Research Article

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Protective properties of AgNPs green-synthesized by *Abelmoschus esculentus* on retinal damage on the virtue of its anti-inflammatory and antioxidant effects in diabetic rat

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Abstract: Eye retinopathy means damage to the retina of the eye, which can have various causes, both congenital and acquired. Diabetes is one of the important causes of eye retinopathy. Retinopathy can develop slowly or quickly, get better on its own, or lead to permanent damage. No treatment is recommended in the early and mild stages. However, close monitoring is essential. Severe form of the disease may require treatment. Recently, the researchers have focused on new options for the treatment of the retinal damages. Present investigation discloses the silver nanoparticles (AgNPs) biosynthesizing capability of the leaves of pharmacologically important *Abelmoschus esculentus*. Rapid, cost-effective, one-step process of formulation has been achieved. New genre AgNPs were characterized by involving ultraviolet-visible spectroscopy, Fourier transform infrared, and field emission scanning electron microscopy analysis. Effect of AgNPs@*Abelmoschus esculentus* was assessed on the retinal injury of diabetic rats in this study. After inducing the diabetes by STZ, all rats were separated in to seven different groups (n = 20) including control, diabetic retinopathy group receiving saline solution, and AgNPs@*Abelmoschus esculentus* treated group receiving AgNPs@*Abelmoschus esculentus* (20, 40, and 80 µg/kg) for a duration of 8 weeks. After completion of the treatment protocol, the body weight and blood glucose were determined. Leukocytosis, retinal vascular permeability, fundus photography, and retinal vessel diameter, the levels of superoxide dismutase (SOD), catalase (CAT), and glutathione (GSH), and concentrations of IL10, NF-κB, and TNFα in the retina were assessed. AgNPs@*Abelmoschus esculentus* in all doses reduced significantly (p ≤ 0.01) the weight, glucose, NF-κB, and TNFα concentrations, retinal leukocytosis, and vascular permeability and increased the concentrations of SOD, CAT, GSH, and IL10. Thus, the present research concludes that AgNPs@*Abelmoschus esculentus* effectively manages the diabetic retinopathy at the best.

Keywords: retinal damage, anti-inflammatory, antioxidant, silver nanoparticles, *Abelmoschus esculentus*

1 Introduction

Retinopathy is one of the diabetes complications that leads to changes in the eye vessels. The retina is the main part of the eye, that is, the work done by different parts of the eye, such as the lens, cornea, etc., is to create an accurate and clear image on the retina so that its effect is sent to the brain and we can see [1–3]. Damage to this part causes retinopathy. This problem in diabetic patients causes blindness. Background retinopathy is the first stage of diabetic retinopathy. At this stage, the small vessels in retina are damaged and blood or fluid leaks from them [4–6]. The leaked liquid causes retina swelling or deposits called “exudate.” Although this stage usually does not affect vision, it may later progress to more severe stages that lead to vision loss. Sometimes the liquid that has leaked collects in the center of vision. The visual center is responsible for observing small details of objects (for example, numbers or letters) [6–8]. This problem is called swelling of the center of vision and may make reading or doing close tasks more difficult. The vessels are fragile and have weaker walls and may lead to bleeding. The vitreous is a clear, jelly-like substance that fills the eye center [5–8]. Leaked blood makes the vitreous cloudy and partially blocks the passage of light from the pupil to the retina, resulting in a blurry image. These abnormal blood vessels...
may become hardened tissue that separates the retina from the back wall of the eye and causes retinal detachment, which, if left untreated, can lead to severe vision loss and blindness. Abnormal blood vessels grow on the iris (the colored part of the eye), around the pupil, and the increase in the intraocular pressure causes glaucoma [8–10]. Proliferative diabetic retinopathy is the main severe type of retinal disease caused by diabetes. About 20% of diabetic patients suffer from it, and it can cause severe vision loss and blindness [10–13]. Non-proliferative retinopathy is a stage that sometimes has mild symptoms and may even be asymptomatic, but if the sensitive point of vision (macula) is involved, vision loss will occur. When bleeding occurs, vision may be impaired or even lost. Proliferative retinopathy does not cause pain, but it is a severe disease that must be treated quickly. High blood pressure and pregnancy may aggravate retinopathy [7–11]. Vascular endothelial growth factor (VEGF) inhibitors stop the neovascularization of the visual field, retina, and iris and reduce fluorescein leakage. Preliminary results show that ranibizumab and aflibercept are valuable and superior to whole retinal photocoagulation in terms of visual acuity, respectively. There are no data to suggest that one VEGF inhibitor is superior to another for reducing neovascularization [12–16]. Although hevacizumab is the least expensive, it is difficult to obtain from compounding pharmacies [17–20]. The choice of a specific VEGF inhibitor for the proliferative retinopathy treatment is often based on availability, physician familiarity with the drug, cost, and patient characteristics (e.g., the presence or absence of diabetic macular edema, the severity of retinopathy, and previous history of intravitreal injection of VEGF-inhibiting drugs). Recently, medicinal plants and herbal nanoparticles have been proposed as treatment options for various diseases such as eye complications [21–25].

The science of nanotechnology has contributed greatly to the development and discovery of modern treatment options, e.g., we can mention the modified nanoparticles use for the selective and targeted delivery of drugs to abnormal tissue [26–31]. The use of nanotechnology in the drugs production is one of the promising fields for the diagnosis and treatment of diseases. Because of their excellent physical characteristics, nanoparticles have been applied as an effective candidate for drug treatment, the most important of which is silver nanoparticles (AgNPs) [32–36]. Although there are different methods for NP synthesis, biocompatible methods such as synthesis using bacteria, fungi, and plants are very simple and cost-effective alternatives to chemical and physical methods [36–38]. Meanwhile, plants have received more attention. Various studies have also shown the therapeutic potential of plant NPs, so that these plants have been applied for the green synthesis of AgNPs [39–42]. If the therapeutic effects of these nanoparticles are approved, this issue can be a step forward in the advancement of disease treatment methods [43–45]. Various studies have proven the role of AgNPs on Casp3 gene and p53 gene in anticancer effects [44–49].

Current research discloses the capability of AgNPs green-formulated using the leaves of pharmacologically important *Abelmoschus esculentus*. One-step, cost-effective, and rapid process of formulation has been gained. Effect of AgNPs@*Abelmoschus esculentus* was assessed on the diabetic rat’s retinal injury as described in Section 2.3.

### 2 Methods and materials

#### 2.1 Preparation of plant extract

Heat soaking method was used for extraction. After weighing, 10 g plant leaves were washed several times using deionized water to remove surface contamination. Then, 50 mL of boiling water was added to it and after 30 min, the obtained extract was passed through Whatman filter paper No. 1. Fresh extract was used in all stages of the experiment.

#### 2.2 Green synthesis and chemical characterization of AgNPs

First, AgNO₃ (10 mM) was weighed using a digital scale to an accuracy of 0.001 g and dissolved in 100 mL of deionized water, and a 0.001 M base solution was obtained. In order to synthesize AgNPs using the extract, 20 mL of *Abelmoschus esculentus* extract was combined with 100 µL of AgNO₃ solution, the change in solution color at room temperature is a sign of the production of AgNPs. The characterization of the formulated AgNPs were analyzed using ultraviolet–visible (UV–Vis) spectrophotometry, field emission scanning electron microscopy (FE-SEM), and Fourier transform infrared (FT-IR).

##### 2.2.1 FT-IR

To assess the functional groups’ changes due to the reduction process, FT-IR analysis was carried out using the NICOLET infrared spectrometer model iS10 in the spectral range of 400–4,000 cm⁻¹. For this purpose, the synthesized NPs were precipitated by a centrifuge at 25,000 rpm, and the precipitate was washed with deionized water three times and dried in air.
2.2.2 UV–Vis spectrophotometry

Considering that AgNPs have a maximum absorption peak in the range of 400–450 nm, in the current study, a spectrophotometer device (Nanodrop product of Jena Analytik Company, Germany) was used in this research to investigate the biosynthesis of AgNPs at a wavelength of 100–600 nm. Deionized water was also used as a negative control. Absorption spectrum diagrams of the studied samples were drawn using the Excel software.

2.2.3 FE-SEM

To assess the size and morphology of the yielded NPs by FE-SEM, the reaction mixture was centrifuged three times. Then, some drops of the resulting sediment were dried on aluminum foil, then, photographs were taken using an electron microscope, Philips FE-SEM machine, model 300-CMC (Netherlands).

2.3 In vivo study

Seven groups of rats (n = 140) were used for the biomedical assessment in the current research. The groups are as follows:

- **Control**: Receiving the distilled water for 8 weeks.
- **Untreated**: Inducing diabetes with STZ (60 mg/kg) and receiving the distilled water for 8 weeks.
- **AgNPs@Abelmoschus esculentus-40**: Inducing diabetes with STZ (60 mg/kg) and receiving the AgNPs@Abelmoschus esculentus at a dose of 40 µg/kg for 8 weeks.
- **AgNPs@Abelmoschus esculentus-80**: Inducing diabetes with STZ (60 mg/kg) and receiving the AgNPs@Abelmoschus esculentus at a dose of 80 µg/kg for 8 weeks.
- **AgNO₃-40**: Inducing diabetes with STZ (60 mg/kg) and receiving the AgNO₃ at a dose of 40 µg/kg for 8 weeks.
- **Abelmoschus esculentus-40**: Inducing diabetes with STZ (60 mg/kg) and receiving the Abelmoschus esculentus at a dose of 40 µg/kg for 8 weeks.

The levels of glutathione (GSH), catalase (CAT), and superoxide dismutase (SOD) parameters were determined in the retinal tissue homogenate as factors of oxidative stresses using the method described by Du et al. [50].

To measure SOD enzyme activity, 0.1 M ethylenediaminetetraacetic acid in 0.3 mM sodium cyanide and 1.5 mM nitroblue tetrazolium test were added to a suitable volume of homogenous tissue in a cuvette and mixed for 5 min at 37°C. Then, 0.12 mM riboflavin was added in 0.067 M potassium phosphate buffer with pH = 8.7 and it was placed at room temperature for 10 min. The absorbance was read in 5 min at 560 nm wavelength and the specific activity was calculated in terms of units per mg of protein [50].

To measure the activity of catalase enzyme, absolute ethanol was added to a certain volume of the tissue extract and incubated in ice for half an hour. Then, Triton-100% was added to it with a final concentration of 1%. This solution was used to measure enzyme activity. The reaction
was started by adding 30 mM to an appropriate volume of tissue sample extract in 50 mM sodium phosphate buffer, pH = 7. Then, the absorbance was read after 3 min at 240 nm wavelength. The specific activity was calculated in terms of units per milligram of protein [50].

To determine the concentration of GSH, ELISA assay was used [50].

2.4 Statistical analysis

The tests results are presented as mean value ± SD after three repetitions. Therapeutic effects were calculated using Origin software. Statistical analysis using SPSS Version software 22 and Duncan’s statistical tests and Student’s T-test were used.

3 Results and discussion

Figure 1 shows the FT-IR spectrum of AgNPs. The bands at 509 and 578 cm⁻¹ belong to Ag–O bond that approves the producing of AgNPs. Furthermore, there is a similarity between AgNPs FT-IR spectrum and green synthetic NPs using extracts [45–49]. The peaks at other regions including 3,319, 2,872, 1,391–1,630, and 1,022 cm⁻¹ belong to the different bonds of organic compounds in the plant extract such as phenolic, flavonoid, triterpenes, which were reported previously [35–39].

A spectrophotometer is a device that measures light intensity as a wavelength function. This operation is performed by refracting the light beam into a spectrum of wavelengths and detecting the intensities with a charged device and displaying the results in the form of a graph. In fact, this method determines the concentration by using the amount of light absorption. In this method, light consists of very small packages called photons, the energy of each of which is transferred to an electron upon impact [28,29]. Transition occurs only when the energy of the photons is equal to the energy required to move the electron to the next energy level. In general, light with a specific wavelength and energy is irradiated to the sample and a certain amount of its energy is absorbed. Then, by measuring the energy passing through the sample by a photodetector, the amount of absorption is determined. A spectrophotometer is a complex device that measures light intensity as a function of wavelength. In this device, the tour is produced by a light source and after passing through the desired sample, the light is emitted in a spectral form [30]. Then, it is detected by sensors and translated into actionable results. The output of the spectrophotometer is always a graph of light intensity vs wavelength. The value of the graph expresses the amount of passage or the amount of absorption. The UV–Vis spectrophotometer method can measure extremely small samples. Therefore, this method is one of the common methods in identifying and checking the characteristics of colloidal NPs, including AgNPs [28,29]. The reason for this is the availability of this technique, low cost, and acceptable results that can be relied upon. The UV–Vis spectrum obtained from the prepared colloid of NPs is shown in Figure 2.
After 10 min, the AgNPs synthesis with the reduction of Ag⁺ ions was clearly visible. After treating the extract with silver salt, the reaction mixture color changed to dark brown, while no color change occurred in the extract as a control. The color change of the reaction is a morphological indicator to detect the synthesis of AgNPs. An ultraviolet spectroscopic absorption of AgNPs in the range of 400–450 nm was reported. In this reaction, the presence of an absorbance at the wavelength of 432 nm with the UV–Vis spectrometer indicated the green synthesis of AgNPs.

Figure 3 indicates the FE-SEM image of AgNPs synthesized with beetroot extract. The FE-SEM image of NPs shows that these NPs are spherical and non-lumpy in appearance, and the boundary between the grains is clearly defined. Also, the average diameter of the particles is about 47 nm. Therefore, NPs are suitable for use in medical applications.

Table 1 indicated that STZ received animals body weight i.e., untreated rats significantly reduced than control rats. Treatment with AgNPs@Abelmoschus esculentus significantly raised the STZ induced diabetic rat’s body weight than untreated group. Furthermore, in AgNPs@Abelmoschus esculentus treated group, rat’s HbA1c% and blood glucose significantly reduced compared to untreated group. It was seen that SOD, GSH, and CAT activities reduced in diabetic animals than control rats. There were notable (p ≤ 0.01) raise in the CAT and SOD activities in the AgNPs@Abelmoschus esculentus treated diabetic rats’ retinal tissue compared to untreated rats. Furthermore, AgNPs@Abelmoschus esculentus significantly raised the GSH level in the treated group than that in the untreated group.

It was seen that AgNPs@Abelmoschus esculentus remarkably (p ≤ 0.01) increased the IL10 level and reduced the TNFα amount in diabetic rats’ retinal tissues compared to untreated group. The findings of AgNPs@Abelmoschus esculentus on the inflammatory cytokine concentration was found to be in a dose dependent manner (Table 2).

**Table 1**: Effect of Abelmoschus esculentus extract-40, AgNO₃-40, and AgNPs@Abelmoschus esculentus on the body weight, biochemical oxidative stress parameters in rats’ retinal tissues (p ≤ 0.01)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control</th>
<th>Untreated</th>
<th>AgNPs-20</th>
<th>AgNPs-40</th>
<th>AgNPs-80</th>
<th>Extract</th>
<th>AgNO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight (g)</td>
<td>230 ± 10ᵃ</td>
<td>140 ± 6⁷</td>
<td>169 ± 8ᵇ</td>
<td>177 ± 12ᵇ</td>
<td>217 ± 13ᵃ</td>
<td>166 ± 7ᵃ</td>
<td>162 ± 6ᵇ</td>
</tr>
<tr>
<td>Blood glucose (mg/dl)</td>
<td>85 ± 5ᵃ</td>
<td>458 ± 14ᶜ</td>
<td>248 ± 15ᵇ</td>
<td>209 ± 11ᵇ</td>
<td>126 ± 12ᵃ</td>
<td>251 ± 16ᵇ</td>
<td>266 ± 11ᵇ</td>
</tr>
<tr>
<td>HbA1c%</td>
<td>4.1 ± 0.5ᵃ</td>
<td>16 ± 2.1ᶜ</td>
<td>10.7 ± 1.2ᵇ</td>
<td>5 ± 0.7ᵇ</td>
<td>11 ± 0.4ᵃ</td>
<td>11.2 ± 0.6ᵇ</td>
<td></td>
</tr>
<tr>
<td>SOD (IU/mg protein)</td>
<td>9.5 ± 1.2ᵃ</td>
<td>1.8 ± 0.3ᶜ</td>
<td>6.2 ± 0.4ᵇ</td>
<td>8.9 ± 0.8ᵇ</td>
<td>9.5 ± 0.8ᵃ</td>
<td>5.6 ± 0.5ᵇ</td>
<td>5.1 ± 0.5ᵇ</td>
</tr>
<tr>
<td>CAT (IU/mg protein)</td>
<td>13.2 ± 0.9ᵃ</td>
<td>4.2 ± 0.5ᶜ</td>
<td>9.9 ± 0.7ᵇ</td>
<td>12.1 ± 0.3ᵇ</td>
<td>12.8 ± 0.6ᵃ</td>
<td>9.6 ± 0.6ᵇ</td>
<td>8.4 ± 0.4ᵇ</td>
</tr>
<tr>
<td>GSH (nmol/mg protein)</td>
<td>19.6 ± 1.3ᵃ</td>
<td>4.5 ± 0.3ᶜ</td>
<td>12.8 ± 0.9ᵇ</td>
<td>16.8 ± 1.4ᵃ</td>
<td>18.7 ± 0.7ᵃ</td>
<td>11.8 ± 0.9ᵇ</td>
<td>10.9 ± 1.3ᵇ</td>
</tr>
</tbody>
</table>

ᵃ,ᵇ,ᶜ indicate the significant difference.
Treatment with AgNPs@Abelmoschus esculentus (all doses) reveals less optic disk vascular leak than untreated rats. AgNPs@Abelmoschus esculentus treated group’s vascular diameter was found to be decreased than untreated group.

Treatment with AgNPs@Abelmoschus esculentus remarkably reduces the leukocytes adherence in the vessels of STZ-induced diabetic rats than untreated group. Furthermore, EB vascular permeability was notably \( p \leq 0.01 \) raised in AgNPs@Abelmoschus esculentus treated rats compared to untreated rats.

In the normal group, the rat’s retinal blood vessels are of normal external appearance. EB is well distributed in the blood vessels. The large blood vessel walls were smooth. The micro-vessels are in good order and no defect area can be observed. The RBCs were evenly and neatly placed in the capillaries. It can be seen that part of superficial retinal blood vessels are dilated and have leakage area in the untreated group. The leakage area size is calculated and analyzed and the results are in the average of 0.95% (Figure 4 and Table 3).

There was a notable raise in the concentration of nuclear factor (NF)-kB p65 in STZ induced diabetic rats’ retinal tissues than control rats. But, treatment with AgNPs@Abelmoschus esculentus remarkably \( p \leq 0.01 \) reduces its level in the retinal tissues in comparison with the untreated rats (Table 4).

Flavonoids are compounds of polyphenol pigments soluble in the water of plants, whose various properties

### Table 2: Effect of Abelmoschus esculentus extract-40, AgNO₃-40, and AgNPs@Abelmoschus esculentus on cytokines \( (p \leq 0.01) \)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control</th>
<th>Untreated</th>
<th>AgNPs-20</th>
<th>AgNPs-40</th>
<th>AgNPs-80</th>
<th>Extract</th>
<th>AgNO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>TNFα (pg/100 mg wet tissue)</td>
<td>34 ± 5ᵃ</td>
<td>194 ± 12ᵇ</td>
<td>116 ± 7ᶜ</td>
<td>73 ± 11ᵇ</td>
<td>50 ± 6ᵇ</td>
<td>127 ± 9ᵇ</td>
<td>133 ± 10ᵇ</td>
</tr>
<tr>
<td>IL10 (pg/100 mg wet tissue)</td>
<td>168 ± 11ᵃ</td>
<td>37 ± 3ᶜ</td>
<td>102 ± 10ᵇ</td>
<td>142 ± 5ᵇ</td>
<td>159 ± 11ᵇ</td>
<td>89 ± 6ᵇ</td>
<td>88 ± 12ᵇ</td>
</tr>
</tbody>
</table>

ᵃ,ᵇ,ᶜ indicate the significant difference.

### Table 3: Effect of Abelmoschus esculentus extract-40, AgNO₃-40, and AgNPs@Abelmoschus esculentus on fundus photography, retinal vessel diameter, retinal leukocytosis, and vascular permeability parameters in retinal tissues of rats \( (p \leq 0.01) \)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control</th>
<th>Untreated</th>
<th>AgNPs-20</th>
<th>AgNPs-40</th>
<th>AgNPs-80</th>
<th>Extract</th>
<th>AgNO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retinal articular diameter (µm)</td>
<td>32 ± 4ᵃ</td>
<td>91 ± 13ᶜ</td>
<td>64 ± 6ᵇ</td>
<td>43 ± 5ᵃ</td>
<td>40 ± 7ᵇ</td>
<td>63 ± 7ᵇ</td>
<td>72 ± 8ᵇ</td>
</tr>
<tr>
<td>Retinal venular diameter (µm)</td>
<td>51 ± 8ᵇ</td>
<td>123 ± 9ᶜ</td>
<td>85 ± 7ᵇ</td>
<td>73 ± 8ᵇ</td>
<td>55 ± 5ᵇ</td>
<td>93 ± 7ᵇ</td>
<td>93 ± 6ᵇ</td>
</tr>
<tr>
<td>Retinal leukocytosis (mm²)</td>
<td>3.6 ± 0.4ᵃ</td>
<td>16.7 ± 0.8ᶜ</td>
<td>8.2 ± 0.9ᵇ</td>
<td>5 ± 0.3ᵃ</td>
<td>3.9 ± 0.5ᵇ</td>
<td>10±1ᵇ</td>
<td>10.3 ± 0.8ᵇ</td>
</tr>
<tr>
<td>EB content in the retina (ng/mg)</td>
<td>3.4 ± 0.3ᵇ</td>
<td>16.4 ± 0.9ᶜ</td>
<td>8 ± 0.8ᵇ</td>
<td>5 ± 0.4ᵇ</td>
<td>3.7 ± 0.3ᵇ</td>
<td>9.7 ± 0.6ᵇ</td>
<td>9.8 ± 0.8ᵇ</td>
</tr>
</tbody>
</table>

ᵃ,ᵇ,ᶜ indicate the significant difference.
have been investigated in the treatment and prevention of human diseases. Flavonoids have antimicrobial, anti-inflammatory, and anticancer properties [51–56]. The most characteristic feature of all flavonoids is their antioxidant action. In the diabetic retinopathy conditions, due to the hyperglycemia effects, the body is exposed to free radicals, and oxidative stress is a cause of diabetic micro and macrovascular disease [57–61]. In addition to increasing the function of internal antioxidants, flavonoids can interact with free radicals in various ways, including direct trapping of free radicals and effect on xanthine oxidase, which is an important pathway in oxidative damage to tissues. Among the plants with antioxidant properties, barberry and okra can be mentioned [58–60]. The barberry has antioxidant properties due to the presence of compounds such as berberine saponin, flavonoids, alkaloids, and steroid components and vitamin C. Therefore, the consumption of this plant has protective effects on different tissues of the body by reducing oxidative stress [60–62]. Also, the treatment of diabetic male rats with oral consumption of aqueous barberry extract has been effective in reducing blood triglycerides and glucose and treating diabetes. This study also showed that the beneficial effects of plant extract and herbal NPs in reducing blood sugar are related to the increase in the level of adiponectin hormone. The findings of this research revealed that plant extract compounds, as flavonoids with high antioxidant properties, restores pancreatic islets of Langerhans and reduces blood sugar levels in diabetic rats. Considering the importance of adiponectin hormone and considering the role of this hormone in prevention of diabetes and its accompanying problems, including diabetic retinopathy [59–61]. Among the various biochemical pathways that are activated in high glucose conditions, the production of AGES and the raise in oxidative stress are particularly important in the diabetic retinopathy progression [62–65]. According to the role of high concentration of glucose in the activation of these pathways and the inflammatory reactions and cell damage caused by it, it can be concluded that factors that have the property of reducing blood sugar and increasing the antioxidant capacity in the body are suitable options for the treatment of diabetic retinopathy [59–62]. Since medicinal plants have important sources of polyphenols, they can be effective in reducing blood sugar on one hand and oxidative stress on the other hand. So, it seems necessary to consider the effective factors found in plants such as polyphenols like quercetin and resveratrol and other phenolic compounds in this field, to improve the vascular and cellular damage caused in the retina of diabetic patients by using the high antioxidant properties of these compounds [62–65].

The properties of okra for diabetes are undeniable. Okra has long been used to treat health problems. Okra contains calcium, folic acid, vitamin C, vitamin B, and potassium. In addition, it is a low-calorie food and has a lot of fiber. There is a lot of talk about the properties of okra for diabetes. Many studies are being done on the properties of okra for diabetes [66–68]. According to a study on okra and blood sugar, okra juice lowered blood sugar levels in mice with gestational diabetes. Research has also been done on the effect of okra seeds because okra seeds have been consumed in Turkey since ancient times to treat the diabetes. The findings of these research works were in the favor of diabetic patients and revealed that the properties of okra for diabetes are undeniable [67–69]. Okra can help control blood sugar levels in diabetic patients in various ways: Okra inhibits enzymes that break down carbohydrates; therefore, less sugar is released into the blood. Okra increases insulin sensitivity. By increasing insulin sensitivity, the body becomes more sensitive to blood sugar levels; therefore, it lowers blood sugar faster. Okra helps to regenerate liver pancreatic beta cells [66–69]. Pancreatic beta cells are responsible for the production of insulin, the function of which in diabetic people is reduced or completely lost. Okra increases insulin

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control</th>
<th>Untreated</th>
<th>AgNPs-20</th>
<th>AgNPs-40</th>
<th>AgNPs-80</th>
<th>Extract</th>
<th>AgNO3</th>
</tr>
</thead>
<tbody>
<tr>
<td>NF-kB p65 (pg/100 mg wet tissue)</td>
<td>2.8 ± 0.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.6 ± 0.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.4 ± 0.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.9 ± 0.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.4 ± 0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.1 ± 0.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.6 ± 0.6&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a, b, c</sup> indicate the significant difference.
secretion. Okra has high fiber that prevents the accumulation of glucose in the blood and more sugar is absorbed [29–33]. It is estimated that eight medium okra contain about 3 g fiber. Dietary fiber has many health benefits. Fibers help to digest food better, reduce appetite, and feel full for a long time. In addition, increasing the consumption of fiber in the diet causes better FBS control and improved sensitivity to insulin. For these reasons, foods that have a lot of fiber are suitable treatment options in the diet of diabetic patients. With these interpretations, one of the main reasons for the properties of okra for diabetes is its high fiber content [66–69]. There is evidence that okra seed extract has anti-stress and antioxidant effects in the mice bloodstream. Managing the levels of stress is an important part of managing diabetes. Long and intense periods of stress can cause FBS levels to rise. Mental health should be a part of diabetes treatment process and reducing stress is another reason why okra is good for diabetes [67–69]. A property of okra for diabetes is that it lowers blood cholesterol levels. Foods containing high fiber content and antioxidant effects are suggested for diabetic people. The American Heart Association notes that diabetic patients are more likely to have elevated blood cholesterol. When the high cholesterol complication is combined with diabetes, it will not benefit diabetic patients at all. This is why it is so important for people with diabetes to follow a cholesterol-lowering diet [66–69]. This was another property of okra for diabetes. Studies have shown that okra reduces the time and intensity of fatigue in diabetics. If people who exercise take okra, they can exercise longer and recover faster after exercise. Improving the performance of the cardiovascular system is an important part of diabetes treatment and prevention. This means that okra can help lead a more active lifestyle; therefore, this will also be a property of okra for diabetes [67–69].

4 Conclusion

In this study, the chemical characterization tests of AgNPs@Abelmoschus esculentus was run by the chemical techniques of UV–Visible spectrophotometer, FT-IR, and FE-SEM. Other results of this research offer that AgNPs@Abelmoschus esculentus effectively controls diabetic retinopathy by regulating the FBS and attenuating the altered inflammatory mediators such as NF-kB, IL10, and TNFα and oxidative stress in the retina of STZ-induced diabetic rat.

4.1 Limitation

There are some limitations in the current research project. (1) We tried to do the clinical examinations periodically in order to find general symptoms of pathology, but we could not do them every day or several times per day. (2) Retinal tissue volume extracted from every rat was low and we could not investigate other immunological and biochemical parameters in it. (3) Retinal tissue volume extracted from every rat was low and we could not investigate the expression of genes involved in it. (4) To reduce the stress condition in diabetic rats, we preferred to weigh them a time per day instead of several times.

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Author contributions: All authors had the same role in conceptualization, data curation, formal analysis, acquisition, investigation, methodology, project administration, resources, software, supervision, validation, visualization, writing – original draft, and writing – review & editing.

Conflict of interest: Authors state no conflict of interest.

Ethical approval: The conducted research is not related to either human or animal use.

Data availability statement: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

References


