filtration (50). Diabetic rats in this study exhibited elevated levels of serum creatinine and urea. However, treatment with palm products significantly reduced these levels, suggesting their renoprotective properties.

In DM, ROS production results from glucose autoxidation, which exacerbates lipid peroxidation, generating more free radicals and end products of lipoxidation. Lipid peroxidation can lead to liver damage and vascular diseases by protein aggregation. Increased plasma MDA levels, a marker of lipid peroxidation, were observed in diabetic rats in this study, consistent with hyperglycemia-induced oxidative stress (51). Treatment with palm products significantly reduced lipid peroxidation and minimized tissue injury.

Streptozotocin-nicotinamide treatment damaged cellular components of pancreatic β-cells, including insulin and amylin, which constitute approximately 70% of the total islet cells in diabetic rats. Glimepiride stimulated pancreatic islet regeneration, leading to increased plasma insulin levels, as confirmed by biochemical assessments and histological photomicrographs. Similarly, palm products in this study protected pancreatic islets from ROS-induced damage. The combined action of phytoconstituents in palm products contributed to their anti-diabetic and antioxidant properties. These antioxidants are essential for mitigating oxidative stress caused by free radicals (52).

Conclusion

The natural edible products of palmyrah, such as palm jaggery and palm honey, administered at a dose of 200 mg/kg, significantly reversed or mitigated the adverse effects of diabetes, including reduced body weight, decreased insulin and total hemoglobin levels and elevated HbA1c levels, bringing them closer to those of normal rats. These products also demonstrated notable restorative effects on cellular architectural changes, with limited regeneration of pancreatic β-cells. Diabetic rats treated with palmyrah products exhibited normalized levels of urea, creatinine and proteins. Furthermore, the antioxidants in the liver's parenchymal cells were restored to normal levels following administration of these products.

Palmyrah jaggery, with a low glycemic index of 35 compared to the glycemic index of table sugar, underscores its potential efficacy as part of anti-diabetic dietary practices. However, future clinical studies are necessary to validate these findings and establish the benefits of palmyrah products for human consumption.

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Authors' contributions

MMI has conceived and participated in the design of study, conducted the experiment, collected data, performed statistical analysis and drafted the original manuscript. AL, PV and RKN participated in the sequence alignment. NM and MK have coordinated the research work. All the authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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