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Research Article

Protective effects of green tea catechins against diabetogenic cataract by inhibiting lens oxidative stress and aldose reductase activity

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Abstract

Aim and Objectives: The present study was designed to evaluate the anticataract activity of green tea catechins like green tea extract (GTE), catechin, and epigallocatechin gallate (EGCG) against glucose-induced cataract model in goat lens. Methodology: The goat lenses were incubated in artificial aqueous humor containing a high concentration of glucose (55 mM) with catechins at different concentrations (50, 100, and 200 µg/mL) and after eight hours anticataract activity was assessed against the glucose control group contains a high concentration of glucose only. The antioxidant activity was assessed by using DPPH and hydrogen peroxide assay. The aldose reductase inhibitory activity was performed using an ex-vivo model in goat lenses. Results and Discussion: The results showed catechins considerably retained the lens transparency and reduced the progression of cataract maturation. catechins significantly restore the lenticular oxidative stress markers (CAT, SOD, GSH, and MDA) and protein contents, when compared to the glucose control group. Moreover, results indicated that EGCG had better anticataract activity than GTE and catechin, which might be due to its potent and better antioxidant and aldose inhibitory activity, which was observed in the study. Conclusion: The results concluded that catechins, particularly EGCG, efficiently prevent or delay cataract development and might be a potential candidate in the future.

Keywords: Aldose reductase, Antioxidant activity, Cataract, Catechins, Epigallocatechin gallate.

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Introduction

Cataract (the opacification of eye lens) is the leading etiology of blindness worldwide and it is responsible for more than 50% of blindness worldwide (1). More than 65 million people have bilateral blindness due to cataract and 28,000 cases are reported daily worldwide. Cataract cause serious vision loss approximately 25% of the population over the age of 65 and 50% over the age of 80 (2). As of 2024, the reported prevalence of cataracts among older adults (aged 45 and above) in India is approximately 14.25% (3). It is a severe physical ailment with serious emotional and financial consequences. A blind person loses their freedom and is more likely to feel a great loss and depression caused by being thrust into darkness (4). According to a study in the United Kingdom, half of patients on a waiting list for surgery die before receiving treatment (5), which is generally associated with old age. It is well known that diabetes is the prime risk factor for exacerbation of cataract. Higher levels of glycosylated hemoglobin are significantly associated with an increased risk of cataract (6). Although several cataractogenic variables have been identified, including age, UV radiation, smoking, and hypertension (7, 8). Polyol activation and free radical oxidative damage are also implicated in the pathology of diabetic cataract development (9, 10). It is anticipated that a 10-year delay in cataract development will lower the prevalence of visually disabled cataract by approximately 45% (11). Thus, it is necessary to develop biochemical remedies or pharmacological interventions that will assist in maintaining lens transparency and reverse the cataractogenous change at least in the immature stage. Although several medications have been tried for cataract prevention and treatment none have proven effective. Flavonoids have been shown to protect against free radical damage in many experimental conditions (12). Previous research indicates that the progression of cataracts can be mitigated or even prevented through the application of natural therapies, especially those plants having rich flavonoids, which have shown significant aldose reductase inhibitory activity (13). The flavonoids those abundantly reported in catechins may have the potency to protect the cataractogenous changes in animals as well as in humans.

Catechins are flavonoids (14) and these are important components of green tea leaves and have potent antioxidant properties and significant physiological activities. They belong to the group of polyphenolic family found in many medicinal plants mainly in green tea. The major sources of catechins are *Camellia sinensis*, *Camellia assumica,* and *Acacia catechu* Linn (15). Green tea contains 75-80% water and polyphenol compounds (flavonols, flavandiols, flavonoids, and phenolic acid) (16), and catechins

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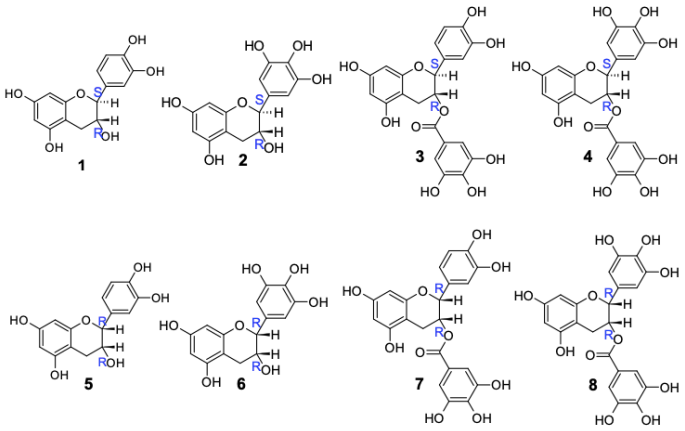
contain more than 75% of the polyphenolic compounds in tea leaves. They are condensation-type tannins with a ring and the basic structure of flavan-3-ol. They have many chemical structural features, such as hydroxyl groups (-OH), that combine easily with the materials (17). The main catechins are (-)-catechin (**1,** C), (-)-gallocatechin (**2**, GC), (-)-catechin gallate (**3**, CG) (-)-gallocatechin gallate (**4**, GCG), and their epimers (-)-epicatechin (**5**, EC), (-)-epigallocatechin (**6**, EGC), (-)-epicatechin gallate (**7**, ECG), and (-)-epigallocatechin gallate (**8**, EGCG). The principal types are EC, ECG, EGC, and EGCG (18), which are prominently present in green tea (19-21).



Green tea catechins are one such compound that has been used for thousands of years as a treatment for different diseases. It has been scientifically reported for glaucoma treatment (22), antidiabetic (23), hypolipidemic (24), hepatoprotective (25), anti-cancer (26), anti-thrombotic (27), anti-obesity (28), anti-microbial (29), and anti-inflammatory activity (30). Catechins also provide several health advantages by scavenging free radicals and retarding extracellular matrix degradation induced by ultraviolet (UV) radiation and pollution (31, 32). In addition, literature demonstrated that catechin mitigates the progression of cataract *via* inhibiting cataract-induced apoptotic cell death in the lens epithelium (33). A study by Yao et al. (2008) demonstrated that EGCG protects cataract formation against mitochondria-mediated apoptosis induced by hydrogen peroxide in human lens epithelial cells through modulation of caspases, MAPK, and AKT pathways (34). A study by Liu et al. (2023) revealed the anticataract activity of EGCG by regulating the RASSF2/AKT pathway (35). Therefore, the present study is designed to evaluate the anticataract activity of catechins like green tea extract (GTE), catechin, and epigallocatechin gallate (EGCG) against glucose-induced cataract model in goat lens. The present study also compares the efficacy of these catechins on aldose reductase inhibition and free radical elimination; this has never been explored previously.

Material and Methods

Drugs and chemicals

GTE, Catechin, and Epigallocatechin gallate (EGCG) were purchased from Otto Chemie Private Limited, Mumbai, India. All other chemicals and reagents (analytical grade) used for the study were procured from the Departmental chemical store.

In-vitro antioxidant activity

The antioxidant activity was performed by 2,2-diphenyl 1-picrylhydrazyl (DPPH) assay (36) and hydrogen peroxide scavenging activity (37). For the DPPH assay, in different amber-colored volumetric flasks, 1 mL of 100 µg/ml of GTE, catechin, and EGCG were mixed with 4 ml of a 0.1 mM methanolic solution of DPPH and shaken vigorously using a vortex shaker. The test tube was allowed to stand at the dark conditions at room temperature for 30 minutes and then absorbance was measured at 517 nm against the blank by using a UV spectrophotometer (UV-1780, Shimadzu Scientific Instruments, Inc., USA). The percentage inhibition was calculated against DPPH control (without test drug sample).

The hydrogen peroxide scavenging activity was estimated spectrophotometrically based on the conversion of hydrogen peroxide into water. In different amber-colored volumetric flasks, 1 mL of 100 µg/ml of GTE, catechin, and EGCG were mixed with 4 ml of 40 mM H_2O_2 and shaken vigorously using a vortex shaker. The test tube was allowed to stand in the dark condition at room temperature for 10 minutes and absorbance was measured at 230 nm against the blank by using a UV spectrophotometer. The percentage inhibition was calculated against H_2O_2 control (without test drug sample).

The following formula was used to calculate scavenging activity for DPPH and hydrogen peroxide assay.

$$\text{Scavenging activity (\%)} = \frac{(\text{Absorbance of control} - \text{Absorbance of sample})}{\text{Absorbance of control}} \text{x } 100$$

Aldose reductase inhibitory activity

Aldose reductase activity was measured using the method established by Hayman and Kinoshita in 1965. First goat eyes were collected from the slaughterhouse and the eye lenses were isolated by extracapsular extraction. The normal clear eye lenses were selected for study and damaged eye lenses were discarded. Further 5 clear lenses were homogenized (10 % w/v) in phosphate buffer (0.1 M pH 7). The lens homogenate was centrifuged at 10000 rpm for 60 min at 4°C to separate the supernatant. To find out the lens aldose reductase activity, 0.5 mL of lens supernatant was mixed with 3.5 ml of phosphate buffer saline, 0.5ml of NADPH ($5x10^{-5}$ M), and 0.5 mL of test samples (100 µg/ml of GTE, catechin or EGCG) or phosphate buffer saline (used as a control). The final reaction mixture was adjusted to a pH of 6.2. The enzymatic reaction was started by adding the substrate DL-glyceraldehyde (0.1 ml, $5x10^{-4}$ M). The absorbance at 340 nm was monitored for 3 minutes. The unit of aldose reductase activity was calculated for each sample (control and test) based on the change in the absorbance over 3 minutes. A unit of activity was defined as a change in absorbance of 0.001 units per minute(38, 39). The percentage of aldose reductase inhibitory activity was then calculated using the following formula

$$\textit{Aldose reductase inhibion (\% Inhibition)} = \frac{(\textit{AR activity in control} - \textit{AR activity in test})}{\textit{AR activity in control}} \times 100$$

Ex-vivo Anticataract activity

The isolated clear normal goat lenses were used to perform the *ex-vivo* anticataract activity of GTE, catechin, and EGCG. The eye lenses were divided into different groups, each containing six lenses. The artificial aqueous humor (AAH: NaCl-140 mM, KCl-5 mM, $MgCl_2$-2 mM, $NaHCO_3$-0.5 mM, $NaH(PO_4)_2$-0.5 mM, $CaCl_4$- 0.4 mM and glucose- 5.5 mM) media was used to incubation of the eye lenses. The anticataract activity of GTE, catechin, and EGCG at 50 µg/ml, 100 µg/ml, and 200 µg/ml each was tested against the glucose-induced model (40). The experimental design and conditions are presented in Table 1. The

lenses were incubated for 8 hours; thereafter pathophysiological parameters were assessed. Each eye lens was separately homogenized (10 % w/v) in phosphate buffer (0.1 M pH 7). The lens homogenate was centrifuged at 10000 rpm for 60 min at 4°C to separate the supernatant for further biochemical analysis.

Table 1: Experimental design of *Ex-vivo* Anticataract activity.

SN	Group	Incubation Media
1	Normal Control	AAH contains 5.5 mM glucose
2	Glucose Control	AAH contains 55 mM glucose
3	GTE 50	AAH contains 55 mM glucose and 50 µg/ml GTE
4	GTE 100	AAH contains 55 mM glucose and 100 µg/ml GTE
5	GTE 200	AAH contains 55 mM glucose and 200 µg/ml GTE
6	Catechin 50	AAH contains 55 mM glucose and 50 µg/ml Catechin
7	Catechin 100	AAH contains 55 mM glucose and 100 µg/ml Catechin
8	Catechin 200	AAH contains 55 mM glucose and 200 µg/ml Catechin
9	EGCG 50	AAH contains 55 mM glucose and 50 µg/ml EGCG
10	EGCG 100	AAH contains 55 mM glucose and 100 µg/ml EGCG
11	EGCG 200	AAH contains 55 mM glucose and 200 µg/ml EGCG

AAH: Artificial aqueous humor, EGCG: Epigallocatechin gallate, GTE: Green tea extract

Lens opacity

After 8 hours of incubation, the lenses were placed on graph paper, and variations in lens transparency were assessed by visualizing the graph line visible through the lens. The graph's lines were visible in normal lenses, but unclear in cloudy or cataract lenses (40). The maturation of cataract was graded as follows: 0 – Clear lens, 1 – Slightly opaque lens, 2 – Moderately opaque, 3 – Mature opaque.

Biochemical Analysis

Oxidative stress markers were assessed in the supernatant of lens homogenates using spectrophotometric techniques as described in a study by Choudhary et al. (2021) (8). The catalase (CAT) enzyme plays a crucial role in the conversion of hydrogen peroxide into water, expressed as a percentage of H_2O_2 consumed per minute per milligram of lens tissue. The assessment of CAT activity was conducted using the spectrophotometric methods (41), which involves the reduction of dichromate in acetic acid to chromic acetate when heated in the presence of hydrogen peroxide. The resulting color change was measured at a wavelength of 570 nm. GSH was estimated using sulfhydryl reagent 5, 5'-dithiobis-2-nitrobenzoic acid (DTNB), which produces a product that absorbs at 412 nm. GSH was used as a standard and measured in µmol/g of lens tissue (42). Superoxide dismutase (SOD) activity was measured using the NBT test described by (43). One unit of SOD is defined as the fraction of enzyme which gave 50% inhibition of NBT decreased in one minute under normal assay conditions. Malondialdehyde (MDA) is a lipid peroxidation biomarker that is measured by the thiobarbituric acid (TBA) reaction (44) expressed in nmol/mg of lens tissue. The protein content was measured by the Lowry et al method (45).

Statistical analysis

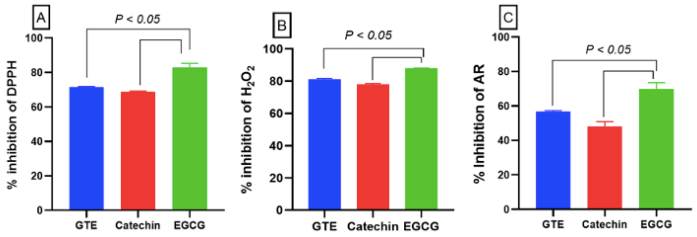
The GraphPad Prism 8.0.1 was used to statistically analyze the observed data. The one-way analysis of variance (ANOVA) parametric test was applied to test the hypothesis. The $P < 0.05$ was considered a significant ($P < 0.05$) difference between groups.

Results

Effects on antioxidant and aldose reductase activities

The antioxidant activity was examined by the DPPH radical and hydrogen peroxide scavenging activity. The results (Figure 1) showed that the GTE, catechin, and epigallocatechin gallate (EGCG) demonstrate potent antioxidant activity by scavenging DPPH and hydrogen peroxide radicals. At the concentration of 100 µg/mL, EGCG showed significant (*P<0.05)* antioxidant activity when compared to GTE and catechin. The percentage inhibition of DPPH radical was found to be 71.52 ± 0.32, 68.77 ± 0.53, and 82.91 ± 2.4 for GTE, catechin, and EGCG respectively, and the percentage inhibition of hydrogen peroxide radical was found to be 81.11 ± 0.58, 78.0 ± 0.66, and 87.78 ± 0.44 for GTE, catechin and EGCG respectively. Moreover, similar results (Figure 1) were observed in lens aldose reductase inhibitory activity. At the concentration of 100 µg/mL, the percentage inhibition of lens aldose reductase activity was found most significant (*P<0.05)* in EGCG (69.75 ± 3.75) when compared to GTE (56.79 ± 0.61) and catechin (48.15 ± 2.82).

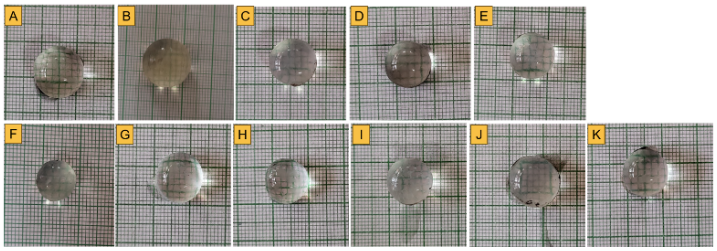
Figure 1: Effects of catechins on antioxidant and lens aldose reductase activities. Data were presented in mean ± SEM (n = 3) and statistically (*P < 0.05,* EGCG vs GTE/catechin) analyzed using one-way ANOVA followed by Tukey's multiple comparisons test. EGCG: Epigallocatechin gallate, GTE: Green tea extract.



Effect on glucose-induced cataract model

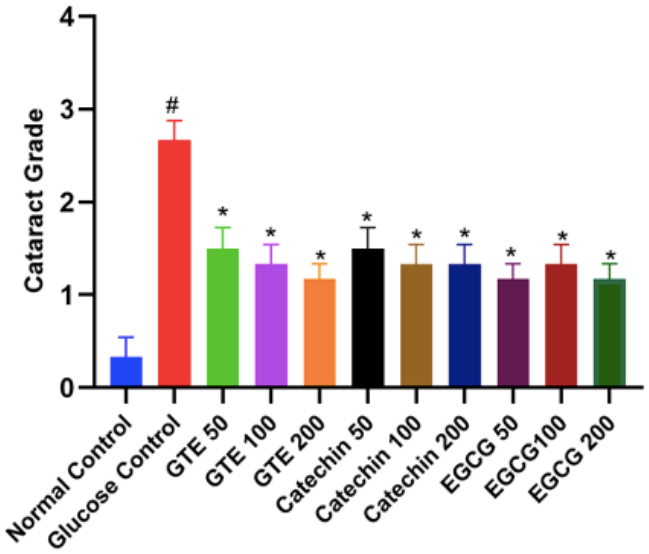
Figure 2 depicts the effects of catechins on lens opacity. After 8 hours of incubation, the transparency of the lenses of experimental groups was examined using a graph paper method. Compared to the normal control group, the eye lenses of the glucose control group were considerably opaque and cloudy, indicating cataract induction when incubated with 55 mM of glucose. Whereas, when the eye lenses were incubated with catechins (GTE, catechin, and EGCG), especially at 200 µg/mL, the eye lenses were considerably transparent and clear when compared to the glucose control group, indicating the potential anticataract activity of catechin. Similar results (Figure 3) were reflected in the cataract grading. The glucose control group showed significant ($P < 0.05$) higher cataract maturation as compared to the normal control group. While the catechins-treated groups showed significant ($P < 0.05$) lower cataract maturation as compared to the glucose control group.

Figure 2: Effect of catechins on lens transparency against glucose-induced experimental cataract on goat lens.



A) Normal control, B) Glucose Control, C) GTE 50, D) GTE 100, E) GTE 200, F) Catechin 50 G) catechin 100, H) catechin 200, I) EGCG 50, J) EGCG 100, and K) EGCG 200. EGCG: Epigallocatechin gallate, GTE: Green tea extract.

Figure 3: Effects of catechins on cataract maturation. Data were presented in mean ± SEM (n = 6) and statistically (#$P < 0.05$ vs the normal control group and *$P < 0.05$ vs the glucose control group) analyzed using one-way ANOVA followed by Tukey's multiple comparisons tests. EGCG: Epigallocatechin gallate GTE: Green tea extract.



Effects of catechins on oxidative stress markers like antioxidants (CAT, GSH, and SOD) and a lipid peroxidant (MDA) are presented in Table 3. The glucose control group showed significant ($P < 0.05$) lower antioxidant levels and higher MDA levels when compared to the normal control group. Whereas, catechins treated groups (GTE, catechin, and EGCG) showed significant ($P < 0.05$) higher antioxidant levels and lower MDA levels when compared to the glucose control group. These findings indicate the potent antioxidant activity of GTE, catechin, and EGCG.

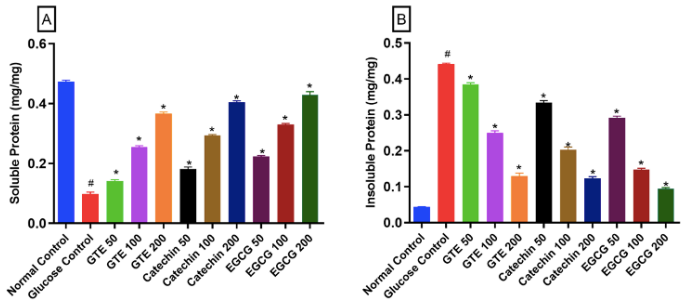
The results of lens protein contents are shown in Figure 4. The glucose-control group showed significant ($P < 0.05$) lower soluble protein content and higher insoluble protein content when compared to the normal control group. Whereas, catechins treated groups (GTE, catechin, and EGCG) showed significant ($P < 0.05$) higher soluble protein content and lower insoluble protein content level when compared to the glucose control group. This finding supports that GTE, catechin, and EGCG play a protective role against protein modification in the lens.

Table 1: Effect of green tea extract, Catechin, and EGCG on oxidative stress markers in glucose-induced model (Ex-vivo)

Groups	CAT (% of H_2O_2 consumed/ min)	GSH (µmols/g)	SOD (U/mg)	MDA (nmol/mg)
Normal Control	52.31 ± 0.51	53.27 ± 0.23	5.857±0.09	4.589±0.19
Glucose Control	6.627± 0.52*	28.52 ± 0.29*	0.920±0.07*	16.39±0.35*
GTE 50	12.74±0.56*	39.97±0.24*	1.272±0.01*	13.87±0.26*
GTE 100	29.02 ± 0.64*	34.35 ± 0.22*	1.772±0.02*	10.09±0.23*
GTE 200	39.28 ± 0.40*	46.54 ± 0.23*	4.025±0.03*	8.867±0.11*
Catechin 50	17.69±0.44*	35.80±0.42*	1.360±0.01*	11.74±0.24*
Catechin 100	33.29 ± 0.26*	40.10 ± 0.17*	2.087±0.03*	8.833±0.15*
Catechin 200	43.50 ± 0.39*	48.61 ± 0.18*	4.947±0.02*	7.989±0.14*
EGCG 50	22.52±0.60*	37.68±0.36*	1.518±0.01*	9.933±0.20*
EGCG 100	35.90 ± 0.27*	41.51 ± 0.15*	2.833±0.04*	8.456±0.14*
EGCG 200	47.27 ± 0.39*	50.89 ± 0.24*	5.178±0.04*	6.567±0.22*

Data were presented in mean ± SEM (n = 6) and statistically (#$P < 0.05$ vs the normal control group and *$P < 0.05$ vs the glucose control group) analyzed using one-way ANOVA followed by Tukey's multiple comparisons tests. EGCG: Epigallocatechin gallate; GTE: Green tea extract; CAT: catalase; GSH: reduced glutathione; SOD: superoxide dismutase; MDA: malondialdehyde.

Figure 4: Effects of catechins on the lens (A) Soluble protein and (B) insoluble protein content. Data were presented in mean ± SEM (n = 6) and statistically (#$P < 0.05$ vs the normal control group and *$P < 0.05$ vs the glucose control group) analyzed using one-way ANOVA followed by Tukey's multiple comparisons tests. EGCG: Epigallocatechin gallate GTE: Green tea extract.



Discussion

The current research revealed the protective effects of catechin against diabetogenic cataract induced by high concentrations of glucose in the goat lenses. It is well established that incubation of the eye lenses in high concentrations of glucose exacerbates the diabetogenic cataract by activation of the polyol pathway and inducing oxidative stress (12), Which was evaluated in the study. The results of the lens opacity (Figure 2) and cataract maturation

(Figure 3) indicate the potential anticataract activity of catechins. That was further validated by evaluating pathophysiological markers like antioxidant, oxidative stress, protein contents, and aldose reductase activity.

Lenticular oxidative stress and polyol activation are the prime pathophysiological factors. The sorbitol pathway begins to use glucose in the lens when it is exposed to a high concentration of glucose. This high glucose concentration activates the aldose reductase enzyme in the lens, which converts glucose into sorbitol, commonly known as polyol. The high sorbitol density renders it imperceptible to the human eye. Subsequently, sorbitol undergoes further metabolic pathways, producing fructose, a toxic substance (46, 47). The accumulation of polyols (sugar alcohols) results in oxidative stress and excessive hydration, which can promote cataract development. The *in-vitro* results indicate the catechins considerably inhibited the lens aldose reductase activity and free radicals (DPPH and H_2O_2) that might be the prime mechanism of action of catechins against diabetogenic cataract, which was reflected in the *ex-vivo* model.

The incubation of goat lenses with catechins significantly reduced the lenticular oxidative damage, which is indicated by the alleviation of antioxidant enzymes such as CAT, SOD, and GSH. It is well known that the above antioxidants are the important pathophysiological defense system of the cells, they protect the cellular damage, especially of protein, lipids, and nucleic acids from the oxidative free radicals and delay the progression of a disease. SOD and CAT eliminate the superoxide anion and H_2O_2 free radicals respectively, and GSH, a non-enzymatic antioxidant maintains the -SH group in the lens protein in reduced form, thereby attenuating the cross-linking of lens crystalline protein (48, 49). Moreover, the prevention of lenticular oxidative damage is reflected in the results of MDA and protein contents. MDA is a lipid peroxidant, an indicator of cellular lipid oxidation, and correlated with the structural modification and cross-links between lens proteins and membranes(50, 51). Furthermore, results showed that catechins positively restore the lens protein content which might be possible due to their potent antioxidant and aldose reductase inhibitory activity. Cataract formation is indicated by a reduction in the total and soluble protein content and elevation of the insoluble protein content of the eye lens, which reflects structural and conformational modification of the lens crystalline proteins. The maintenance of the eye lens transparency over a lifetime relies on the definite structure and solubility of these proteins, such observation was made within the cataract control group (52). The significant restoration of lens protein in the catechins group suggests that these catechins may protect against protein modification.

Conclusion

The results concluded that catechins, particularly epigallocatechin gallate (EGCG), efficiently decrease aldose reductase activity and reduce lenticular oxidative stress. The results indicate the potential therapeutic usefulness of catechins in preventing or delaying cataract development, especially in people with diabetes. Further research is required, including *in-vivo* studies is necessary to confirm these results and explore the potential for using catechins as a natural treatment for cataracts and associated diabetic problems. The results also indicate that EGCG had better anticataract activity because of its potent antioxidant and aldose reductase inhibitory activity.

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Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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