RESEARCH PAPER

Evaluation of α-Amylase and α-Glucosidase Inhibitory Activity and Antihyperglycemic Effect of Black Carrot (*Daucus carota ssp. sativus var. atrorubens Alef.*) hydro-alcoholic Extract

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Abstract:

Diabetes mellitus is a syndrome involving chronic hyperglycemia and the deleterious effects of oxidative stress and impaired glucose metabolism that lead to complications. This paper aimed to determine the hypoglycemic activity of a black carrot (Daucus carota ssp. sativus var. atrorubens Alef.) hydroalcoholic extract and its inhibitory activity toward α-amylase and α-glucosidase enzymes. The 13.7% w/w crude extract was obtained through Soxhlet extraction using 70% ethanol as the solvent. Preliminary phytochemical screening indicated the presence of diverse secondary metabolites, including glycosides, tannins, alkaloids, flavonoids, phenolics, and saponins. Moreover, the total phenolic content (84.6 ± 2.1 mg GAE/g extract) and total anthocyanins (42.8 ± 1.5 mg C3G/g extract) were found to be considerable, which suggests that the extract possesses a profound antioxidant activity. In vitro assays revealed a potent inhibitory activity of the extract against α-amylase and α-glucosidase enzymes, which implies its capacity to reduce postprandial glucose levels. An in-vivo antidiabetic trial was carried out on streptozotocin-induced diabetic Wistar rats. The oral administration of the extract for 28 days caused a dose-dependent decrease in fasting blood glucose levels compared to the diabetic control group. Moreover, the high-dose treatment group exhibited comparable results to the control group receiving the standard medication. In addition, the extract was found to positively influence serum biochemical markers in diabetic rats. The obtained results confirm the hypoglycemic potential of the black carrot extract due to enhanced glucose utilization, antioxidant properties, and enzyme inhibition. Thus, the current findings provide a rationale for the further investigation of this botanical extract as a source of bioactive compounds for the adjuvant therapy of diabetes.

Keyword: Black carrot; *Daucus carota ssp. sativus var. atrorubens Alef.*; α-amylase inhibition; α-glucosidase inhibition; Antihyperglycemic activity; Streptozotocin; Phenolic compounds; Anthocyanins; OGTT; Antidiabetic activity

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Introduction:

Diabetes mellitus (DM) is a syndrome manifested by chronic hyperglycemia due to impaired secretion or utilization of insulin or both. Dysfunctions of carbohydrate, protein, and lipid metabolism are frequently part of the pathology and lead to secondary complications such as neuropathy, nephropathy, retinopathy, and cardiovascular disease. The alarming rise of DM prevalence around the world constitutes a significant social and health problem [1, 2]. Besides disturbing carbohydrate metabolism, oxidative stress damages lipids, proteins, and DNA, and plays a vital role in the pathogenesis

of DM and its complications. Conventional antidiabetic therapy involving insulin and oral hypoglycemic agents is effective but may be associated with side effects, high cost, and poor patient compliance. This has triggered a great interest in natural remedies and plant products as complementary and alternative treatment of DM. Medicinal plants provide a wide range of bioactive compounds including glycosides, alkaloids, flavonoids, and phenolics with antioxidant and antihyperglycemic activities [3, 4].

One of the most promising dietary interventions in the management of postprandial hyperglycemia is the inhibition of carbohydrates-hydrolyzing enzymes, specifically α-amylase and α-glucosidase. These enzymes catalyze the breakdown of complex carbohydrates into simpler sugars, facilitating glucose absorption. The inhibition of α -amylase and α -glucosidase significantly suppresses postprandial glucose excursion and delays glucose appearance in the circulation. Many phytochemicals have been reported to inhibit these enzymes and play a role in the control of hyperglycemia [5]. Black carrot has attracted considerable attention due to a high content of anthocyanins and phenolics. The distinctive dark purple color of black carrots is caused by anthocyanins, which are flavonoid pigments that are water-soluble. They can also improve insulin sensitivity and control glucose metabolism in addition to scavenging free radicals. Previous studies have shown that diets rich in anthocyanins may benefit individuals with diabetes in terms of glycemic control and reduction of oxidative stress [6, 7].

Despite the well-documented nutritional and medicinal benefits of the black carrot, few studies assessed its ability to block enzymes and reduce blood sugar levels in vivo. The purpose of this study was to investigate antihyperglycemic effects and inhibitory activities of black carrot extract in rats which were induced to develop diabetes by streptozotocin. Studies were aimed at assessing its effects on glucose tolerance as well as its phytochemical profile, total phenolic content, and total anthocyanin content [8, 9].

This research can provide scientific evidence for the application of black carrots as a natural medicinal agent in the treatment of DM and contribute to the development of new plant-based antidiabetic formulations.

Although black carrot is considered a good source of anthocyanins and antioxidants, scarce information is available about simultaneous effects of digestion enzymes inhibition and antihyperglycemic activities in experimental diabetes models. Thus, the present study was conducted to evaluate in vitro and in vivo antidiabetic effects of black carrot hydroalcoholic extract.

Material and Methods:

2.1 Chemicals and Reagents

All chemicals and reagents used in this experiment were of the analytical grade. The drug streptozotocin (STZ), used to cause diabetes, was supplied by a certified biochemical supplier. Reputable chemical vendors supplied the solvents, such as ethanol and methanol, used for extraction and phytochemical analysis. The Folin-Ciocalteu reagent, sodium carbonate, ferric chloride, hydrochloric acid, and Dragendorff's reagent were utilized for phytochemical and phenolic studies. Using commercial diagnostic kits, biochemical parameters including blood glucose, total cholesterol, triglycerides, HDL, and LDL were estimated.

2.2 Plant Material

The origin and quality of the freshly bought black carrot (*Daucus carota ssp. sativus var. atrorubens Alef.*) roots were confirmed by a trained botanist at a local market. The plant material was thoroughly rinsed with distilled water to remove any impurities that might have stuck before being left to dry in the shade for a few days. Before storing the dried material in sealed containers, it was ground to a coarse powder using a mechanical grinder [10, 11]. The plant material was authenticated by Dr. Sanjay Desai (Associate Professor, Department of Botany, Maharshi Dayanand College, University of Mumbai), and a voucher specimen was deposited for future reference.

2.3 Preparation of Black Carrot Extract

A hydroalcoholic solvent of 70% ethanol was used to conduct Soxhlet extraction on 500 g of powdered plant material. Once the solvent in the siphon tube started to lose its color, the extraction procedure was continued. The resultant extract was filtered through Whatman filter paper to remove any insoluble remains. The filtrate was dried in a vacuum desiccator and concentrated at low pressure with a rotary evaporator to produce a semi-solid crude extract. The extract was stored at 4°C for subsequent experimental use. For the purpose of calculating the percentage yield of the dried extract, the starting weight of the plant material and the final weight were utilized [12].

Black carrot (*Daucus carota* ssp. *sativus* var. *atrorubens* Alef.) root material was macerated in ethanol for an extraction duration of up to 6

hours, carried out over two cycles to maximize anthocyanin recovery, with the pooled filtrates from both cycles combined. The combined extract was concentrated using a rotary evaporator maintained at 40–50 °C to minimize thermal degradation of the anthocyanin content, and further dried to a final moisture content of 8–10%, yielding a stable semi-solid extract suitable for weighing, storage, and preparation of dosing solutions.

2.4 Preliminary Phytochemical Screening

Qualitative phytochemical analysis of the black carrot extract was carried out using standard chemical tests to detect the presence of major secondary metabolites. The following tests were performed:

- **Alkaloids:** Dragendorff's test
- **Flavonoids:** Shinoda test
- **Phenolic compounds:** Ferric chloride test
- **Tannins:** Gelatin test
- **Saponins:** Froth test
- **Glycosides:** Fehling's test

The presence of phytochemicals was confirmed based on characteristic color changes or precipitate formation.

2.5 Determination of Total Phenolic Content

The amount of total phenolic compounds (TPC) was determined using the Folin-Ciocalteau colorimetric method. An aliquot portion of Folin-Ciocalteau reagent, sodium carbonate solution, and extract were mixed with each other to prepare an alkaline solution. The mixture was left to stand at room temperature for 30 min to obtain a blue-colored complex. At the same time, a UV-visible spectrophotometer was set at 765 nm to measure absorbance. The calibration curve was constructed using standard gallic acid. As such, the results obtained were expressed in mg gallic acid equivalent (GAE) per gram of extract [13].

2.6 Determination of Total Anthocyanin Content

The content of total anthocyanin was analyzed using the pH differential spectrophotometric method. Initially, two different buffer solutions with pH 1.0 and 4.5 were prepared by appropriately diluting the stock solutions. Then, the extract solution was divided into two equal portions and mixed with each buffer solution. A UV-visible spectrophotometer was used to measure the absorbance of diluted extracts at 520 and 700 nm. The difference in absorbance (A520 − A700) was used to determine the concentration of anthocyanins. Finally, the results were expressed as milligrams of cyanidin-3-glucoside (C3G) equivalents per gram of extract [14].

2.7 In-Vitro Enzyme Inhibitory Activities

2.7.1 α-Amylase Inhibitory Activity

α Amylase inhibitory activity of the extract was accessed by following the procedure described by Akash et al. with slight modifications [15]. Briefly, the enzyme α-amylase from porcine pancreas was used and dissolved in phosphate buffer solution (0.02 M, pH 6.9) to obtain a working solution of 1 U/mL. The reaction mixture comprised 0.5 mL of enzyme solution, 0.5 mL of the sample solution, and 1 mL of phosphate buffer. The mixture was pre-incubated at 37 0 C for 10 min. Afterwards, 1 mL of 1% w/v starch solution prepared in phosphate buffer was added to start the reaction. After incubating the mixture at 37 0 C for 15 min, 2 mL of DNSA reagent was added and boiled in a water bath for 5 min. The mixture was cooled down to room temperature and then diluted with distilled water. The absorbance of the resulting solution was measured at 540 nm using a UV-visible spectrophotometer. Acarbose was used as a standard drug to determine % inhibition of α-amylase activity according to the following equation [15]

$$\% \text{ inhibition} = \frac{A_{control} - A_{sample}}{A_{control}} \times 100$$

2.7.2 α-Glucosidase Inhibitory Activity

The α-glucosidase inhibitory activity was evaluated using a standard *in vitro* assay. α-Glucosidase enzyme (from yeast) was used, with an enzyme concentration of 1 U/mL prepared in phosphate buffer (0.1 M, pH 6.8). The reaction mixture consisted of 0.5 mL of enzyme solution, 0.5 mL of extract at different concentrations, and 1 mL of phosphate buffer. The mixture was pre-incubated at 37°C for 10 minutes. Following this, 0.5 mL of substrate solution (p-nitrophenyl-α-D-glucopyranoside, 5 mM) was added, and the reaction was incubated at 37°C for 20 minutes. The reaction was stopped by adding 2 mL of sodium carbonate (0.1 M). The release of p-nitrophenol was measured spectrophotometrically at 405 nm. Acarbose was used as the reference standard. The percentage inhibition of α-glucosidase activity was calculated using the following formula [16].

$$\% \text{ inhibition} = \frac{A_{control} - A_{sample}}{A_{control}} \times 100$$

2.8 Experimental Animals

All experimental procedures involving animals were approved by the Institutional Animal Ethics Committee (IAEC) and conducted in accordance with CCSEA guidelines. Healthy adult Wistar albino rats (180–220 g) of either sex were used in the study. The animals were housed in polypropylene cages under standard laboratory conditions (temperature 22 ± 2°C, relative humidity 55 ± 5%, and a 12-hour light/dark cycle). The rats were provided with standard pellet diet and water ad libitum. The animals were acclimatized to laboratory conditions for one week prior to the experiment.

2.9 Induction of Diabetes

Experimental diabetes was induced by a single intraperitoneal injection of streptozotocin (STZ) at a dose of 50 mg/kg body weight, freshly prepared in cold citrate buffer (0.1 M, pH 4.5). The animals were fasted overnight prior to injection. After STZ administration, the rats were provided with 5% glucose solution for 24 hours to prevent hypoglycemic shock. After 72 hours, fasting blood glucose levels were measured using a glucometer, and rats with glucose levels above 250 mg/dL were considered diabetic and included in the study.

2.10 Experimental Design

After confirmation of diabetes, animals were randomly divided into seven groups (n = 8 per group):

Group I: Normal control (vehicle only)

Group II: Diabetic control (STZ-induced, untreated)

Group III: Standard drug (Glibenclamide, 0.5 mg/kg, p.o.)

Group IV: Standard antioxidant (Ascorbic acid, 500 mg/kg, p.o.)

Group V: Low dose extract (100 mg/kg, p.o.)

Group VI: Intermediate dose extract (200 mg/kg, p.o.)

Group VII: High dose extract (400 mg/kg, p.o.)

Diabetes was induced using streptozotocin (STZ) at a dose of 50 mg/kg body weight, administered via intraperitoneal (i.p.) injection in citrate buffer (0.1 M, pH 4.5). Animals were randomized based on body weight using randomization methos using validated tool, ensuring equal distribution across groups. All treatments were administered orally (p.o.) once daily for 28 days.

2.11 Statistical Analysis

The mean ± standard deviation (SD) was used to express all experimental results. After running one-way ANOVA, suitable post hoc tests (Data were analyzed using one-way ANOVA followed by Tukey's multiple comparison test) were used to conduct the statistical analysis. A statistically significant result was defined as a p-value less than 0.05. Statistical analysis was performed using Graph pad prism version 10.4.1.

3.0 Result and Discussion:

3.1 Percentage Yield of Black Carrot Extract

Hydroalcoholic extraction of black carrot using a Soxhlet apparatus resulted in 68.5 g of extract, or 13.7% weight-for-weight, from 500 g of dried plant material (Table 1). The extract was obtained as a dark-purple semi-solid mass, consistent with the presence of anthocyanin pigments which meant it contained anthocyanins and other phenolic chemicals. Based on the relatively high yield, it appears that polar phytoconstituents are efficiently extracted using the hydroalcoholic solvent system. Because of the anthocyanins, which are known to have antioxidant and antidiabetic properties, the extract is a deep purple color [17, 18].

Table 1: Percentage Yield of Black Carrot Extract

Parameter	Value
Weight of dried plant Powder	500 g
Weight of dried extract Obtained	68.5 g
Percentage yield	13.7 %

3.2 Preliminary Phytochemical Screening

Preliminary phytochemical screening revealed the presence of bioactive components such as alkaloids, flavonoids, phenolic compounds, tannins, saponins, and glycosides (Table 2). A number of pharmacological effects, including anti-inflammatory, antidiabetic, and antioxidant capabilities, are suggested by these phytoconstituents in black carrot extract. The phenolics and flavonoids play a crucial role in reducing oxidative stress, an important risk factor for diabetes. [19, 20].

Table 2: Preliminary Phytochemical Screening Results

Phytochemial	Test Performed	Observation	Result
Alkaloids	Dragendorff's test	Orange precipitate	+
Flavonoids	Shinoda	Pink	+

	(Dragendorff's test)	coloration	
Phenolic compounds	Ferric chloride test	Blue- green coloration	+
Tannins	Gelatin test	White precipitate	+
Saponins	Froth test	Stable foam	+
Glycosides	Fehling's test	Brick-red precipitate	+

(+ = Present)

3.3 Total Phenolic Content

The extract indicated a notable amount of phenolic compounds, with a total phenolic content of 84.6 ± 2.1 mg GAE/g, as shown in Table 3. In order to protect living systems from oxidative stress and free radicals, phenolic compounds are crucial. Its substantial phenolic concentration lends credence to the extract's potent antioxidant capabilities. Phenols in the extract may enhance its antihyperglycemic effects because oxidative stress is associated with pancreatic β-cell failure in diabetes [21]. The gallic acid calibration curve and phenolic concentration are shown graphically in Figure 1.

Table 3: Total Phenolic Content of Black Carrot Extract

Sample	**Absorbance (765 nm)**	**Total Phenolic Content**
Black carrot extract	0.682 ± 0.03	84.6 ± 2.1 mg GAE/g extract

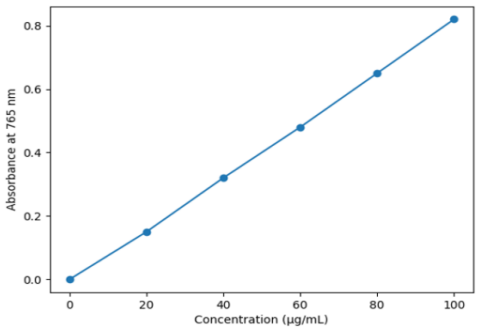


Figure 1: Standard calibration curve of gallic acid.

3.4 Total Anthocyanin Content

According to Table 4, which shows a total anthocyanin concentration of 42.8 ± 1.5 mg C3G/g extract, black carrots are abundant in anthocyanins. The powerful antioxidant properties of anthocyanins aid in the reduction of oxidative stress and the improvement of glucose metabolism. Their existence agrees with the extract's unusual purple color. These compounds enhance insulin sensitivity and inhibit hyperglycemia-causing pathways, according to the research [22].

Table 4: Total Anthocyanin Content

Sample	Absorbance Difference	Anthocyanin Content
Black carrot extract	0.451 ± 0.02	42.8 ± 1.5 Mg C3G/g extract

3.5 α-Amylase Inhibitory Activity

The results showed a dose-dependent response; the extract increased the inhibition from 37.59% to 60.73% in 1 mg/mL. Although the extract had lower inhibitory efficacy than the common medicine acarbose, it still demonstrated considerable inhibition, suggesting its potential as a natural enzyme inhibitor. The α-amylase enzyme breaks down starch into glucose and maltose, which are simple carbohydrates. The observed α-amylase inhibitory effect can be explained by the presence of phenolic compounds and anthocyanins. Similar results have been obtained for extracts of anthocyanin-rich berries and purple vegetables, where enzyme inhibition contributed to reduced postprandial glucose excursions. The inhibition of this enzyme helps manage postprandial

hyperglycemia by delaying the release of glucose into the bloodstream and reducing the breakdown of carbohydrates. Moderate α-amylase inhibition may be advantageous to avoid gastrointestinal adverse effects, since excessive inhibition of α-amylase, a gastrointestinal adverse effect of some synthetic drugs, can cause bloating and diarrhea, among other symptoms. Its well-balanced inhibitory activity may provide effective glycemic control with minimal adverse effects. The inhibitory activity documented is due to the presence of phenolic chemicals, flavonoids, and anthocyanins compounds. These compounds are known to interact with digestive enzymes via hydrophobic and hydrogen bonding interactions, implying that they lower enzyme activity. The extract also demonstrates selective inhibitory activity, which is good for antidiabetic treatment, unlike the significant α-glucosidase inhibitory activity found in this study. Its dual mechanism includes both strong inhibition of α-glucosidase and mild inhibition of α-amylase, which enhances its therapeutic potential [23, 24]. The black carrot extract had α-amylase inhibitory activity that was dose-dependent (Table 5). The inhibition ranged from 37.59% in 1 mg/mL to 60.73% in 20 mg/mL of the extract. This suggests that moderate enzyme inhibition would be achieved with the black carrot extract. The standard drug acarbose had stronger inhibitory activity, reaching 96.85% at 20 mg/mL. IC_{50} Value are for black carrot extract: ~ 9.5 mg/mL and acarbose: ~ 6.73 mg/mL. This indicates that although the extract is less potent than acarbose, it demonstrates moderate inhibition, which is considered to be beneficial to prevent gastrointestinal side effects associated with strong α-amylase inhibition.

Table 5: *In-vitro* glucose metabolism assays

		Absorbance		% Inhibition	
		Carrot Extract	Acarbose	Carrot Extract	Acarbose
α- Amylase	Control	2.759	3.362	0	0
	1 mg/ mL	2.346	3.127	37.59	6.99
	2 mg/mL	2.200	2.785	41.47	17.16
	4 mg/ mL	1.999	2.214	46.82	34.15
	8 mg/ mL	1.865	1.362	50.39	59.49
	12 mg/ mL	1.747	0.488	53.52	85.48
	16 mg/ mL	1.668	0.25	55.63	92.56
	20 mg/ mL	1.476	0.106	60.73	96.85
	Mean			**43.27**	**49.09**
	Standard Deviation (S.D.)			**19.03**	**39.69**

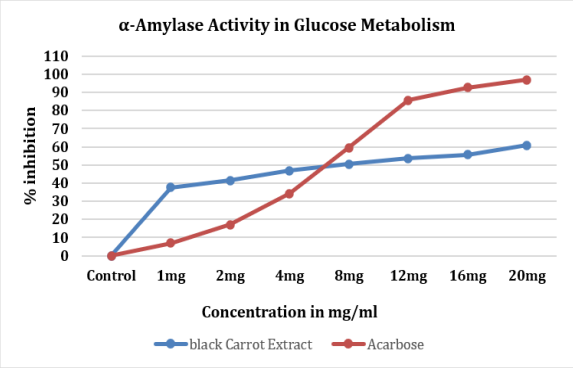


Figure 2: α-Amylase Activity in Glucose Metabolism

3.6 α-Glucosidase Inhibitory Activity

The considerable α-glucosidase inhibitory activity of the black carrot extract was shown to be concentration-dependent by the progressive increase in percentage inhibition with increasing extract concentration. The extract exhibited a strong inhibitory potential of enzymes, with a maximum inhibition of around 51.21% at 20 mg/mL. The digestion of carbohydrates is facilitated by α-glucosidase, which catalyzes the final step of disaccharide hydrolysis into glucose. Reducing postprandial blood glucose levels is as

simple as blocking this enzyme, which delays glucose absorption in the intestines. The study found that black carrot extract had a considerable inhibitory action, suggesting that it might significantly control the release of glucose into the bloodstream.

This potent inhibition could be due to the high levels of phenolic compounds and anthocyanins, which have been found to alter enzyme kinetics and interact with enzyme active sites. These bioactive compounds may form complexes with α-glucosidase, which could lead to reduced catalytic activity. Preferential inhibition of α-glucosidase over α-amylase is considered desirable for managing postprandial hyperglycemia while minimizing gastrointestinal discomfort. In general, the findings indicate that black carrot extract could be useful in managing postprandial hyperglycemia and shows promising outcomes as a natural α-glucosidase inhibitor, comparable to traditional antidiabetic medications [25, 26].

The black carrot extract demonstrated strong α-glucosidase inhibitory activity (Table 6), with inhibition increasing from 26.16% to 51.21% across concentrations. IC_{50} Value for the black carrot extract is ~ 17.98 mg/mL and for the acarbose is ~ 7.12 mg/mL. The extract showed stronger inhibition of α-glucosidase than α-amylase, which is therapeutically desirable.

Table 6: *In-vitro* glucose metabolism assays

		Absorbance		% Inhibition	
		Carrot Extract	Acarbose	Carrot Extract	Acarbose
α- Glucosidase	Control	2.804	2.974	0	0
	1 mg	2.809	2.516	26.16	15.40
	2 mg	2.666	1.943	29.92	34.67
	4 mg	2.522	1.772	33.70	40.42
	8 mg	2.399	1.355	36.93	54.44
	12 mg	2.142	0.632	43.69	78.75
	16 mg	1.978	0.457	48.00	84.63
	20 mg	1.856	0.232	51.21	92.20
	Mean			**33.70**	**50.06**
	Standard Deviation (S.D.)			**16.16**	**33.49**

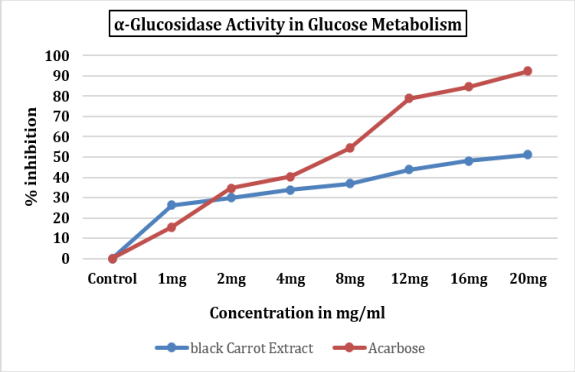


Figure 3: α-Glucosidase Activity in Glucose Metabolism

3.7 *In-Vivo* Antidiabetic Activity

All the experimental animals survived without any stress, abnormal behaviour and signs of deaths during the acclimatization period. The animals in the diabetic group developed the classical symptoms of diabetes such as polyuria, polydipsia and low activity after a single dose of streptozotocin (50 mg/kg, i.p.) for 72 hours. The fasting blood glucose levels were estimated to confirm diabetes mellitus in the experimental animals after 72 hours of STZ administration. The animals with fasting glucose levels above 250 mg/dL were selected for the investigation. From the initial screening, it was evident that the diabetic control group had significantly higher glucose levels (~389 mg/dL) than the normal control group (~105 mg/dL), indicating a successful induction of diabetes mellitus in the former.

The effect of black carrot extract on the fasting blood glucose levels of the experimental animals after 28 days of treatment is presented in Figure 4. It can be seen that normal control animals maintained normal fasting glucose levels varying between 104–110 mg/dL throughout the experimental period. On the other hand, the diabetic control animals were characterized with high glucose levels varying between 390–398 mg/dL as a result of STZ-induced pancreatic damage. However, treatment with standard drug

(Glibenclamide, 0.5 mg/kg) significantly reduced the blood glucose levels (335.88 mg/dL – 204.50 mg/dL)($p < 0.05$) after 28 days of administration and was considered effective for diabetes management in this study. Similarly, treatment with ascorbic acid (500 mg/kg) also resulted in significant reduction of blood glucose levels (383.13 mg/dL – 216.13 mg/dL). On the other hand, the black carrot extract showed a dose dependent antihyperglycemic effect. A slight reduction in the fasting glucose levels was recorded (387.25 mg/dL – 327.75 mg/dL), while a moderate activity was observed (407.75 mg/dL – 268.25 mg/dL). The most significant reduction in the mean fasting blood glucose levels was observed (393.63 mg/dL – 217.00 mg/dL) and considered statistically significant($p < 0.05$) and comparable with the standard drug.

It is evident that the comparison between the treatment groups indicate that the highest dose of the extract (400 mg/kg) recorded a reduction in blood glucose levels comparable with Glibenclamide but mild. However, the intermediate dose exhibited substantial improvement and moderate activity was recorded in the lowest extract concentration.

On the other hand, the reduction in glucose levels recorded in the extract treated experimental animals is statistically significant compared with the diabetic control($p < 0.05$).

Table 7: Effect of Black Carrot Extract on Fasting Blood Glucose Levels (mg/dL)

Group	Day 0	Day 7	Day 14	Day 21	Day 28
Normal Control	105. 38	104.75	106.63	107.38	109.75
Diabetic Control	389.00	398.00	398.14	395.14	393.14
Standard (Glibenclamide)	335.88	332.38	273.13	233.38	204.50
Standard (Ascorbic Acid)	383.13	334.25	281.75	241.25	216.13
Low Dose (100 mg/kg)	387.25	373.50	357.13	342.25	327.75
Intermediate Dose (200 mg/kg)	407.75	376.75	336.88	299.50	268.25
High Dose (400mg/kg)	393.63	351.00	307.25	251.38	217.00

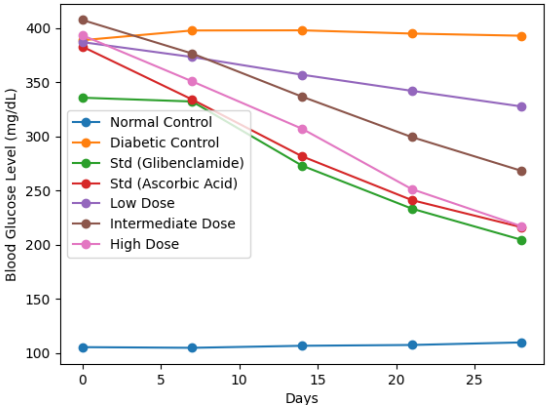


Figure 4: Effect of black carrot extract on fasting blood glucose levels in streptozotocin-induced diabetic rats over 28 days.

Study Limitations

The present study has a number of limitations. The active compounds responsible for the observed antidiabetic activity were not isolated and characterized. In addition, evaluations of insulin levels and biomarkers of oxidative stress were not carried out. Further studies, including the identification of compounds, mechanistic investigations, and prolonged safety assessments, are needed.

Conclusion

This study demonstrated that the hydroalcoholic extract of black carrot exhibited considerable antioxidant and antidiabetic potential based on phytochemical and enzymatic investigations. The extract was obtained with satisfactory yield and was found to contain significant bioactive constituents including alkaloids, glycosides, tannins, saponins, phenolic and flavonoid compounds. It was found analytically with high total phenolic contents and high total anthocyanin contents which point to a great antioxidant potential. A crucial factor in the course and development of diabetes mellitus, oxidative stress, is significantly reduced by the phytoconstituents. The black carrot extract showed significant inhibitory effect against α-amylase and α-glucosidase in the in vitro enzyme inhibition assays. This suggests that the extract

could slow down digestion of carbohydrates and glucose absorption. The most crucial challenge in diabetes treatment management, namely postprandial hyperglycemia, is efficiently addressed with this approach. Findings of this study indicate that black carrot extract can be beneficial in the treatment of diabetes mellitus in a natural way. The combination of antioxidant activities and enzyme inhibition potential is of particular importance in the context of functional meals and herbal remedies. The hydroalcoholic extract of black carrot appeared as a good candidate for adjunctive antidiabetic treatment with the ability to inhibit α-amylase and α-glucosidase activities and to improve hyperglycemia in streptozotocin-induced diabetic rats. The observed antidiabetic effects could be related to the high contents of phenolics and anthocyanins in the tested extract. Further studies should be conducted to identify the active constituents and to elucidate the mechanism of action at level of cellular signalling.

Funding

None

Conflict of Interest

None

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