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Ameliorative effects of medicinal plants on diabetes mellitus-induced male reproductive dysfunction in experimental animal models

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ABSTRACT

Diabetes mellitus (DM) is a rapidly growing metabolic disorder characterized by chronic hyperglycemia and associated systemic complications. Increasing evidence indicates that DM adversely affects male reproductive health by impairing spermatogenesis, hormonal balance, and fertility, primarily through oxidative stress and metabolic disturbances. Conventional therapies remain essential but may not fully prevent long-term complications. Medicinal plants and their bioactive phytochemicals have gained attention due to their multi-targeted antidiabetic, antioxidant, and fertility-protective effects. A comprehensive literature search was conducted using major scientific databases, including PubMed, Scopus, Web of Science, and Google Scholar, to identify relevant studies on medicinal plants that ameliorate diabetes induced male reproductive dysfunctions. Findings from these database-indexed studies indicate that numerous medicinal plants and polyherbal formulations exhibit significant antidiabetic and fertility-protective effects, mainly through antioxidant, anti-inflammatory, and glycemic regulatory mechanisms. This review summarizes recent evidence on medicinal plants and polyherbal formulations that improve glycemic control and male reproductive functions in diabetic conditions, highlighting their therapeutic mechanisms and potential clinical relevance.

Keywords: Diabetes mellitus, Male reproductive dysfunction, Medicinal plants, Oxidative stress, Antioxidants, Spermatogenesis.

INTRODUCTION

Diabetes mellitus is a chronic metabolic disorder marked by persistent hyperglycemia due to defects in insulin secretion, insulin action, or both, which disrupts carbohydrate, lipid, and protein metabolism and leads to progressive metabolic dysfunction [1].

The worldwide burden of diabetes has increased dramatically, rising from about 200 million cases in 1990 to nearly 830 million in 2022, with roughly 14% of adults aged 18 years and above affected. In 2021, diabetes was directly responsible for approximately 1.6 million deaths, nearly half of which occurred in individuals under 70 years of age. Moreover, about 530,000 fatalities from kidney-related conditions were attributed to diabetes, while high blood glucose levels were associated with almost 11% of deaths caused by cardiovascular diseases [2]. The International Diabetes Federation (IDF) Atlas reports that in 2024, approximately 589 million adults between 20 and 79 years of age were living with diabetes, representing about 11.1% of the global population within this age group [3]. Projections based on expected demographic changes, such as population growth, aging, and increasing urbanization—suggest that the number of diabetes cases could rise by about 45% worldwide, reaching nearly 853 million by 2050. The most significant increases are anticipated in Africa (around 142%) and in the Middle East and North Africa region (about 95%) (IDF, 2025) [4]. In 2021, the prevalence of diabetes was estimated at 10.5% globally, 8.8% in Southeast Asia, and 9.6% in India. These figures are projected to increase by 2045, reaching approximately 12.5% worldwide, 11.5% in Southeast Asia, and 10.9% in India [5].

DM is generally classified into two primary forms: Type I and Type II, both characterized by impaired metabolism of carbohydrates, fats, and proteins. Globally, about 422 million people are affected by diabetes, of which roughly 10% have Type I DM. This form develops due to autoimmune processes or injury that destroy pancreatic beta cells. The risk of damage to insulin-producing cells is influenced by factors such as genetic background, ethnicity, age, and sex [6-8]. Type II DM has emerged as the most common form of diabetes globally, representing nearly 90–95% of all cases. Although it was once considered a condition primarily affecting middle-aged and elderly individuals, its occurrence among younger age groups has increased markedly in recent years, suggesting a further rise in prevalence in the future. This type of DM develops mainly due to decreased responsiveness of body tissues to the metabolic effects of insulin. It is often referred to as a "lifestyle disease" because it is strongly associated with factors such as unhealthy diet patterns, physical inactivity, and excess body weight [9]. Gestational diabetes mellitus (GDM) refers to glucose intolerance that is first detected during pregnancy, most commonly emerging in the third trimester. Its prevalence varies among populations and tends to be higher in groups with an increased risk of developing type 2 diabetes. Overall, GDM is estimated to occur in about 8-9% of pregnancies [10].

The management of diabetes and its complications involves both primary and secondary strategies. Primary prevention focuses on adopting a balanced diet, maintaining a healthy body weight, engaging in regular physical exercise, and making appropriate lifestyle modifications, which can help protect high-risk individuals and delay or reduce the need for medical treatment [11,12]. Secondary preventions mainly rely on pharmacological interventions, including early diagnosis and proper management through antidiabetic medications. Type 1 DM is primarily treated with external insulin administration, while the management of type 2 DM includes a range of therapeutic options, among which insulin therapy may also be required [13-15].

EFFECT OF DIABETES ON MALE REPRODUCTIVE FUNCTIONS

DM develops due to an absolute or relative deficiency of insulin, as well as resistance to its action. As a result, the body cannot properly use insulin, leading to disturbances in normal metabolic processes. Persistently elevated blood glucose levels over time can cause serious complications, including diabetic neuropathy and damage to blood vessels [16]. Diabetes is known to adversely affect reproductive functions in both males and females and is considered a significant complication of the disease. Increasing evidence suggests that both type 1 and type 2 DM are linked with impaired reproductive health in men as well as women [17-20]. Moreover, diabetes-induced metabolic disturbances lead to oxidative stress, altered zinc metabolism, and insulin resistance, all of which can negatively influence male fertility and overall reproductive performance [16]. DM negatively influences multiple components of male reproductive health, such as spermatogenesis, sperm maturation, fertility capacity, erectile function, and ejaculation, thereby contributing to male infertility [17]. Furthermore, recent studies examining fertility trends in contemporary populations have emphasized a clear association between the increasing burden of diabetes and the decline in birth and fertility rates [18,21]. Harmful effects of diabetes on various reproductive parameters are given below:

Effect on testes

The testes perform two primary functions: testosterone secretion and sperm production [22] Maintaining proper testicular structure is vital for its proper functioning [23]. DM significantly reduces testicular mass and Leydig cells count, which is likely tied to lower testosterone levels and structural changes induced by the condition. High blood sugar has also been shown to trigger cell death and structural damage in the testes [24-26]. Histological changes include a higher percentage of empty tubules, degeneration of seminiferous epithelium, thinning of the spermatogenic layer and also degradation of various types of germ cells [26,27].

Effect on epididymis

Diabetes related damage to the epididymis results in impaired sperm parameters (count, motility, viability), sperm maturation and storage capabilities. This condition disrupts epididymal function by affecting mitochondrial activity and promoting oxidative stress, as well as causing autophagy dysregulation within the tissue. Evidences showed that effected rats exhibited a marked reduction of epithelial height and a thicker fibromuscular layer of the epididymis compared to controls, along with basal membrane shrinkage and epithelial vacuolization in STZ-induced diabetic models [28,29].

Effect on accessory glands

Studies have shown that causing experimental rodents to develop DM results in substantial structural damage, failure of the secretory system, and a decrease in the body weight of accessory glands [20,30,31]. The detrimental effects of diabetes on male reproductive health are also well known, especially when it comes to the reduction of secretions of male accessory glands such as seminal vesicles [32]. One of the main pathogenic factors influencing the seminal vesicles in diabetics has been found to be oxidative stress-driven cell death. Diabetes has a detrimental effect on the prostate, as seen by a significant rise in the apoptotic index and a significant reduction in mast cell number, height of epithelial, and androgen receptor expression [33].

Effect on sperm parameters

Diabetes mellitus leads to notable alterations in semen quality, including reduced sperm density and motility, alongside increased fragmentation of sperm DNA and apoptosis [20,39,34]. In diabetic rats, vacuolar changes have been observed in the mitochondria of spermatogonia, with a decrease in the conversion of spermatogonia to primary spermatocytes and a rise in the number of non-functional spermatogonia. Additionally, the number of sperm in the epididymis is significantly diminished. Diabetes also compromises the integrity of sperm DNA [27].

Effect on reproductive hormones

The role of abnormal hormone regulation in diabetic induced male reproductive dysfunction is multifaceted. Diabetes can affect the hypothalamus or anterior pituitary leading to secondary testicular failure exhibited by low serum levels of gonadotropins and testosterone [35]. Harmful effects of diabetes on male reproductive functions are illustrated in Figure 1.

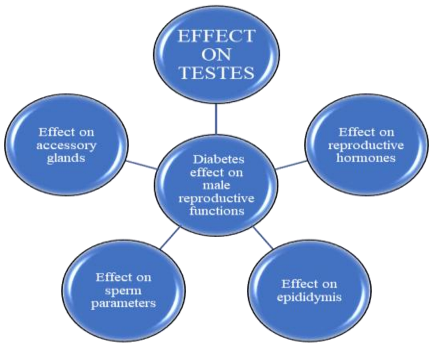

Figure 1: Effect of diabetes on male reproductive functions

In recent years, increasing attention has been directed toward traditional and complementary medicine, especially medicinal plants and herbal formulations, owing to their multi-targeted therapeutic potential, comparatively lower toxicity and adverse effects, wide natural availability, and cost-effectiveness [20,36].

AMELIORATIVE EFFECT OF MEDICINAL PLANTS ON DIABETES INDUCED MALE REPRODUCTIVE DYSFUNCTIONS

Medicinal plants and herbs serve as rich sources of numerous bioactive phytochemicals such as alkaloids, phenolic compounds, flavonoids, tannins, terpenoids, saponins, and glycosides. These constituents may function through additive or synergistic actions, modulating various biological pathways to help prevent or manage diabetes and its associated complications, thereby offering broad therapeutic benefits [36]. More than 800 plant species have demonstrated antidiabetic potential through experimental evidence, with studies conducted using diverse diabetic models, including those rooted in traditional healthcare systems such as Chinese herbal medicine, Japanese Kampo medicine, Indian Ayurveda, African traditional medicine, and others [37-39]. Additionally, several medicinal plants [20,40,41] and phytochemicals, such as beta-carotene [42], curcumin [43], lutein [44], rutin, naringin [45], and quercetin [46] have been shown to improve male reproductive function in diabetic experimental models, primarily by reducing oxidative stress and/or enhancing glycemic control. Ameliorative effect of various plants/plant parts on diabetes induced male reproductive dysfunctions are given below:

Ameliorative effect on testes

Some plants, like *Eruca sativa*, *Morus alba*, *Trigonella foenum-graecum*, *Stevia rebaudiana*, *Psidium guajava*, *Moringa oleifera* extract-treated diabetic rats, showed significant improvement in testicular outcomes, including increased testis weight and serum testosterone levels, along with enhanced antioxidant status marked by total antioxidant capacity, elevated GSH, GPx, GR, and CAT activities, and reduced lipid peroxidation [47-52]. Treatment with extracts of *Ambrosia maritime*, *Artemisia annua,* and *Artemisia Judaica* showed restoration of normal seminiferous tubule architecture including, increased diameters of seminiferous tubules, improved connective tissue integrity and collagen distribution, and a reduction in germinal epithelium apoptosis with decreased caspase-3 expression [53]. *Aloe vera* and *Morus alba* plant extract treatment showed an increase in spermatogenic cell populations, including spermatogonia and Leydig cells, supported by upregulation of steroidogenic mechanisms such as StAR mRNA expression [48,54]. Curcumin extract of *Curcuma longa* showed anti-inflammatory and cytoprotective effects on testicular tissue, through suppression of pro-inflammatory cytokines and NF-κB activity, activation of Nrf-2 signaling, and downregulation of apoptotic pathways involving JNK and p38 [43]. Overall, these changes reflect improved testicular function, structural integrity, and oxidative balance in diabetic conditions.

Ameliorative effect on epididymis

Eruca sativa, Morus alba, Piper sarmantosum, Dracaena arborea, Cassia fistula and *Cinnamon* plants extract treatment in diabetic rats increased epididymal weight and sperm concentration in the epididymis, along with enhanced sperm motility, viability, and overall semen quality, while reducing abnormal sperm forms [47,55-59]. Treatment with *Anacardium occidentale* plant extract showed restoration of normal epididymal architecture and luminal sperm aggregation comparable to normoglycemic conditions, along with reduced tissue degeneration [60]. Extract treatment with *Citrullus colocynthis* and *Garcinia kola,* improved antioxidant defence by decreasing oxidative stress markers such as lipid peroxidation and H_2O_2, and modulating enzymatic activities including increased SOD, CAT, GPx, and POD [61,62]. Overall, these effects indicate improved epididymal integrity, function, and oxidative balance in diabetic conditions.

Ameliorative effect on accessory glands

Eruca sativa extract treatment in diabetic rats showed beneficial effects on accessory glands, including increased weight of seminal vesicles and prostate [47]. Treatment with *Ginkgo biloba* leaves extract restored normal prostatic architecture by reducing epithelial stratification, cellular degeneration, nuclear abnormalities, and ultrastructural damage, thereby preserving glandular integrity and function under diabetic conditions [63].

Ameliorative effect on sperm parameters

Across the studies, treatment with *Alove vera, Salvia officinalis,* and *Olea europaea* plants extract in diabetic rats consistently improved testicular sperm parameters, with significant increases in sperm count and motility, along with enhanced sperm viability and a higher proportion of normal sperm morphology compared to untreated diabetic controls [54,64,65]. These findings indicate improved spermatogenesis within the testes, reflecting better sperm production and overall sperm quality following extract administration. Extract treatment of *Morus alba*, *Nigella sativa* and *Gynura procumbens* plants in diabetic rats consistently improved epididymal sperm parameters, demonstrated by a significant increase in epididymal sperm count and motility, along with an enhanced percentage of viable (live) sperm [55,66,67]. Aqueous extract of *Cinnamon* is reported to improved sperm morphology, including a reduction in abnormal head and tail defects [57]. These findings indicate improved sperm maturation and quality within the epididymis following extract administration.

Ameliorative effect on reproductive hormones

Extract treatment *Gorgonema latifolium, Citrus aurantium, and Crassocephalum crepidioides* plants in diabetic rats significantly improved reproductive hormonal profiles, evidenced by elevated serum testosterone, follicle-stimulating hormone (FSH), luteinizing hormone (LH) [68-70]. Hydroethanolic extract of *Fleurya aestuans* is also reported to enhance prolactin levels [71]. Esculeoside A, an extract of *Solanum lycopersicum*, also enhances serum FSH, LH, and testosterone levels. These effects are associated with enhanced steroidogenesis through the upregulation of key enzymes, including StAR, CYP11A1, CYP17A1, and 3β-HSD1, as well as improved endocrine regulation, likely mediated by antioxidant activity, activation of the Nrf2 pathway, and suppression of inflammatory mediators. [72]. Ameliorative effects of various medicinal plants on diabetes induced male reproductive dysfunctions are illustrated in Figure 2.

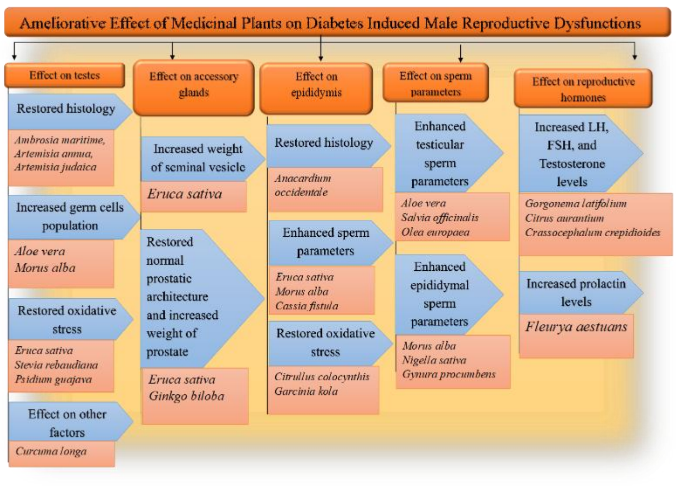

Figure 2: Ameliorative effect of medicinal plants on diabetes induced male reproductive dysfunctions

An appraisal of the medicinal plants, extracts, polyherbal formulations having modulatory effects on glycemic index and/or male reproductive functions in diabetic animals published during the last decade has been presented in Table 1.

Table 1: Plants/Herbs showing ameliorative effect on glycemic index and reproductive dysfunctions in male diabetic animals

Plant (family)	Part used	Extract	Dose/mode/ Duration	Animal models	Effect on blood glucose, insulin	Effects observed on reproductive functions	References
Eruca sativa (Brassicaceae)	Leaves	Aqueous extract	250 and 500 mg/kg b.wt./day, orally for 8 weeks	STZ-induced diabetic rats	Significant decline in the blood glucose level	In extract-treated diabetic rats, there was a marked increase in the mass of the testes, epididymis, seminal vesicles, and prostate gland, accompanied by higher serum testosterone concentrations. Moreover, testicular GSH content increased, while TBARS levels showed a noticeable decrease.	[47]
Gorgonema latifolium (Asclepiadaceae)	Leaves	Ethanolic extract	200 mg/kg b.wt./day, orally for 21 days	ALX-induced diabetic rats	Significant decrease in blood glucose level	Compared with diabetic control rats, extract-treated diabetic rats exhibited elevated levels of serum testosterone, FSH, and LH, along with improved sperm viability and a higher percentage of normal sperm morphology.	[68]
Alove vera (Liliaceae)	Leaves	Aqueous extract	400 mg/kg b.wt./ day, orally for 30 days	STZ-induced diabetic rats	Significantly decreased serum glucose level	Serum testosterone levels, seminiferous tubule and germinal layer diameters, sperm count, motility, and the numbers of spermatogonia and Leydig cells were significantly higher in extract treated group, compared to diabetic control group, likely due to the plant's antioxidant and antidiabetic effects.	[54]
Biophytum sensitivum (Oxalidaceae)	Whole plant	Methanolic extract	250 and 500 mg/kg b.wt./day, orally for 4 weeks	STZ-induced diabetic rats	-	Extract administration in diabetic animals reduced testicular damage and markedly improved sperm count, motility, and viability compared with diabetic controls.	[73]
Moringa oleifera (Moringaceae)	Leaves	80% Ethanolic extract	500 mg/kg b.wt./ day, orally for 28 days	STZ-induced diabetic rats	Significant lowering of blood glucose level	In extract-treated diabetic rats, testosterone, LH, and FSH levels rose significantly, along with notable improvement in testicular structure and spermatogenesis compared to diabetic controls.	[74]
Morus alba (Moraceae)	Fruit	Aqueous extract	100 mg/kg b.wt./day, orally for 12 weeks	STZ-induced diabetic rats	Significant decline in the blood glucose level	Extract administration markedly enhanced epididymal sperm count, motility, and viability, along with higher serum testosterone and FSH levels compared to diabetic controls. It also produced a moderate rise in seminiferous tubule diameter and germinal epithelium height.	[55]
Morus alba (Moraceae)	Leaves	50% Ethanolic extract	1 g/kg b.wt./ day, orally for 8 weeks	STZ-induced diabetic rats	Significantly lowered the serum glucose level and increased serum insulin level	Extract treatment elevated testicular TAC, GPx, and GR activities, reduced MDA levels, and increased serum free testosterone in diabetic rats, likely through induction of StAR mRNA expression.	[48]
Ocimum gratissimum (Lamiaceae)	Leaves	Ethanolic extract	200 mg/kg b.wt./day, orally for 21 days	ALX-induced diabetic rats	Significant decrease in blood glucose level	Extract-treated diabetic rats exhibited higher serum testosterone, FSH, and LH levels, along with improved sperm count, viability, and normal morphology compared with diabetic controls.	[68]
Nigella sativa (Ranunculaceae)	Seeds	Oil	1 mL/kg b.wt./day by gavage for 64 days.	STZ-induced diabetic rats	Significantly decreased fasting blood glucose level and increased serum insulin level	Serum testosterone, reproductive organ weights, epididymal sperm count, and live sperm percentage increased significantly, along with higher testicular SOD, GSH, and CAT activities and reduced MDA levels versus diabetic controls, likely due to the hypoglycemic, hypolipidemic, and antioxidant effects of *N. sativa*.	[66]
Piper sarmantosum Roxb. (Piperaceae)	Leaves	Aqueous extract	60 and 100 mg/100 g b.wt./day, orally for 21 days	STZ-induced diabetic mice	Significantly lowered the FBG level and increased plasma insulin level.	Extract treatment in diabetic rats significantly raised plasma testosterone, sperm concentration in the epididymis and vas deferens, and the numbers of motile and viable sperms, while reducing abnormal sperms, likely due to flavonoids such as quercetin, hesperetin, and naringenin.	[56]
Tridax procumbens (Asteraceace)	Whole plant	50% methanolic extract	250 mg/kg b.wt./day, orally for 30 days	ALX-induced diabetic rats	-	Extract-treated diabetic rats showed marked enhancement in mating behavior and higher serum testosterone levels compared with diabetic controls.	[75]

Ambrosia maritime (Asteraceae)	Arial part	Aqueous extract	28.5 mg/kg b.wt. twice/day, orally for 2 weeks	ALX-induced diabetic rats	-	Extract-treated diabetic rats showed notable restoration of seminiferous tubule diameter, connective tissue integrity, collagen distribution, and reduced germinal epithelium apoptosis, along with decreased caspase-3 positive cell expression versus diabetic controls.	[53]
Artemisia annua (Asteraceae)	Arial part	Aqueous extract	28.5 mg/kg b.wt. twice/day, orally for 2 weeks	ALX-induced diabetic rats	-	Extract-treated diabetic rats demonstrated significant restoration of seminiferous tubule diameter and connective tissue, with mild improvement in germinal epithelium apoptosis.	[53]
Artemisia Judaica (Asteraceae)	Arial part	Aqueous extract	28.5 mg/kg b.wt. twice/day, orally for 2 weeks	ALX-induced diabetic rats	-	Extract-treated diabetic rats showed enlarged seminiferous tubules, reduced connective tissue, and minimal, non-significant improvement in germinal epithelium apoptosis and caspase-3 expression versus diabetic controls.	[53]
Citrus aurantium (Rutaceae)	Fruit	50% Ethanolic extract	100 and 200 mg/kg b.wt./ day, orally for 56 days	STZ-induced diabetic rats	-	Serum testosterone, LH, FSH, and Leydig cell number (at high dose) increased significantly in the treated group,compared to the diabetic group, likely due to the extract's antioxidant action.	[69]
Citrullus colocynthis (Cucurbitacea)	Seeds pulp	Powder	10 mg/kg b.wt./ day, orally for 2 weeks	STZ-induced diabetic rats	Significantly decreased serum glucose level	Testosterone levels and reproductive organ weight ratios rose significantly in the treated group, versus diabetic controls, likely due to the antihyperglycemic action of colocynth saponosides.	[76]
Chrozophora tinctoria (Euphorbiaceae)	Aerial part	Aqueous extract	28.5 mg/kg b.wt. twice/day, orally for 2 weeks	ALX-induced diabetic rats	-	Extract-treated diabetic rats showed enlarged seminiferous tubules, normalized collagen distribution, reduced connective tissue and germinal epithelium apoptosis, along with decline in caspase-3 positive cell expression versus diabetic controls.	[53]
Curcuma longa (Zingiberaceae)	Rhizome	Curcumin	100 mg/kg b.wt./day, orally for 8 weeks	STZ-induced diabetic rats	Significant decrease in blood glucose and an increase in insulin levels	Curcumin treatment significantly increased absolute and relative testis weight and serum testosterone, reduced pro-inflammatory cytokines and NF-κB nuclear translocation, activated Nrf-2 for antioxidant defense, and limited apoptosis by lowering JNK and p38 gene expression in testicular tissue.	[43]
Nigella sativa (Ranunculaceae)	Seeds	Powder	300 mg/kg (powder) and 4 mg/kg (thymoqinone), b.wt./ day, orally for 45 days	STZ-induced diabetic rats	-	Diabetic groups treated with *N. sativa* powder and thymoquinone significantly normalized serum levels of testosterone and LH as compared to diabetic control groups. Thymoquinone is a major antioxidant component of *N. sativa.*	[77]
Phoenix dactylifera (Arecaceae)	Seeds	Powder	5, 10 and 15% of diet/ day, orally for 70 days	STZ-induced diabetic rats	Highly significant decrease blood glucose level.	Extract-treated diabetic rats showed higher testosterone, improved sperm quality, reduced abnormalities, lower testicular TBARS, increased SOD activity, and marked recovery of testicular damage versus diabetic controls.	[78]
Pronu samygdalus (Rosaceae)	Seeds	Oil	1 mL/kg b.wt./day, mixed in diet for 5 weeks	ALX-induced diabetic rats	-	Sperm count and the proportion of live, motile sperm increased significantly, while sperm morphology remained unchanged compared to diabetic controls.	[79]
Trigonella foenum-graecum (Fabaceae)	Seeds	Powder	1 g/kg b.wt./day, orally for 8 weeks	STZ-induced diabetic rats	-	Extract-treated diabetic rats showed higher testis weight, epididymal sperm count, and testicular GSH, with reduced TBARS versus diabetic controls; the best outcomes occurred with fenugreek plus insulin or glimepiride, likely due to its antioxidant, hypoglycemic, and steroidogenic effects.	[49]
Tribulus terrestris (Zygophyllaceae)	Fruits	Aqueous extract	10 mg/kg, b.wt./day, orally by gastric tube daily for 8 weeks.	STZ- induced diabetic rats	-	*T. terrestris* reduced oxidative stress, restored testicular antioxidant enzymes, improved serum lipid profile, and repaired tubular damage toward normal morphology; overall, it showed stronger protection against spermatotoxicity and testicular injury than metformin by improving redox balance in diabetic male rats.	[80]
Aloe vera (Asphodelaceae)	Leaves	Aqueous-ethanol extract of	10, 20, and 40 mg of extract per 10 mL of ex- vivo media	(*Ex-vivo)* STZ-induced diabetic rats epididymal washed sperm samples	-	The extract reversed diabetes-induced sperm oxidative damage, most prominently at 20 mg/10 mL by restoring antioxidant enzyme activity and reducing lipid peroxidation in sperm, testes, and metabolic organs in a dose- and time-dependent manner.	[81]

Anacardium occidentale (Anacardiaceae)	Leaves	Ethanolic extract	300 mg/kg b.wt./day, orally for 17 days	STZ-induced diabetic rats	Significant decrease in blood glucose level	Extract-treated diabetic rats exhibited restored epididymal structure and luminal sperm aggregation similar to normoglycemic rats.	[60]
Salvia officinalis L. (Lamiaceae)	Leaves	Aqueous extract	300 mg/kg b.wt./day, orally for 5 weeks	ALX-induced diabetic rats	Significantly reduced blood glucose level	Extract administration in diabetic rats significantly improved all testicular function parameters, including sperm count, viability, motility, and morphology as compared with untreated diabetic controls.	[64]
Tribulus terrestris (Gygophyllaceae)	Seeds	Hydroalcoholic	100, 250 and 500 mg/kg b.wt./day, orally for 15 days	STZ-induced diabetic rats	Significant reduction in blood glucose level	Extract-treated diabetic rats showed higher sperm motility and count, enlarged seminiferous tubules, more normal sperm morphology, increased testosterone, and greater final body weight compared to untreated diabetic rats.	[65]
Olea europaea (Oleaceae)	Leaves	80% Ethanolic extract	65 mg/kg b.wt./day, orally for 1 month	STZ-induced diabetic rats	Significant decrease in blood glucose level	Extract-treated diabetic rats showed increased testis weight, sperm count, and serum FSH, LH, and testosterone, along with enhanced antioxidant status (SOD, CAT, GPx, GST, GSH) and reduced MDA and NO levels in testicular tissue.	[82]
Gynura procumbens (Compositae)	Leaves	Aqueous and Ethanolic extract	50, 100 and 150 mg/kg b.wt./day, orally for 6 weeks	STZ-induced diabetic rats	Significant decrease fasting blood glucose level	Both extracts significantly improved epididymal sperm count, motility, and testosterone while reducing sperm mortality in diabetic rats, likely due to flavonoid glycosides such as kaempferol-3-glycoside that enhance insulin activity.	[67]
Hypoxis hemerocallidea (African Potato) (Hypoxidaceace)	Corms	-	200 and 800 mg/kg b.wt./day by gavage for 6 weeks	STZ-induced diabetic rats	Significantly reduced blood glucose level	Extract-treated diabetic rats showed higher body and reproductive organ weights, improved sperm motility and morphology, elevated testosterone and estradiol, enhanced antioxidant status (FRAP, ORAC, SOD, CAT, GSHt), and reduced lipid peroxidation compared to diabetic controls.	[83]
Kaempferia parviflora (Zingiberaceae)	Rhizome	Ethanolic extract	140, 280 and 420 mg/kg b.wt./day, orally for 6 weeks	STZ-induced diabetic rats	No effect on blood glucose level	Extract treatment significantly enhanced sperm density, elevated serum testosterone, and improved testicular architecture in diabetic rats.	[84]
Lyceum barbarum (Solanaceae)	-	Poly-saccharide	10, 20 and 40 mg/kg b.wt./day, orally for 62 days	STZ-induced diabetic mice	-	Polysaccharide treatment in diabetic mice increased reproductive organ weights, improved sperm parameters and testicular histology, and enhanced antioxidant enzyme activity.	[85]
Olea europaea (Oleaceae)	Leaves	Ethanolic extract	15 mg/kg b.wt./day, orally for 1 month	NA-STZ-induced diabetic rats	-	Extract-treated diabetic rats showed restoration of normal seminiferous tubule architecture and marked improvement in hematological parameters.	[86]
Pseudocedrela kotschyi (Meliaceace)	Roots	Ethanolic extract	250 and 500 mg/kg b.wt./day, orally for 4 weeks	ALX-induced diabetic rats	Significant decrease in plasma glucose level	Extract-treated diabetic rats showed increased body and reproductive organ weights, higher testosterone, improved sperm count and motility, enhanced testicular antioxidants (GSH, CAT, SOD, GPx), and reduced MDA levels.	[87]
Vernonia cinerea (Compositae)	Leaves and stem	Ethanolic extract	10 and 40 mg/kg b.wt./day, orally for 30 days	STZ-induced diabetic rats	Significant decrease in blood glucose level	Extract treatment restored sperm motility and testosterone levels, reduced testicular damage, and at higher doses improved sperm count along with showing antidiabetic activity in diabetic rats.	[88]
Xanthosoma sagittifolium (Araceae)	Corms	Powder	100 g feed contained 25, 50, 75 or 100% X. sagittifolium on a wt./wt. basis. for 14 days	ALX-induced diabetic rats	-	In diabetic rats, *X. sagittifolium* powder improved sperm motility, viability, and count (without affecting volume) and increased seminiferous tubule and luminal diameters on histology.	[89]
Nasturtum officinalis (Brassicaceae)	Aerial parts	Hydro-alcoholic extract	250, 500 mg/kg, b.wt./day, orally by gavage for 21 days	STZ-induced diabetic rats	-	Extract treatment increased fast sperm motility and elevated testosterone, LH, and FSH levels, indicating that hydroalcoholic watercress extract improves reproductive parameters and sex hormones in diabetic rats.	[90]
Gynura procumbens (Asteraceae)	Leaves	Aqueous extract	150, 300 and 450 mg/kg, b.wt./day, orally for 14 days	STZ-induced diabetic rats	Significant decrease in blood glucose levels	Extract administration reduced fasting blood glucose, raised plasma testosterone, improved sperm quality and fertility, and enhanced sexual behavior by increasing mounting frequency and shortening mounting latency in diabetic rats.	[91]

Nigella sativa (Ranunculaceae)	Seeds	Thymoquinone (TQ)	50mg/kg, b.wt./day, orally by gavage for 12 weeks	STZ-induced diabetic rats	-	TQ improved sperm parameters, reduced testicular NO and MDA, increased GSH and SOD, downregulated iNOS and NF-κB, and upregulated aromatase expression, thereby protecting against diabetes-induced reproductive dysfunction through antioxidant and hypoglycemic actions.	[92]
Citrullus colocynthis (Cucurbitaceae)	Pulp		10 mg/kg, b.wt./day, orally for 2 weeks	STZ- induced diabetic rats	Significant decrease in blood glucose levels	In diabetic rats, extract treatment lowered H_2O_2, MDA levels and CAT activity, while increasing POD activity in both testes and epididymis.	[61]
Cinnamon zeylanicum (Lauraceae)	Bark	Aqueous extract	500 mg/kg, b.wt./day, orally for 6 weeks	ALX-induced diabetic rats	Significant decrease in blood glucose levels	Six weeks of oral extract administration significantly raised testosterone, reduced testicular degeneration, and improved fertility while lowering blood glucose in diabetic male rats, suggesting potential benefits of bark extract for diabetes-related sexual dysfunction.	[93]
Loranthus micranthus (Loranthaceae)	Leaves	Aqueous-methanolic extract	100 and 200 mg/kg b.wt./day, orally for 14 days	STZ-induced diabetic rats	Significant reduction in the blood glucose level (45.9% and 84.7% on the 7th and 14th post-treatment days, respectively)	*L. micranthus* treatment enhanced antioxidant status, reduced lipid peroxidation, improved testicular structure, and upregulated BCl-2, while boosting steroidogenic enzyme activity, steroid hormone levels, and sperm quality in diabetic rats.	[94]
Crassocephalum crepidioides (Asteraceae)	Whole plant	Methanolic extract	500 mg/kg b.wt./day, orally for 28 days	STZ-induced diabetic rats	Significantly decrease in blood and serum glucose levels	*C. crepidioides*extract lowered glucose levels, improved sperm quality and reproductive hormones (TT, FSH, LH), reduced testicular degeneration and inflammation, and preserved overall testicular function in diabetic rats.	[70]
Stevia rebaudiana (Asteraceae)	Leaves	Aquatic extract	400 mg/kg, b.wt./day, by gavage for 2 weeks	STZ-NA induced diabetic	Significant decrease in blood glucose levels	Due to its antioxidant properties, stevia reduced testicular MDA levels and increased CAT activity, suggesting benefits in alleviating diabetes-related male reproductive complications.	[50]
Ferulago angulata (Apiaceae)	Leaves and stem	Hydro-alcoholic extract	100, 200 and 400 mg/kg, b.wt./day	STZ-induced diabetic rats	-	*F. angulata* extract (200–400 mg/kg) increased serum testosterone, sperm count, viability, motility, normal morphology, seminiferous tubule diameter, and germinal epithelium maturity in diabetic male rats, demonstrating its antioxidant-mediated improvement of reproductive parameters.	[95]
Curcuma longa (Zingiberaceae)	Whole plant	Cucurmin	50,100 and 100 mg/kg, b.wt./day	ALX-induced diabetic rats	-	Cucurmin treatment (100–150 mg/kg) significantly improved sperm concentration, motility, average path velocity (VAP), curvilinear velocity (VCL), straight line velocity (VSL), and increased germinal epithelium diameter and thickness of seminiferous tubules compared with diabetic rats.	[96]
Cyperus esculentus (Cyperaceae)	Seed	Ethanolic extract	400, 800 mg/kg b.wt./day, orally for 21 days	ALX-induced diabetic rats	Significant decrease in blood glucose levels	A higher dose of ethanolic *C. esculentus* seed extract significantly increased sperm count and motility, raised normal sperm numbers, and reduced abnormal sperm, suggesting its potential to improve sperm quality in DM.	[97]
Ginkgo biloba (Ginkgoaceae)	Leaves	*G. biloba* leaves extract	100 mg/kg b.wt./day, orally for 6 weeks	STZ-induced diabetic rats	-	In diabetic rats, the prostate showed epithelial stratification, pyknotic nuclei, disrupted basement membrane, irregular nuclei, cytoplasmic vacuoles, dilated rough ER, and loss of apical microvilli, with extensive cellular degeneration. Ginkgo extract largely restored these prostatic alterations, indicating its protective effect against diabetes-induced prostatic damage.	[63]
Laminaria japonica (Laminariaceae)	Whole plant	Fucoxanthin-rich extract	-	STZ-NA induced diabetic rats	Fucoxanthin administration improved insulin resistance	Fucoxanthin improved sperm motility, reduced abnormal sperm, and inhibited lipid peroxidation, while restoring hypothalamic GPR54 and SOCS-3 expression and normalizing LH and testosterone levels, demonstrating antioxidant, anti-inflammatory, and reproductive-protective effects in diabetic males.	[98]
Trigonella foenum graecum (Fabaceae)	Seeds	Water extract	500 mg/kg, b.wt./day, orally for 8 weeks	STZ-induced diabetic rats	Significant elevation of serum levels of insulin.	Combining Fenugreek seed extract with Glimepiride improved body weight, glycemic control, hematological, biochemical, and histological parameters, and reduced diabetes complications in STZ-induced rats, showing greater benefits than either treatment alone.	[99]

Olea europaea (Oleaceae)	Leaves	Ethanolic extract	250 and 500 mg/kg, b.wt./day, orally for 9 weeks	STZ-induced diabetic rats	Significant elevation of serum levels of insulin.	STZ reduced serum insulin, testosterone, FSH, LH, testicular antioxidants, and sperm quality while increasing MDA and damaging testicular structure. *O. europaea* leaf extract significantly restored these parameters, highlighting its potential to counter diabetes-induced hyperglycemia and oxidative stress.	[100]
Silybum marium (Asteraceae)	Seed	Silymarin (SMN) component	100, 200 mg/kg, b.wt./day, orally by gavage for 5 weeks	STZ-induced diabetic rats	-	SMN treatment improved sperm quality (count, motility, morphology, DNA integrity, viability), enhanced reproductive performance, reduced lipid peroxidation, and boosted antioxidant enzymes. It upregulated Bcl-2, downregulated Bax and Caspase-3, and restored serum testosterone levels in diabetic rats.	[101]
Nigella sativa (Ranunculaceae)	Seeds	Hydro-alcoholic extract	200,400 mg/kg, b.wt./day, with gavage for 90 days	10% Fructose-induced diabetic rats	-	*N. sativa* improved male reproductive parameters, including increased numbers of spermatogonia, spermatids, Sertoli cells, and Leydig cells in experimental groups.	[102]
Stevia rebaudiana (Asteraceae)	Leaves	Ethanolic extract	5, 50 and 100 mg/kg, b.wt./day, orally for 28 days	STZ-induced diabetic rats	Significant decrease in blood glucose levels	Low-dose stevia extract (5 mg/kg) increased ejaculation and intromission frequency and preserved Leydig cell numbers in STZ-induced diabetic rats, suggesting aphrodisiac effects likely due to its antioxidant, vasodilatory, and antidiabetic properties, while serum testosterone and other sexual behaviors remained unchanged.	[103]
Galega officinalis (Fabaceae)	Whole plant	Hydro-walcoholic extract	50mg /kg, b.wt./day, orally for 8 weeks	STZ-induced diabetic rats	Significant reduction in the glucose plasma levels and increased the insulin levels	*G. officinalis* extract (50 mg/kg) improved seminiferous tubule diameter and Johnson score, restored testicular antioxidant enzymes (SOD, CAT), reduced MDA levels, and enhanced sperm parameters in diabetic rats.	[104]
Ocimum gratissimum (Lamiaceae)	Leaves	Aqueous extract	400 mg/kg, b.wt./day, orally for 28 days	ALX-induced diabetic rtas	Significant decrease in blood glucose levels	Sperm count remained unchanged in the diabetic group but decreased in the extract-treated group, while abnormal sperm cells increased in the extract, diabetic and diabetic + extract groups. Testicular histology showed mild seminiferous tubule vacuolation, disorganized germinal epithelium, arrested spermatogenesis with empty lumens, reduced seminiferous tubule diameter and enlarged interstitial spaces compared with the control group.	[105]
Cinnamon (Lauraceae)	Bark	Aqueous extract	80 mg/kg, b.wt./day, orally for 4 weeks	ALX-induced diabetic rats	-	Cinnamon powder significantly improved fertility parameters—including testosterone, epididymal weight, sperm count, motility, and morphology (normal sperm count, abnormal head sperms, abnormal tail sperms), in both normal and diabetic rats, with diabetic rats showing greater improvements.	[57]
Fleurya aestuans (Urticaceae)	Leaves	Hydroethanolic extract	50, 75 and 200 mg/kg, b.wt./day, orally for 28 days	ALX-induced diabetic rats	Significant decrease in blood glucose levels	The extract significantly enhanced sperm quality (count, motility, viability, morphology), reproductive hormones (LH, FSH, testosterone, prolactin), and antioxidant status (SOD, CAT, GSH).	[71]
Fumaria parviflora (Papaveraceae)	Whole plant	Hydroalcoholic Extract	250 mg/kg, b.wt./day, orally for 20 days	STZ- induced diabetic rats	-	Hydroalcoholic *C. zeylanicum* extract protects the male reproductive system by reducing lipid peroxidation, preventing abnormal sperm formation, and mitigating testicular cell apoptosis.	[106]
Anacyclus pyrethrum (Asteraceae)	Root	Alcoholic extract	50, 100 and 150 mg/kg, b.wt./day, orally for 4 weeks	STZ-induced diabetic rats	-	*A. pyrethrum* alcoholic root extract significantly increased serum FSH, LH, testosterone, and the weights of the epididymis, testes, and body compared with diabetic control and placebo groups.	[107]
Garcinia kola (Guttiferae)	Seeds	Kolaviron (KV) extract	100 mg/kg, b.wt., five times per week, orally for 6 weeks	STZ-induced diabetic rats	Significant decrease in blood glucose levels	Diabetes increased testicular and epididymal lipid peroxidation and reduced antioxidant enzyme activities. KV treatment mitigated LPO and enhanced SOD, CAT, and GPx activities, demonstrating its antioxidative effects in STZ-induced diabetic reproductive tissues.	[62]
Annona muricata (Annonaceae)	Leaves	Ethanolic extract	100,200 mg/kg, b.wt./day, by oral gavage for 14 days	STZ-induced diabetic rats	Significant decrease in blood glucose levels	Extract treatment enhanced sperm viability, count, motility, morphology, and testicular weight, improving overall testicular function and structure, likely due to the antioxidant effects of *A. muricata* leaf extract.	[108]
Commiphora myrrha (Burseraceae)	Dried myrrh gum-resin	Ethanolic extract	100, 200, 300, and 500 mg/kg, b.wt., /day, orally for 28	STZ-induced diabetic rats	-	Extract treatment, particularly at 500 mg/kg, significantly increased sperm concentration, motility, viability, and sex hormones while reducing testicular MDA	[109]

			days			levels and germ cell apoptosis compared with untreated diabetic rats.	
Auricularia polytricha (Auriculariaceae)	Whole plant	Ethanolic extract	250,500, and 1000 mg/kg, b.wt./day, by oral gastric intubation for 3 weeks	STZ-induced diabetic rats	-	*A. polytricha* administration reversed diabetes-induced changes in sperm parameters(sperm count, sperm motility, and morphology), gonadotropic hormones, and testicular histology, likely due to its bioactive phytochemicals, highlighting its potential against diabetes-related testicular dysfunction.	[110]
Azadiracta indica (Meliaceae)	Leaves	Ethanolic extract	250 mg/kg, b.wt./day, by gastric tube for 2 weeks	STZ-induced diabetic rats	-	In diabetic rats, testicular antioxidants and serum testosterone were significantly reduced, while serum cholesterol, triglycerides, and LDL levels increased and HDL levels decreased. Additionally, testicular tissues showed histological and ultrastructural damage—particularly in spermatogenic and interstitial cells—along with COX-2 overexpression.	[111]
Moringa oleifera (Moringaceae)	Leaves	Aqueous extract	0, 10, 50,100, 250, 500 and 1,000 µg/mL) for 24 h,	*In-vitro* [TM3 cell line (mouse Leydig cells)]	-	In TM3 cells, plant extract increased testosterone production by 34–45% at 500–1,000 µg/mL and raised glutathione at 250 µg/mL, while other antioxidant parameters remained unchanged, demonstrating its androgenic effect likely linked to antioxidant activity.	[112]
Momordica charantia (Cucurbitaceae)	Fruits	Ethanolic extract	250,500 mg/kg, b.wt./day, orally via oral tube for 12 weeks	STZ-induced diabetic rats	Significant reduction in blood glucose, HbA1c and marked elevation of serum levels of insulin.	Extract administration in diabetic rats increased serum testosterone and gonadotropins, restored testicular antioxidants, improved histology, and reduced spermatogenic and Sertoli cell apoptosis through upregulation of Bcl-2, downregulation of Bax and caspase-3, and a lowered Bax/Bcl-2 ratio.	[113]
Coffea arabica (Rubiaceae)	Beans	Water extract	50, 100mg/kg, b.wt./day, orally for 28 days	HFD/STZ-induced diabetic rats	-	Green coffee treatment in diabetic rats increased antioxidants (GSH, SOD, CAT, GPx, GR), reduced lipid peroxidation and nitric oxide, and lowered IL-1β, TNF-α, Bax, and caspase-3 levels, demonstrating its ability to reverse HFD- and STZ-induced testicular oxidative damage.	[114]
Psidium guajava (Myrtaceae)	Leaves	Ethanolic extract	100, 200 mg/kg, b.wt./day, orally for 2 weeks	STZ-induced diabetic rats	Significant decrease in blood glucose levels	In extract-treated rats, testis weight, sperm count, motility, and viability increased, while abnormal sperm decreased, and testicular lesions were absent. Plant extract appears to exert antihyperglycemic and antioxidant effects, improving diabetes-related reproductive complications.	[51]
Diplotaenia turcica (Umbelliferae)	Roots	Ethanolic extract	100 and 200 mg/kg, b.wt./day,through gastric gavage for 28 days	STZ- induced diabetic rats	-	*D. turcica* root extract at 100 mg/kg improved sperm motility, density, and testosterone levels in diabetic rats, whereas the 200 mg/kg dose showed no such effect.	[115]
Cleome rutidosperma (Cleomaceae)	Leaves	Methanolic extract	100, 200 and 400 mg/kg, b.wt./day, orally for 14 days	ALX-induced diabetic rats	Significant decrease in blood glucose levels	*C. rutidosperma* extract, particularly at 200 mg/kg, reduced abnormal sperm, improved motility, viability, and count, and restored spermatogenesis and Sertoli cell integrity in diabetic rats compared to untreated controls.	[116]
Artemisia judaica (Asteraceae)	Flower tip	Ethanolic extract	300 mg/kg, b.wt./day, orally for 28 days	HFD/STZ-induced diabetic rats	-	*A. judaica* extract prevented STZ + HFD-induced disruptions in male sex hormones, oxidative stress, inflammation, and testicular cell apoptosis. Its antioxidant, anti-inflammatory, and antiapoptotic effects alleviated diabetes-induced testicular damage, performing comparably or better than metformin	[117]
Gynura procumbens (Asteraceae)	Leaves	Aqueous extract	150, 300, 450 mg/kg, b.wt./day, by oral gavage for 7 days	STZ-induced diabetic rats	Significant decrease in blood glucose levels	7-day extract treatment, especially at 450 mg/kg, enhanced sperm quality, seminiferous tubule histology, LH, FSH, and testosterone levels, improved libido (higher mounting frequency, shorter latency), and increased implantation sites compared with controls	[118]
Aloe vera (Asphodelaceae)	Leaves	Ethanolic extract	200 and 400 mg/kg, b.wt./ day, orally for 4 weeks	STZ-induced diabetic rats	-	Aloe vera peel extract significantly increased sperm motility, concentration, and testosterone levels in diabetic rats compared with controls.	[119]
Echinacea purpurea (Asteraceae)		Ethanolic extract	93, 279, and 465 mg/kg, b.wt./ day, orally for 4 weeks	STZ-NA - induced diabetic rats	Significant decrease in blood glucose levels	EPE improved sperm motility, morphology, mitochondrial function, and testosterone-synthesizing enzymes, increased antioxidant enzymes (SOD, CAT, GSH), and reduced proinflammatory cytokines (NO, IL-1β,	[120]

						TNF-α) and testicular TLR4/phospho-NF-κB p65, suggesting it alleviates diabetes-induced male infertility via anti-inflammatory and antioxidant effects.	
Rydingia persica (Lamiaceae)	Aerial parts	Powder	200,400,600 mg/kg, b.wt./day, orally for 2 weeks	STZ-induced diabetic rats	Significant decrease in blood glucose levels	*R. persica* treatment in diabetic rats restored oxidant-antioxidant balance, improved testicular histology, and normalized serum testosterone and LH levels, with the highest dose showing the greatest effect.	[121]
Kigelia africana (Bignoniaceae)	Stem bark	Ethanolic extract	250 mg/kg, b.wt./day, orally by gavage for 6 weeks	STZ-induced diabetic rats	Significant decrease in blood glucose levels	Ethanolic extract treatment in diabetic rats increased serum LH and testosterone, restored sperm count and motility, reduced MDA, and enhanced SOD activity. It normalized elevated ALT and AST levels and reversed reductions in total protein and albumin, likely through its phytochemicals and antioxidant effects improving reproductive and metabolic parameters.	[122]
Costus afer (Costaceae)	Leaves m	Ethanolic extract	100, 200 mg/kg, b.wt./day, orally for 4 weeks	Fructose/ STZ-induced diabetic rats	-	Extract administration reduced testicular and epididymal degeneration, improved pituitary-gonadal hormone levels, and enhanced sperm morphology.	[123]
Zingiber officinale (Zingiberaceae)	Roots	Aqueous extract	Ginger extract (300, 600 mg, kg, b.wt./day), and vit E (200 mg/kg) orally for 65 days	STZ-induced diabetic rats	-	Co-administration of ginger extract and Vitamin E in STZ-induced diabetic rats increased fertility index, testis and epididymis weights, serum testosterone, and semen quality, while reducing testicular degeneration and restoring spermatogenesis.	[124]
Moringa oleifera (Moringaceae)	Leaves	Hydroaclcoh olic extract	100, 250, and 500 mg/kg b.wt./day, orally for 60 days	STZ-induced diabetic rats	-	Oral leaf extract administration in diabetic rats increased serum testosterone, LH, and FSH, restored testicular histology, reduced TBARS, and enhanced antioxidant markers, showing effects comparable to glibenclamide.	[52]
Turnera diffusa Willd. ex-Schult. (Passifloraceae)	Leaves	Aqueous extract	100 and 200 mg/kg, b.wt./day, orally for 28 days	T2DM rats	-	*T. diffusa* treatment in diabetic rats restored sperm count, motility, and viability, reduced morphological abnormalities and DNA fragmentation, lowered testicular NOX-2 and lipid peroxidation, and enhanced antioxidant enzymes (SOD, CAT, GPx). It also reduced testicular inflammation via NF-κB, p-Ikkβ, and TNF-α downregulation, increased steroidogenic proteins (StAR, CYP11A1, SHBG, ARA54, 3 and 17β-HSD) and plasma testosterone, and elevated Sertoli cell markers (Connexin 43, N-cadherin, occludin).	[125]
Psidium guajava (Myrtle)	Leaves	Ethanolic extract	125 and 250 mg/kg, b.wt./day, orally for 14 days	STZ- induced diabetic rats	Significant decrease in blood glucose levels	Plant ethanolic extract treatment significantly increased FSH and LH levels in diabetic rats, likely via hypothalamic stimulation, suggesting *P. guajava* extract may enhance male fertility in diabetes.	[126]
Anacardium occidentale (Anacardiaceae)	Nuts	Methanolic extract	100, 200 mg/kg, b.wt./day, orally for 28 days	STZ/ HFD- induced diabetic rats	-	*A. occidentale* nut improves testicular function by reducing oxidative stress, inflammation, and apoptosis caused by chronic hyperglycemia.	[127]
Apium graveolent (Apiaceae)	Leaves	Aqueous extract	200 mg/kg, b.wt./day, orally for 30 days	STZ-induced diabetic rats	-	Celery extract (200 mg/kg) increased sperm count, seminiferous tubule diameter, and the weights and volumes of the testis, epididymis, and vas deferens, while also elevating liver enzymes AST and ALT.	[128]
Retama raetam (Fabaceae)	Fruits	Methanolic extract	10, 20 and 30 mg/kg, b.wt./day, orally for 12 weeks	HFD/ STZ-induced diabetic rats	-	*R. raetam* extract counteracted HFD/STZ-induced oxidative stress by boosting testicular antioxidants (SOD, GSH) and reducing MDA. It restored gene expression by increasing CYP17, STAR, 3βHSD, and BCL2 and decreasing BAX, with Bax showing strong binding affinity to *R. raetam* bioactive compounds.	[129]
Moringa oleifera (Moringaceae)	Leaves	Ethanolic extract	100, 250, and 500 mg/kg b.wt./day, orally for 60 days	STZ-induced diabetic rats	-	Oral *M. oleifera* administration (100–500 mg/kg) increased absolute and relative reproductive organ weights and restored reproductive tissue biochemical parameters in diabetic rats, showing effects comparable to glibenclamide.	[58]

Rosmarinus officinalis (Lamiaceae)	Leaves	Ethanolic extract	200, 400 mg/kg, b.wt./day, orally for 4 weeks	STZ-induced diabetic rats	Significant decrease in blood glucose levels	Extract treatment (200–400 mg/kg) increased serum testosterone, FSH, and LH, reduced testicular MDA, enhanced GSH, SOD, and GPx, and protected against STZ-induced testicular damage by lowering caspase-3–mediated apoptosis.	[130]
Euphorbia heterophylla (Euphorbiaceae)	Aerial parts	Ethanolic extract	50, 100, 200 mg/kg, b.wt./day, orally for 8 weeks	STZ-induced diabetic rats	-	Ethanolic treatment mitigated STZ-induced damage by restoring testosterone and antioxidant levels, reducing pro-inflammatory cytokines, improving testicular microcirculation, and inhibiting testicular apoptosis.	[131]
Dracaena arborea (Asparagaceae)		Aqueous and ethanolic extract	500 mg/kg (aqueous) and 100 mg/kg (ethanol), b.wt./day, orally by gavage for 4 weeks	STZ-induced diabetic rats	-	*D. arborea* extract, despite lacking antihyperglycemic effects, improved sexual behavior, fertility parameters, serum testosterone and total protein, and restored testicular and epididymal structure in diabetic rats, likely due to its androgenic constituents.	[58]
Solanum lycopersicum (Solanaceae)	Fruits	Esculeoside A (ESA) extract	100 mg/kg, b.wt./day, orally for 12 weeks	STZ-induced diabetic rats	-	ESA did not prevent weight loss, hyperglycemia, or hypoinsulinemia in STZ-DM rats but improved dyslipidemia, sperm count, motility, viability, and reduced sperm abnormalities. It increased serum FSH, LH, and testosterone, upregulated testicular steroidogenic enzymes (StAR, CYP11A1, CYP17A1, 3β-HSD1), enhanced Nrf2 activity and antioxidant levels (HO-1, SOD, GSH), lowered MDA and Keap1, and suppressed NF-κB, TNF-α, and IL-6. These protective effects were blocked by Brusatol.	[72]
Cassia fistula (Caesalpiniaceae)	Pod	Hydroalcoholic extract	100, 250 and 500 mg/kg b.wt./day, orally for 60 days	STZ-induced diabetic rats	Significant increase in insulin levels	*C. fistula* extracts improved testosterone, LH, and FSH levels, restored testicular histology, reduced lipid peroxidation (TBARS), and increased antioxidants (SOD, CAT, GSH, and ascorbic acid) in diabetic rats.	[132]
Polyherbal drugs							
Cinnamomum cassia (Lauraceae) + Zingiber officinale (Zingiberaceae)+ ***Eugena caryophyllus*** (Myrtaceae)	Bark + Rhizome + buds	Aqueous extract	2.0 mL (200 mg)/kg b.wt./day, orally for 15 days	STZ-induced diabetic rats	Significantly lowered of blood glucose level	In extract-treated diabetic rats, testicular histology improved, testosterone levels were restored, sperm count and motility increased, sperm abnormalities decreased, and caspase-3 and VEGF expression were reduced, indicating the herbal blend helps maintain oxidative balance and prevent reproductive dysfunction.	[133]
Nigella sativa (Ranunculaceae) +***Zingiber officinale*** (Zingiberaceae) **+** ***Punica granatum*** (Punicaceae)	Seeds		80 mg/kg, 100 mg/kg/rat 500 mg/rat/day	STZ-induced diabetic rats	-	*P. granatum*, Ginger, and *N. sativa* reduced oxidative stress and inflammation in diabetic rats, improving seminiferous tubule function and increasing sperm count and motility, with greater efficacy than metformin.	[134]
Hibiscus sabdariffa (Malvaceae)+***Ceratonia silique*** (Fabaceae)	Calyx + Whole plant	Aqueous extract	100, 200 mg/kg, b.wt./day, orally through gastric tube for 30 days	ALX-induced diabetic rats	Significant decrease in blood glucose levels	Treatment with *H. sabdariffa* calyx and *C. siliqua* extracts increased serum testosterone, FSH, and LH, and improved testicular and pancreatic histology in diabetic rats.	[135]
Chicoriumintybus (Asteraceae) + ***Portulaca oleracea*** (Portulacaceae)	Seed	Ethanolic extract	250+ 200 mg/kg, b.wt./day, orally for 30 days	STZ-induced diabetic rats	Normalization of fasting blood glucose (FBG), serum fructosamine, insulin levels, and insulin resistance (HOMA-IR)	Both plant seed extracts protected against diabetes-induced testicular dysfunction by reducing MDA, AO, and XO, enhancing antioxidants (GSH, SOD, CAT, TAC), improving sperm quality, testosterone, vimentin, and body/testis weight, correcting lipid profile, lowering proinflammatory cytokines (TNF-α, CRP, IL-6), and reducing apoptosis and DNA damage (↓8OHdG, caspase-3; ↑Bcl-2), demonstrating antihyperglycemic, antilipidemic, antioxidant, anti-inflammatory, and antiapoptotic effects.	[136]

Abbreviations: ALT: Alanine Aminotransferase; ALX: Alloxan; AO: Antioxidant; AST: Aspartate Aminotransferase; CAT: Catalase; CRP: C-Reactive Protein; DM: Diabetes Mellitus; FRAP: Ferric Reducing Antioxidant Power; FSH: Follicle Stimulating Hormone; GPx: Glutathione Peroxidase; GR: Glutathione Reductase; GSH: Reduced Glutathione; GSHt: Total Glutathione; GST: Glutathione S-Transferase; HDF: High Dextrose Feed; HDL: High Density Lipoprotein; HFD: High Fat Diet; HSD: Hydroxysteroid Dehydrogenase; JNK: c-Jun N-terminal Kinase; LDL: Low Density Lipoprotein; LH: Luteinizing Hormone; MDA: Malondialdehyde; NA: Nicotinamide; NF-κB: Nuclear Factor Kappa B; NO: Nitric Oxide; NOX-2: NADPH Oxidase 2; Nrf-2: Nuclear Factor Erythroid 2-Related Factor 2; ORAC: Oxygen Radical Absorbance Capacity; POD: Peroxidase; SHBG: Sex Hormone Binding Globulin; SOD: Superoxide Dismutase; STAR: Steroidogenic Acute Regulatory Protein; STZ: Streptozotocin; TAC: Total Antioxidant Capacity; TBARS: Thiobarbituric Acid Reactive Substances; TNF: Tumor Necrosis Factor; TT: Total Testosterone; VEGF: Vascular Endothelial Growth Factor; XO: Xanthine Oxidase.

CONCLUSION

Diabetes mellitus induced male reproductive dysfunction is a significant complication associated with oxidative stress, hormonal imbalance, and impaired spermatogenesis. Evidence from experimental studies indicates that various medicinal plants and polyherbal formulations can ameliorate these alterations through antidiabetic, antioxidant, and anti-inflammatory mechanisms, thereby improving glycemic control and reproductive functions. However, most findings are based on preclinical studies; therefore, further clinical investigations and standardization are required to confirm their therapeutic efficacy and safety. Overall, medicinal plants represent a promising complementary approach for managing diabetes-related male reproductive dysfunction.

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TJ contributed to conceptualization, original draft preparation, review and editing, and visualization; AJ to review and editing; GSB to editing; and RNJ to original draft preparation and review and editing. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data that support the findings of this study are available and will be made available upon request.

Use of AI in Drafting of Manuscript

The authors declare that they have not used any generative AI/AI-assisted technologies in the writing of this manuscript.

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