Ameliorative effect of *Amaranthus tricolor* L. leaves on scopolamine-induced cognitive dysfunction and oxidative stress in rats

Vrushabh B. Hupparage1*, Vijaykumar P. Rasal1, Vishal S. Patil1,2*, Priyanka P. Patil1,2, Shubham G. Mulange1, Ajay P. Malgi1, Sathgowda A. Patil1, Ashwini R. Karade1

1Department of Pharmacology and Toxicology, College of Pharmacy, KLE Academy of Higher Education and Research, Belagavi, India. 
2ICMR-National Institute of Traditional Medicine, Belagavi, India.

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**ABSTRACT**

Ayurveda is a holistic system that uses mostly herbs and minerals in prescriptions that play a crucial role in the treatment of various diseases because of their therapeutic effects, often on multiple targets. In the present study, we assessed the memory-enhancing activity of a leafy vegetable “*Amaranthus tricolor* L.” against scopolamine (SCP)-induced cognitive dysfunction and oxidative stress in rats. Initially, we screened *A. tricolor* leaves’ ethanolic extract for its acetylcholinesterase (AChE) inhibitory and antioxidant activity using standard procedures. The memory-enhancing activity in rats was performed by using the Morris water maze (MWM), the elevated plus maze (EPM), Actophotometer, and Cook’s pole climbing (CPC) apparatus. Biochemical parameters, mainly AChE and butyrylcholinesterase (BChE) enzyme levels measured in the hippocampus and cortex, amyloid beta, reduced glutathione (GSH), superoxide dismutase, and lipid peroxidation (LPO) level, were measured in whole brain tissue. *A. tricolor* leaves’ extract showed potent AChE inhibition and antioxidant activity on the scavenging of 2,2-diphenyl-1-picryl-hydrazyl-hydrate (DPPH). The EPM, MWM, CPC, and Actophotometer showed that SCP administration increased transfer latency (TL) and decreased escape latency time (ELT) and locomotion, respectively, on day 7 and 14, whereas combined therapy of SCP with Donepezil and SCP with 800 mg/kg *A. tricolor* extract significantly reversed the ELT, TL, and locomotion from day 7 to 14. Moreover, AChE and BChE activities and GSH and Malondialdehyde (MDA) levels were significantly elevated in SCP-treated rats, and treatment with *A. tricolor* elevated the biochemical parameters altered by the SCP administration. *A. tricolor* leaves’ extract ameliorates SCP-induced cognitive dysfunction and oxidative stress by the restoration of the cholinergic system’s function, inhibiting Amyloid precursor protein (APP) deposition, and via antioxidant potency, i.e. increasing GSH level, by inhibiting the LPO in the brain. The current study suggests that *A. tricolor* leaves could be a valuable source for the treatment of cognitive dysfunction and oxidative stress associated with Alzheimer’s disease.

**INTRODUCTION**

During the twentieth century, the significant increase in life expectancy made Alzheimer’s disease (AD) the most widely perceived progressive neurodegenerative disorder (NDD) with high incidence and multifaceted pathogenesis. AD is a polygenic disease that involves multi-protein and multi-pathways in its progression (Uddin *et al.*, 2016). AD is characterized by the presence of extreme amounts of extracellular deposits containing insoluble amyloid-β plaques, neurofibrillar tangles, and cholinergic deficits. The etiology of AD remains obscure because this disease is perplexingly caused by aging in concert with a complex interaction of both genetic factors and environmental risk. Numerous studies have reported that central cholinergic neurons are involved in learning and memory. During aging, the elevated central cholinergic system is associated with the decline in memory storage, ultimately impairing the retention of newly assimilated information (Huang *et al.*, 2009). Hence, AD is an age-related progressive NDD that involves unavoidable loss of cognition, accounting for ~60% of all cases, and over 35M people...
are diagnosed with AD worldwide and about 7.7M new cases are diagnosed every year (Ali et al., 2015).

Currently, there is no satisfactory treatment available for AD. The current AD therapy includes utilization of conventional acetylcholinesterase (AChE) inhibitors, viz. tacrine, physostigmine, and donepezil. However, extreme utilization of these agents is associated with negative effects (Asaduzzaman et al., 2014). In this way, it investigates the use of conventional spices as an elective resource for the treatment or management of various cognitive disorders. Herbal medicines are widely utilized as a major source for the treatment of cognitive dysfunctions due to the presence of various chemical constituents, antioxidant properties, and are associated with less toxicity compared to modern synthetic medicines. Furthermore, antioxidants have endogenous and exogenous properties which control the oxidation of neuron cells and act against oxidative stress-related harmful effects. The major role of antioxidants is scavenging free radicals and improving the antioxidant status (Uttara et al., 2009). In order to regulate the development of free radical-mediated oxidative stress in the brain, antioxidant defense enzymes, such as reduced glutathione (GSH), catalase, and lipid peroxidation (LPO), play an important role (Sharma et al., 2013).

*Amaranthus tricolor* L. belongs to the family Amaranthaceae. *A. tricolor* is also known as “Tambdi Bhaji/Lal Saag” and is native to a large part of India. The leaves are rich in antioxidant compounds, act as a free radical scavengers (defense mechanism against oxidation), reduce oxidative stress, and act as an anti-inflammatory herb. The alkaloids, carbohydrates, cardiac glycosides, flavonoids, phenol, amino acids/proteins, saponins, tannins, terpenoids, pterocarps, triterpenes, steroids, quinones, resins, and “coumarins” are found to be the major chemical constituents of the leaves. *A. tricolor* leaves were utilized as traditional medicine and for neuroprotection, as an astringent, to strengthen the liver and improve vision, as a hepatoprotective and anti-nociceptive, and as an anti-inflammatory, anti-cancer, and anti-arthritic (Al-Dosari et al., 2010; Amicarrelli et al., 2012; Amornrit et al., 2016; Sable et al., 2017). Therefore, the present study aimed to evaluate the effect of *A. tricolor* leaves’ ethanolic extract on scopolamine (SCP)-induced cognitive dysfunction and oxidative stress in rats.

**MATERIALS AND METHODS**

**Chemicals and equipment**

SCPHBr (Vital Laboratories Pvt. Ltd, Gujarat), Donepezil (Aptex pharmaceuticals, Bengaluru), Acetylthiocholine iodide (Sigma, St. Louis, MO), 5,5'-dithio-bis-(2-nitrobenzoic acid) (Sigma, St. Louis, MO), and distilled water were used wherever mentioned. Double distilled ethanol was used for extraction. Enzyme-linked immunosorbent assay (ELISA) plate reader (Thermo Scientific Multiskan GO version 1.00.40), centrifuge (Remi), elevated plus maze (EPM), Morris’ water maze (MWM), Actophotometer (INCO, Ambala, India), Cook’s pole climbing (CPC) apparatus (INCO), electronic weighing balance, rotary evaporator, refrigerator, etc. were used in the current study.

**Plant material**

*Amaranthus tricolor* fresh leaves were collected from Dhamane (15.797209, 74.545502), Belagavi, Karnataka, India. The plant leaves were authenticated by Dr. Harsha Hegde, Scientist E, ICMR-National Institute of Traditional Medicine, Belagavi. Accession number: RMRC-1440. The herbarium was prepared and stored for further reference. The fresh leaves were washed under distilled water to remove adhered dirty material, shade dried, coarsely powdered, and subjected to maceration using 95% v/v ethanol for 7 days with occasional shaking. After maceration, the powder obtained was further subjected to Soxhlet extraction. The mixture was filtered and concentrated using a rotary evaporator under reduced pressure. The extract was stored in an airtight light resistance glass container for further use.

**In vitro antioxidant assay**

**DPHP radical scavenging assay**

The DPHP radical scavenging assay was analyzed by using the Blois method (Blois et al., 1958). A stock solution of 1 mg/ml plant extract, 1 mg/ml Ascorbic acid, 5.85 mg DPHP in 150 ml methanol was prepared and stored in the light resistance area. Briefly, 0.4 ml plant extract (50–800 µg/ml) and the standard drug were mixed with a 3.6 ml methanolic solution of DPHP (0.1 mM). An equal amount of methanol (0.4 ml) was used as a blank with a DPHP solution (3.6 ml). The above-mentioned mixture was vortexed for 1 minute and incubated for 30 minutes at 37°C. After incubation, the absorbance of each sample against methanol as blank by using the ELISA microplate reader at 517 nm was noted. The percentage of DPHP scavenging was calculated by using the following formula: DPHP inhibition(%) = (Acontrol−A sample/Acontrol) × 100. The results were reported as IC50 value.

**In vitro AChE enzyme assay**

AChE enzyme inhibition activity was performed according to Ellman’s method (Ellman et al., 1961). The AChE enzyme of 6.67 U/ml−1 stock solution was prepared by dissolving it in 20 mM sodium Phosphate-buffered saline (PBS) (pH 7.6), and the solutions were stored at −80°C for further use. Acetylthiocholine iodide was used as a substrate. In a test tube, 1.7 ml of 50 mM Tris HCl buffer (pH 8.0) and 250 µl of different concentrations of plant extract (10, 20, 40, 80, 160, and 320 µg/ml) and donepezil (1, 2, 4, 8, 16, and 32 µg/ml) were added. The reaction mixture was incubated for 15 minutes and 10 µl AChE enzyme and 20 µl DTNB were added. The mixture was vortexed for 1 minute and incubated for 45 seconds for 3 minutes. The enzyme inhibition was calculated from the rate of change in absorbance with time.

\[
\% \text{Inhibition} = 100 - \left(\frac{\text{Change of sample Abs}}{\text{Change of blank Abs}}\right) \times 100
\]

**Experimental animals**

Wistar rats (either sex, 180 ± 20 g) were acquired from Invivo Biosciences, Bengaluru, housed in a clean and transparent polypropylene cage, and were divided into six groups (n = 6). Animals were maintained under the 12 hours light-dark cycle at 23°C ± 2°C. Relative humidity was maintained at 45%–55%. The study protocol was reviewed and approved by the Institutional Animal Ethical Committee, KLE College of Pharmacy, Belagavi, Resolution No. KLECOP/CPCSEA – Reg.No.221/Po/Re/S/2000/
Experimental procedure

The dose of the extract was selected based on the previously reported acute toxicity study reports. Ethanolic extract of leaves showed no mortality at 2,000 mg/kg, thus we selected the 1/2.5th, 1/5th, 1/10th doses of the LD<sub>50</sub> value as therapeutic doses. The extract was administered orally using Carboxymethyl cellulose (CMC) as a suspending agent (Al-Dosari et al., 2010). Group I received food and water. Group II (negative control) received SCP (1 mg/kg/day; i.p.) for 14 days (Zahra et al., 2015). Group III (positive control) received SCP (1 mg/kg/day; i.p.) with donepezil HCl (3 mg/kg/day; p.o.) for 14 days (Zahra et al., 2015). Group IV, V, and VI received SCP (1 mg/kg/day; i.p.) with <i>A. tricolor</i> L. extract of 200, 400, and 800 mg/kg/day, p.o., respectively, for 14 days. All the animals were subjected to exteroceptive behavioral models of memory on day 0, 7, and 14, and brain tissue samples for biochemical estimation.

In vivo screening models for memory (exteroceptive behavioral models)

Elevated plus maze

Short-term memory was evaluated by using Bhuvanendran et al.’s (2018) method. The EPM consists of two open arms crossed over two closed arms having dimensions of 50 × 10 cm. Four arms were connected using a central square having 10 × 10 cm dimensions. During the assessment of memory via the EPM, the rats were individually placed at one end of the open arm facing away from the central stage (platform), and the time taken for the rat to move from an open arm to a closed arm (initial transfer latency) was recorded using a stopwatch. The animals were allowed to explore the maze for 120 seconds. If the animal did not enter the closed arms within 120 seconds, it was directed on the back into one of the closed arms and the transfer latency (TL) was given as 120 seconds. Later, the rat was allowed to explore the maze for 30 seconds to become familiar with the maze and was then returned to its cage. Each group was tested on day 0, 7, and 14.

Morris water maze

Escape latency time (ELT) was assessed using Ishola et al.’s (2018) method. It consists of a large circular water tank having 110 cm diameter and 60 cm height. It is made of black opaque polyvinyl chloride or hardboard coated with fiberglass or resin with a white surface and filled with water (26°C ± 2°C) to a depth of 30 cm. The floor of the circular tank was marked into four equal quadrants. In all trials, 2 cm below the surface of the water, a black round platform of 10 cm diameter was placed in a constant position. The cut-off time given to individual rats was 120 seconds. The time taken for the rat to locate the escape platform was noted. If the rat was unable to find/locate the platform within the cut-off time, it was directed to the stage (platform) and was permitted to stay on it for 10 seconds. Each group was tested on day 0, 7, and 14.

Actophotometer

Photoactometer is utilized to access locomotion in the experimental animals. The apparatus functions based on photoelectric cells that are connected to the circuit with a counter. A motion count was recorded when the beam of light falling on the photocell was cut off by the rat. The cut-off time given to individual rats was 120 seconds. Each rat’s locomotor activity was noted. Each time the apparatus was wiped with 10% ethanol to avoid intervention due to animal odor. Each group was tested on day 0, 7, and 14 (Bhosale et al., 2011).

Cook’s pole climbing

Cook’s pole climbing method is a conditional avoidance/escape latency procedure used to screen Central nervous system (CNS) activity. The apparatus’ floor acts as a source of shock. The experimental rats were subjected to training under a well-closed, electrical, grid-less, light chamber with a buzzer. This was carried routinely. Animals were subjected to training in such a way that the animal learned to climb the pole within 120 seconds. Each group was tested on day 0, 7, and 14 (Kadian et al., 2014).

Biochemical estimation

Cerebral cortex and hippocampus AChE and Butyrylcholinesterase (BChE) enzymes estimation

At the end of the study, the rats are decapitated; their brains are removed quickly and kept in ice-cold saline. The cerebral cortex and hippocampus were isolated, weighed, and homogenized in 0.1M (pH 8) PBS. Briefly, 0.4 ml of the homogenate was added to a test tube containing 2.6 ml PBS (0.1M, pH 8). Furthermore, 100 µl of DTNB reagent, followed by 10 µl of acetylthiocholine iodide solution (butyrylthiocholine iodide for BChE enzyme estimation), was added. The absorbance was then noted at 412 nm for 5 minutes and change in absorbance per minute was also noted (Ellman et al., 1961). The “rate of moles of substrate hydrolyzed per minute per gram of tissue” was calculated by the following equation: \( R = 5.74 \times 10^{-4} (\Delta A/Co) \). Where \( R \) = rate in moles of substrate hydrolyzed per minute per gram of tissue; \( \Delta A \) = change in absorbance per minute; and \( Co = \) original concentration of tissue (mg/ml).

Estimation of amyloid beta (Aβ<sub>1-42</sub>)

The capacity of rat brain Aβ<sub>1-42</sub> levels was estimated according to the sandwich ELISA kit for rat Aβ<sub>1-42</sub> manual (YH Bioserach Laboratory, Shanghai, China) (Pattanashatti et al., 2017). The weighed brain tissue sample was homogenized in 0.1M PBS (pH 7.4) and centrifuged at 5,000 rpm. The supernatant was used for the detection of Aβ<sub>1-42</sub>. All reagents, standard solutions, and samples were prepared as per instructions and methodology given in the manual. Reagents were kept at room temperature before use (assay solutions should be at room temperature). The standard curve analysis was run in parallel to the test samples. The absorbance was measured in the multi-scan spectrum spectrophotometer (Thermo Scientific, Waltham, MA, Multiskan GO) at 450 nm. All the readings were performed in triplicate.

In vivo antioxidants

Rat brain was removed, weighed, and homogenized in cold 0.05M PBS (pH 7.4). Furthermore, homogenates were centrifuged at 10,000 rpm for 10 minutes at 4°C (MPW-350 R, Korea) and post-mitochondrial supernatant was utilized for the
estimation of Total protein (TP) and LPO. The supernatant was further centrifuged at 15,000 rpm for 1 hour at 4°C. The supernatant obtained was utilized to estimate superoxide dismutase (SOD) and GSH (Shalavadi et al., 2012).

**Estimation of LPO in rat brain**

Thiobarbituric acid reactive substances in the homogenate were estimated by the method described by Shalavadi et al. (2012). Briefly, 0.5 ml of 10% homogenate was incubated with 15% Trichloroacetic acid (TCA), 0.375% 2-Thiobarbituric acid (TBA), and 5 N HCl at 95°C for 15 minutes; the mixture was cooled, centrifuged, and the absorbance of the supernatant was measured at 512 nm against an appropriate blank. The LPO levels were determined by using the following equation: \( \epsilon = 1.56 \times 10^5 \text{M}^{-1} \text{cm}^{-1} \).

**Estimation of reduced GSH**

5% tissue homogenate was prepared in 20 mM Ethylenediaminetetraacetic acid (EDTA) (pH 4.7). Briefly, 100 µl of the homogenate was added to 1 ml 0.2 M Tris-EDTA buffer (pH 8.2) and 0.9 ml 20 Mm EDTA (pH 4.7), followed by 20 µl of Ellman’s reagent (10 mmol/l DTNB in methanol), and incubated for 30 minutes. Samples were further centrifuged and the absorbance was noted at 412 nm.

**Estimation of SOD**

SOD activity was estimated based on the ability of SOD to inhibit the auto-oxidation of epinephrine to adrenochrome at alkaline pH. Briefly, 25 µl of the supernatant obtained from the centrifuged brain homogenate was added to a mixture of 0.1 mM epinephrine in carbonate buffer (pH 10.2). The formation of adrenochrome was measured at 295 nm. The SOD activity (U/mg of protein) was calculated by using the standard plot.

**Statistical analysis**

The results were expressed as Mean ± SEM. The difference among the group was determined using one-way and two-way analyses of variance (ANOVA), followed by Tukey’s multiple comparison test and Bonferroni’s multi-comparison test as *post hoc* tests using GraphPad Prism software version 5.0.

**RESULTS**

**Plant extraction**

The percentage yield (w/w) of *A. tricolor* L. leaves’ ethanolic extract by maceration method was found to be 5.2%, followed by the Soxhlet extraction method, which was found to be 2.3%.

**In vitro antioxidant assay**

**DPPH radical scavenging assay**

Ascorbic acid was used as the reference compound. The IC\(_{50}\) value of ascorbic acid was found to be 67.12 µg/ml, whereas IC\(_{50}\) value of *A. tricolor* extract was found to be 236.42 µg/ml. The results suggest that the ascorbic acid has a more radical scavenging activity compared to the *A. tricolor* ethanolic extract. The IC\(_{50}\) value is shown in Figure 1a and Table 1.

![Figure 1](image-url)  
**Table 1.** Effect of *A. tricolor* on free radical scavenging assay by using DPPH and AChE enzyme.

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<td><em>A. tricolor</em></td>
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</tr>
<tr>
<td>Donepezil</td>
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**In vitro AChE enzyme assay**

The AChE enzyme inhibitory activity of *A. tricolor* extract and clinically proven drug donepezil are shown in Table 1. The IC\(_{50}\) value of *A. tricolor* was found to be 193.9 µg/ml and donepezil was found to be 1.96 µg/ml. This suggests that donepezil is 100 times more potent than *A. tricolor* extract. The IC\(_{50}\) value and standard calibration curve are shown in Figure 1b and Table 1, respectively.

**In vivo studies**

**Effect of *A. tricolor* extract on TL using EPM**

The rats were exposed to the EPM to assess the TL retrieval of memory. The TL of the SCP group was significantly decreased on day 7 (p < 0.05) and 14 (p < 0.001) compared to the normal group, whereas SCP with Donepezil 3 mg/kg was significantly increased in TL on day 7 (p < 0.01) and 14 (p < 0.001) compared to SCP alone (Group II). However, the administration of SCP with *Amaranthus tricolor* L. (AT) 400 mg/kg and SCP + AT 800 mg/kg was significantly increased TL on day 14 (p < 0.01 and p < 0.001, respectively) compared with SCP alone (Group II). The effect of *A. tricolor* on TL is shown in Figure 2a and Table 2a.

**Effect of *A. tricolor* extract on ELT using MWM**

The ELT was evaluated on day 0, 7, and 14 from the duration of the treatment period. Group II (SCP 1 mg/kg/day) showed significantly increased ELT on day 7 and 14 compared to the normal group (p < 0.001), whereas treatment of SCP with Donepezil 3 mg/kg significantly decreased ELT on day 7 and 14 (p < 0.001) compared to SCP alone. However, SCP with AT 200, 400, and 800 mg/kg/day showed a significant decrease in ELT on day 7 and 14 (p < 0.001) compared to SCP alone. The effect of *A. tricolor* on ELT is shown in Figure 2b and Table 2b.

**Effect of *A. tricolor* extract on locomotor activity using Actophotometer**

The locomotion of the SCP group was significantly decreased on day 7 and 14 (p < 0.001) compared to the normal group. Treatment of SCP with Donepezil 3 mg/kg and SCP with AT 400 and 800 mg/kg group was significant increased (p < 0.001) on

**Figure 2.** Effect of *A. tricolor* leaves’ extract on exteroceptive behavioral models: (a) EPM, (b) MWM, (c) Actophotometer, and (d) CPC. Number of rats in each group is n = 6. All the data were analyzed by two-way ANOVA, followed by Bonferroni’s multi-comparison test as post hoc test and expressed in Mean ± SEM. *p < 0.05; ***p < 0.001 compared to normal group, #p < 0.05; ##p < 0.01; ### p < 0.001 compared to SCP group.
The SCP group showed a significantly increased level of AChE enzyme activity compared to the normal group (p < 0.001) in the hippocampus and cerebral cortex. Treatment of SCP with Donepezil (DNPZ) showed significantly reduced levels of AChE activity in the hippocampus and cortex (p < 0.001). However, no significant change in AChE activity was observed in the hippocampus and cortex on the treatment of SCP with AT 200 mg/kg, whereas the treatment of SCP with AT 400 mg/kg showed significantly reduced AChE activity in the cortex (p < 0.01). Treatment of SCP with 800 mg/kg showed a significant change in AChE activity in the hippocampus (p < 0.05) and cortex (p < 0.001). The effect of A. tricolor on the hippocampus and cerebral cortex AChE enzyme activity is shown in Table 3 and Figure 3a and b.

The SCP group showed a significant decrease in BChE enzyme activity compared to the normal group (p < 0.001) in the hippocampus and cerebral cortex. However, a significant increase in BChE activity was observed in the rat hippocampus and cortex treated of SCP with DNPZ (p < 0.01) compared to the SCP group. BChE enzyme activity is shown in Table 3 and Figure 3c and d.

**Effect of A. tricolor on locomotion using CPC**

The SCP group showed a significant increase in the level of Amyloid-beta (1–42) compared to the normal group (p < 0.001) in the whole rat brain. However, the treatment of SCP with Donepezil showed a significant decrease in Amyloid beta (1–42) in the whole brain (p > 0.001) compared to SCP alone. However, the treatment of SCP with AT 400 mg/kg showed significantly reduced level of Amyloid-beta (1–42) (p < 0.01) and SCP with AT 800 mg/kg (p < 0.001) compared to SCP alone. The effect of A. tricolor on rat brain Amyloid beta (1–42) level is shown in Table 4 and Figure 4a.

**In vivo antioxidants**

The SCP group showed a significantly increased level of MDA (p < 0.001) compared to the normal group. Treatment of SCP with DNPZ showed a significant decline in the MDA level (p < 0.001) compared to SCP alone. The effect of A. tricolor on locomotion is shown in Figure 2c and Table 2c.
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Table 3. Effect of *A. tricolor* on the hippocampus and cerebral cortex AChE and BChE enzymes.

<table>
<thead>
<tr>
<th>Treatment groups</th>
<th>AChE enzyme activity (in moles × 10^−6/minutes/g of tissue)</th>
<th>BChE enzyme activity (in moles × 10^−6/minutes/g of tissue)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hippocampus</td>
<td>Cerebral cortex</td>
</tr>
<tr>
<td>Normal</td>
<td>06.06 ± 0.251</td>
<td>01.55 ± 0.356</td>
</tr>
<tr>
<td>SCP</td>
<td>13.77 ± 0.688***</td>
<td>10.83 ± 0.240***</td>
</tr>
<tr>
<td>SCP + DNPZ</td>
<td>06.29 ± 1.297***</td>
<td>03.38 ± 0.859***</td>
</tr>
<tr>
<td>SCP + AT200</td>
<td>12.63 ± 0.664</td>
<td>08.72 ± 0.077</td>
</tr>
<tr>
<td>SCP + AT400</td>
<td>10.14 ± 1.141</td>
<td>06.82 ± 0.147***</td>
</tr>
<tr>
<td>SCP + AT800</td>
<td>08.98 ± 0.710***</td>
<td>05.08 ± 0.733***</td>
</tr>
</tbody>
</table>

Values are expressed in mean ± SEM: (n = 6); Analyzed by one-way ANOVA, followed by Tukey’s multiple comparison test.

*** p < 0.001 compared to normal group, # p < 0.05; ## p < 0.01; ### p < 0.001 compared to SCP group.

<0.001) compared to the SCP group, whereas SCP with AT 800 mg/kg showed a significant decrease in the MDA level (p < 0.01) compared to SCP group. The effect of *A. tricolor* on the MDA level is shown in Figure 4b and Table 4.

**Effect of A. tricolor extract on reduced GSH**

The SCP group showed a significantly decreased level of GSH (p < 0.001) compared to the normal group. Treatment of SCP with the DNPZ group indicated a significant increase in the reduced GSH level (p < 0.001), whereas treatment of SCP with AT 400 mg/kg (p < 0.01) and SCP with AT 800 mg/kg (p < 0.001) showed a significant increase in GSH level. However, no significant change was observed in SCP with AT 200 mg/kg. The effect of *A. tricolor* on a reduced GSH level is shown in Figure 4c and Table 4.

**Effect of A. tricolor extract on reduced SOD**

The SCP group showed a significant decline in the SOD level (p < 0.001) compared to the normal group. Treatment of...
SCP with DNPZ and SCP with AT 800 mg/kg group indicated a significant increase in the reduced SOD level ($p < 0.01$ and $p < 0.05$, respectively) compared to SCP alone. The effect of *A. tricolor* on a reduced SOD level is shown in Figure 4d and Table 4.

**DISCUSSION**

Ayurveda is an ancient system of medicine that originated and was practiced in India since ages (Sheeja Malar *et al.*, 2017). It is a holistic system that uses mostly herbal plants, vegetables, and minerals in prescriptions that play a crucial role in the treatment of various diseases because of their antioxidants properties and therapeutic effects. The primary central goal in neuroscience is the advancement of pharmacologically successful medicines which ease neurodegenerative issues. The high event of dementia, in AD, in old individuals gives solid inspiration to look and build up the new substances with the possibility to invert the deficit in

### Table 4. Effect of *A. tricolor* on amyloid-beta (1–42), LPO, GSH, and SOD on rat whole brain.

<table>
<thead>
<tr>
<th>Treatment groups</th>
<th>Amyloid-beta (1–42) concentration in pg/ml</th>
<th>LPO (in nmoles of MDA/mg protein)</th>
<th>GSH (in µmoles/mg of protein)</th>
<th>SOD (units/mg of protein)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>1.07 ± 0.049</td>
<td>07.00 ± 1.186</td>
<td>9.41 ± 0.657</td>
<td>288.1 ± 21.99</td>
</tr>
<tr>
<td>SCP</td>
<td>2.15 ± 0.155***</td>
<td>20.11 ± 1.341**</td>
<td>1.34 ± 0.166**</td>
<td>107.3 ± 05.83***</td>
</tr>
<tr>
<td>SCP + DNPZ</td>
<td>1.15 ± 0.043**</td>
<td>07.83 ± 1.106**</td>
<td>7.00 ± 0.423**</td>
<td>264.7 ± 28.83**</td>
</tr>
<tr>
<td>SCP + AT200</td>
<td>2.10 ± 0.049</td>
<td>17.13 ± 0.233</td>
<td>2.33 ± 0.332</td>
<td>131.7 ± 12.67</td>
</tr>
<tr>
<td>SCP + AT400</td>
<td>1.63 ± 0.021**</td>
<td>14.86 ± 1.398</td>
<td>4.14 ± 0.300**</td>
<td>185.8 ± 19.47</td>
</tr>
<tr>
<td>SCP + AT800</td>
<td>1.39 ± 0.026**</td>
<td>10.99 ± 1.070**</td>
<td>5.88 ± 0.335**</td>
<td>212.1 ± 28.65**</td>
</tr>
</tbody>
</table>

Values are expressed in mean ± SEM: ($n = 6$); Analyzed by one-way ANOVA, followed by Tukey’s multiple comparison test.

***$p < 0.001$ compared to normal group, $fp < 0.05$; ###$p < 0.01$; ####$p < 0.001$ compared to SCP group.

![Figure 4. Effect of *A. tricolor* leaves’ extract on (a) β-Amyloid (Aβ1–42), (b) LPO-Malondialdehyde, (c) GSH, and (d) SOD. All the data were analyzed by one-way ANOVA, followed by Tukey’s multiple comparison test and expressed in Mean ± SEM. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$ compared to normal group, $fp < 0.05$; ###$p < 0.01$; ####$p < 0.001$ compared to SCP group.](image-url)
short and long-term memory. The current pharmacotherapy of AD includes the extreme utilization of conventional AChE inhibitors, i.e. donepezil, rivastigmine, etc., which is apparent to cause a verity of adverse effect and also lose the effect as the disease progresses (Waldemar et al., 2007; Mayo Clinic, 2018). *A. tricolor* is a leafy vegetable and has a high content of antioxidants and secondary metabolites. One of the studies conducted on *A. tricolor* L. showed a neuroprotective effect on gene expression of Receptor for advanced glycation endproducts (RAGE) during oxidative stress in SH-SY5Y cells. However, the potential of biochemicals regulated by the bioactive phytoconstituents from *A. tricolor* L. in the management of cognitive impairment has not been elucidated clearly.

SCP-induced memory impairment is one of the best models for assessment of drug candidates for their memory-enhancing potency by utilizing various models such as MWM, EPM, Actophotometer, CPC, and also for determining the level of ACh, BCh, MDA, and GSH in the hippocampus and cerebrum. In the current study, to assess the neuroprotective activity of *A. tricolor*, we administered SCP alone and in combination with 200, 400, and 800 mg/kg/day *A. tricolor* extract to the rats and examined their behavior by utilizing MWM, EPM, Actophotometer, and CPC, followed by determining the level of AChE and BChE enzyme activity and reduced antioxidant defence mechanism, i.e. reduced GSH and SOD levels and MDA level in the rat brain. A clinically approved drug “Donepezil” is used as an internal standard at 3 mg/kg/day dose.

An imbalance in the free radical and Reactive oxygen species (ROS) generation decreases the antioxidant defense mechanism leading to cell damage and inflammation (Manoharan et al., 2016). Furthermore, generation (production) of ROS lead to various unwanted reactions, including DNA damage, lipid abnormalities, and damage to the proteins (Khansari et al., 2009). Researchers demonstrated that plant extracts with higher flavonoid contents usually have the best free radical scavenging property (antioxidant activity). In the current study, the ethanolic extract exhibited strong DPPH scavenging activity and the extract treated in combination with the SCP significantly reversed the oxidative stress meditated by the SCP in rat brain by reducing the MDA level and increasing GSH and SOD levels ($p < 0.001$).

The memory-improving activity of *A. tricolor* against SCP-induced cognitive impairment in rats was examined by utilizing the MWM, EPM, CPC, Actophotometer, and by assessing the biochemical from the cerebrum. The short-term memory was tested utilizing MWM and CPC apparatus. In the current study, animals treated with SCP elevated the brain function by altering the ELT, TL, and locomotion. However, combined therapy of SCP and *A. tricolor* for 14 days showed a dose-dependent decline in the ELT and an increase in the TL and locomotion in rats. Among the selected doses, 800 mg/kg showed better activity compared to the clinically approved drug. The outcomes of the results propose that the administration of *A. tricolor* changes the neuronal performance of rats from day 7 to 14 and reduced the risk of development of AD by acting as an antioxidant and altering the disease-associated proteins and pathways. Furthermore, we examined the cholinergic function and beta-amyloid level of the brain to elucidate the memory improvement mechanism of *A. tricolor*. ACh and BCh neurotransmitters involved in the memory improvement, the concentration of ACh is reduced, and BCh is increased in AD due to rapid hydrolysis by AChE and BChE enzyme activity, respectively (Jung et al., 2009). In the current study, initially, we examined *A. tricolor* on the AChE enzyme and *A. tricolor* extract showed good inhibitory activity. The *in vivo* hippocampus and cerebral cortex AChE and BChE inhibitory role of *A. tricolor* was performed at the end of the study, and the resulting outcome showed the dose-dependent significant decline in AChE and BChE enzyme activity on the treatment of 200, 400, and 800 mg/kg of *A. tricolor* extract compared to SCP alone. The results suggest that the administration of 400 and 800 mg/kg of *A. tricolor* extract could be the potent inhibitory dose compared to Donepezil. Amyloid beta (1–42) level on the whole brain of the rat was examined using a sandwich ELISA kit. Results showed that *A. tricolor* 800 mg/kg significantly reduced the level of deposition of amyloid-beta in the brain compared to the SCP. Therefore, *A. tricolor* leaves’ ethanolic extract could be the potent treatment regimen against oxidative stress-mediated AD.

CONCLUSION

In conclusion, the current study describes the molecular mechanism of *A. tricolor* on cognitive improvement via *in vitro* and *in vivo* studies. *Amaranthus tricolor* ameliorates the SCP-induced cognitive dysfunction and oxidative stress by the restoration of the cholinergic function, reducing APP deposition, by inhibiting the LPO, increasing GSH, and SOD function in the brain. The study also demonstrated the improvement of memory by utilizing MWM, EPM, Actophotometer, Cock’s pole climbing behavioral models. Therefore, the present study helps the multipronged solutions to tackle AD in the future.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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None.

REFERENCES


