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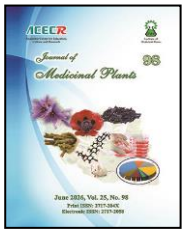

Research Article

Therapeutic effect of hydroalcoholic extract of *Portulaca oleracea* against cuprizone-induced demyelination by targeting Nrf2/HO-1/NQO-1/NF-kB in C57BL/6 mice

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ABSTRACT

Background: Multiple sclerosis (MS) is a chronic autoimmune disorder of the central nervous system that leads to inflammatory demyelination and axonal damage. **Objective**: This study evaluated the therapeutic potential of *Portulaca oleracea* extract in a mice model of CPZ-induced multiple sclerosis. **Methods:** In the present experiment, CPZ was used to induce an MS-like conditions in mice. During the final two weeks of CPZ exposure, mice received *P. oleracea* extract at doses of 100, 200, or 300 mg/kg/day by intraperitoneal injection. After the study period, behavioral tests, histochemical examination, and immunohistochemical analysis were performed to assess HO-1, NQO-1, p-Nrf2, and NF-κB p65. **Results:** Compared with control group, mice fed CPZ showed significant weight loss, impaired motor function, and significant demyelination of the corpus callosum in LFB staining. Administration of *P. oleracea* during the last two weeks improved behavioral deficits and reduced CPZ-associated weight loss and myelin damage. In the corpus callosum, CPZ decreased the expression of HO-1, NQO-1, and p-Nrf2 while increasing the expression of NF-κB p65. These changes were partially reversed by treatment with the extract. **Conclusion:** *P.* oleracea may be a potential candidate for further preclinical research on MS.

1. Introduction

Multiple sclerosis (MS) is a long-standing inflammatory disorder that causes demyelination within the central nervous system (CNS) [1] which causes various degrees of myelin and axon destruction [2]. Inflammation-

Abbreviations: CNS, Central Nervous System; CPZ, Cuprizone; HO-1, Heme Oxygenase-1; IHC, Immunohistochemistry; LFB, Luxol Fast Blue; MS, Multiple Sclerosis; NF-κB, Nuclear Factor Kappa B; NQO-1, NAD(P)H Quinone Oxidoreductase 1; Nrf2, Nuclear Factor Erythroid 2-related Factor 2; OFT, Open Field Test; PBMCs, Peripheral Blood Mononuclear Cells; ROS, Reactive Oxygen Species; SEM, Standard Error of the Mean

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related loss of myelin and axonal damage in the Corpus Callosum are the characteristics of MS, which may contribute to poor function on challenging tasks [3]. MS usually begins between the ages of 20- 40. Based on investigations, 2.8 million individuals worldwide suffer from MS, and due to motor, autonomic, and cognitive impairments, causes significant disability [4, 5]. In the majority of patients, the condition is first characterized by reversible neurological impairment episodes, which are frequently followed by a gradual neurological decline, over time [6, 7]. Oxidative stress is regarded as one of the major pathogenic mechanisms involved in MS. Oxidative stress can activate phase II detoxification enzymes, particularly NQO-1, a key antioxidant enzyme. [8, 9]. Nuclear factor erythroid-2-related factor 2 (Nrf2) functions as a nuclear transcription factor that modulates cellular redox balance and antioxidant gene expression. One of the cellular protective factors is the transcription factor Nrf2. This transcription factor increases cell survival in the face of various stresses. It also has a significant role in protection against oxidative stress and cell damage caused by chemicals [10-12], and development of inflammation could be slowed down by activating the Nrf2 pathway [13, 14]. According to several reports, the pathophysiology of MS might be constrained to downregulation the the Nrf2-regulated antioxidant signaling axis involving HO-1 and NQO1 [11, 15]. HO-1, an Nrf2-responsive enzyme, mediates heme catabolism to biliverdin while releasing free iron and carbon monoxide, which helps protect cells from oxidative injury [16]. HO-1 expression is significantly downregulated during MS exacerbation in peripheral blood mononuclear cells (PBMCs) of patients with the condition [17, 18]. NQO1 is another Nrf2-regulated gene which expresses NQO1 enzyme with several protective effects including detoxification and anti-tumor activity [19]. Several studies have been indicated that activating Nrf2/HO-1/NQO1 signaling decreased the ROS generation, improved myelin integrity and behavioral changes in multiple sclerosis [20, 21]. Based on some research in astrocytes, macrophages, T cells, oligodendrocytes, and neurons in the CNS of MS patients, the transcription factor nuclear factor-kappa B (NF-κB) is activated, which accelerates the progression of MS by increasing inflammation. p65:p50 is the most prevalent type of NF-κB triggered by pathogenic stimuli [22-24].

Interferon *β*, glatiramer acetate, mitoxantrone, natalizumab, and fingolimod are commonly used to treat MS, and these medications present physicians with several challenges, including efficacy and adverse effects [1, 25]. *Portulaca oleracea* L., a member of the Portulacaceae family, contains diverse phytochemicals, including terpenoids, flavonoids, alkaloids, coumarins, and cerebrosides, in addition to vitamins, fatty acids, proteins, sterols, and minerals. The constituents of *P. oleracea* have been associated with neuroprotective, analgesic, hepatoprotective, antioxidant, immunomodulatory, and anti-inflammatory activities [26-30]. Its traditional medicinal use and the neuroprotective and antinociceptive effects of its constituents have also been reported [31, 32]. The anti-inflammatory properties of *P. oleracea* have been associated with suppression of iNOS and COX-2 expression, together with attenuation of NF-κB and MAPK signaling [33]. Experimental studies have also reported that *P. oleracea* reduces p65 phosphorylation and nuclear translocation, while lowering NO, TNF-*α*, and IL-6 production [28, 34, 35]. Other

findings link the antioxidant and anti-inflammatory effects of *P. oleracea* to modulation of the Nrf2/HO-1/NQO1/NF-κB axis, with increased Nrf2 and HO-1 expression after treatment [34]. On the other hand, studies indicate that *P. oleracea* modifies the triggered Th1 ailments such as hepatitis and MS [36]]. There are different models for MS induction, including ethidium bromide (EB), lysolecithin, and cuprizone. The cuprizone (CPZ) model is a toxic demyelination model. In this paradigm, young mice consume the copper chelator CPZ, resulting in oligodendrocyte injury and subsequent myelin loss and then there is a period of remyelination recovery time [37-40]. Given the burden of MS and the traditional use of *P. oleracea*, this study examined whether its extract could improve CPZ-associated behavioral impairment in mice.

2. Materials and methods

2.1. Chemicals

Cuprizone (CPZ) was obtained from Merck KGaA, Germany. NF-kB p65 ((F-6): SANTA CRUZ -8008) and p-Nrf2 (phospho S40) antibody [EP1809Y] abcam76026, HO-1 (A-3): SANTA CRUZ-136960, Anti-NQO1 antibody abcam34173 and the secondary antibody m-IgGκ BP-HRP (SANTA CRUZ-516102) were used for immuhistochemistry tests.

2.2. Extraction method

Plant material of *P. oleracea* was obtained from a local herbal supplier and authenticated at the Herbarium Institute of Kermanshah University of Medical Sciences (herbarium code: 001/001/151). After washing with distilled water, the material was air-dried at 25 °C and pulverized using a mechanical mill. The powder was extracted with ethanol/distilled water (70:30, v/v) on a shaker for 72 h. After concentration by rotary evaporation and drying in an incubator, the hydroalcoholic extract was reconstituted in the extraction solvent to obtain the target concentrations [41].

2.3. Animals

Thirty-five male C57BL/6 mice (8 weeks old, 20–25 g) were included in the study. Following procurement from the Pasteur Institute of Karaj, the animals were kept under standard laboratory conditions at 25 °C and a 12-h light/dark cycle, according to the ethical standards of Kermanshah University of Medical Sciences, Iran (IR.KUMS.REC.1400.232).

2.4. Cuprizone-induced demyelination and subsequent P. oleracea extract treatment

Animals received a normal diet containing 0.2 % (w/w) CPZ to induce demyelination [42, 43]. Mice were randomly assigned to five experimental groups, with seven animals per group.

1) Control group: animals that received standard food for 6 weeks.

2) CPZ group: mice exposed to a diet containing 0.2 % (w/w) CPZ for a 6-week period.

3) CPZ group + 100mg/kg *P. oleracea* extract (P1): Animals that received food containing 0.2 % CPZ for 6 weeks and 100mg/kg *P. oleracea* extract by intraperitoneal (i.p.) injection for the last two weeks of the study.

4) CPZ group + 200mg/kg *P. oleracea* extract (P2): Animals that received food containing 0.2 % CPZ for 6 weeks and 200 mg/kg *P. oleracea* extract by i.p. injection for the last two weeks of the study.

5) CPZ group + 300mg/kg *P. oleracea* extract (P3): Animals that received food containing 0.2 % CPZ for 6 weeks and 300 mg/kg *P. oleracea* extract by i.p. injection during the final 2 weeks of the experimentAll the selected doses were chosen by previous studies [25, 44-47].

2.5. Behavioral tests

At the completion of the experiment, the open field test (OFT), pole test, and rotarod test were conducted to assess locomotor activity, coordination, and motor balance in mice. For the pole test, each mouse was positioned at the upper end of the bar, and the time required to reach the base was recorded. The bar had 1 cm diameter and measured 50-60 cm tall (cut-off time: 1min). Three times of this test were run, each with a five-minute break in between [44].

To assess each mouse's motor learning and sensorimotor coordination, the Rotarod test was used. The gadget rotated at 25 revolutions per minute, and the mice's contact angle with the rotating cylinder was 45 degrees. Three times of this test were conducted, each with a three-minute break (cut-off time: 5 min) [25].

The OFT is an uncomplicated sensorimotor test designed to assess general levels of activity. In this experiment, mice are placed in a wooden box (50 cm x 60 cm x 40 cm). The bottom of the box is divided into 16 equal squares, and the number of houses they pass through in 5 minutes is calculated [44].

2.6. Brain preparations

After completion of the behavioral assays, anesthesia was induced with ketamine (50 mg/kg) and xylazine (10 mg/kg) via the intraperitoneal route, after which the brains were removed and fixed in 10 % formalin for histopathological examination, including IHC, H&E, and LFB staining.

2.7. Myelin staining

A common technique for observing myelin and evaluating the process of demyelination is LFB staining. With this method, myelin, neuropil, and neuronal structures appear blue, pink, and purple, respectively. Corpus callosum tissues were cut into 5-um sagittal cuts and dried for an entire night at 37 °C. Following deparaffinization, clarification, hydration in ethanol (95 %), rinsing with distilled water, and staining with LFB (0.1 %), tissues were processed. Ethanol (95 %) and water were used to clean away extra dyes. 70 percent ethanol and 0.05 % lithium carbonate were used to induce tissue differentiation. Finally, xylene was used to clean and mount dehydrated tissue sections [25].

2.8. Hematoxylin and eosin (H&E) staining

Five-micrometer sections of the prefrontal cortex were prepared using a microtome. Slides were stained with hematoxylin for 6 h at 60 °C and subsequently rinsed with distilled water. Differentiation was performed using 10 % acetic acid and 85 % ethanol. Sections were then immersed in saturated lithium carbonate, washed with water, and counterstained with eosin [25].

2.9. Immunohistochemistry (IHC) staining

Paraffin-embedded corpus callosum sections (5 μm) were used to evaluate HO-1, NQO-1, NF-κB p65, and p-Nrf2 expression. Sections were deparaffinized in xylene, passed through ethanol, and rehydrated in citrate buffer. Following antigen retrieval in citrate buffer (pH 6.0) at 90 °C for 15 min, samples were blocked with 1 % BSA for 1 h at 37 °C [25].

2.10. Data analysis

GraphPad Prism 9 (San Diego, CA, USA) was used for statistical analysis. Group differences were examined by one-way ANOVA with Tukey's post hoc multiple-comparison test. Data are presented as mean ± SEM, and $P < 0.05$ was considered statistically significant. Quantification of LFB and IHC data was performed in ImageJ.

3. Results

3.1. Bodyweight

Body weight was measured on a weekly basis, as shown in Figure 1A and B. Compared with the control group, mice exposed to CPZ exhibited a marked reduction in body weight after the first week, and this decline persisted throughout the 6-week experimental period ($P < 0.05$). Throughout the study, body weight in the CPZ group remained consistently lower than that of the controls. In the last 2 weeks of the experiment, treatment with P. oleracea extract at all three doses significantly alleviated CPZ-induced weight loss relative to the CPZ group ($P < 0.05$).

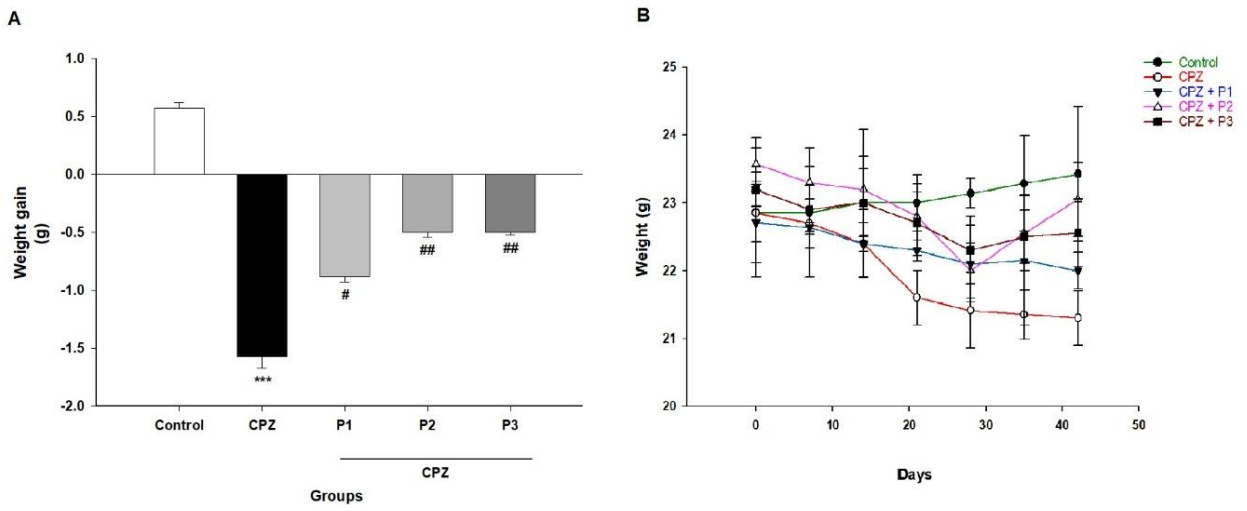

Fig. 1. The body weight changes (n = 7). (A) Weight gain, (B) the body weight variations during 6 weeks. CPZ: CPZ group; CPZ + P1: *P. oleracea* extract 100 mg/kg treated-CPZ group; CPZ + P2: *P. oleracea* extract 200 mg/kg treated-CPZ group; CPZ + P3: *P. oleracea* extract 300 mg/kg treated-CPZ group. $^{\#}P < 0.05$; $^{\#\#}P < 0.01$ compared with the CPZ group; $^{***}P < 0.001$ compared with control group.

3.2. Behavioral tests

3.2.1. The pole test

Motor coordination was assessed using the pole test, and the results are presented in Figure 2A. Mice given CPZ performed worse than the control group in terms of motor coordination ($F(4, 94) = 4.736$, $P < 0.05$). While mice that were treated with 100 and 200 mg/kg *P. oleracea* extract, performed better ($P < 0.05$) versus the CPZ group ($P < 0.05$). However, there was no significant difference for the dose of 300 mg/kg.

3.2.2. Rotarod performance test

Rotarod performance was significantly reduced in the CPZ group, as indicated by a shorter latency to fall compared with controls ($F(4, 83) = 7.041$, $P < 0.001$). Compared to the CPZ group, the rats who took 100, 200, and 300 mg/kg *P. oleracea* extract, spent a lot longer time on the rotating cylinder, indicating improved motor coordination ($P < 0.01$, $P < 0.01$, $P < 0.05$ respectively) (Figure 2B).

3.2.3. Open field test (OFT)

Figure 2C shows that CPZ exposure markedly reduced movement counts and increased immobility time in mice ($F(4, 27) = 7.200$, $P < 0.01$). In contrast, the number of movements of mice that received the *P. oleracea* extract increased meaningfully versus the CPZ group ($P < 0.01$, $P < 0.05$, $P < 0.01$ respectively at 100, 200, and 300 mg/kg).

3.3. Myelin staining (Luxol fast blue staining)

LFB staining demonstrated marked corpus callosum demyelination in the CPZ group compared with the control group ($F(4, 12) = 4.159$, $P < 0.01$). This was demonstrated by a considerable decrease in the intensity of the blue color. *P. oleracea* treatment (3 doses) reduced the demyelination process seen in the CPZ group and protected myelin from damage caused by CPZ ($P < 0.05$). An area of myelin rich in lipids and the beneficial effects of *P. oleracea* on myelin repair are revealed by the blue color's intensity, which is similar to the control group (figure 3A-B).

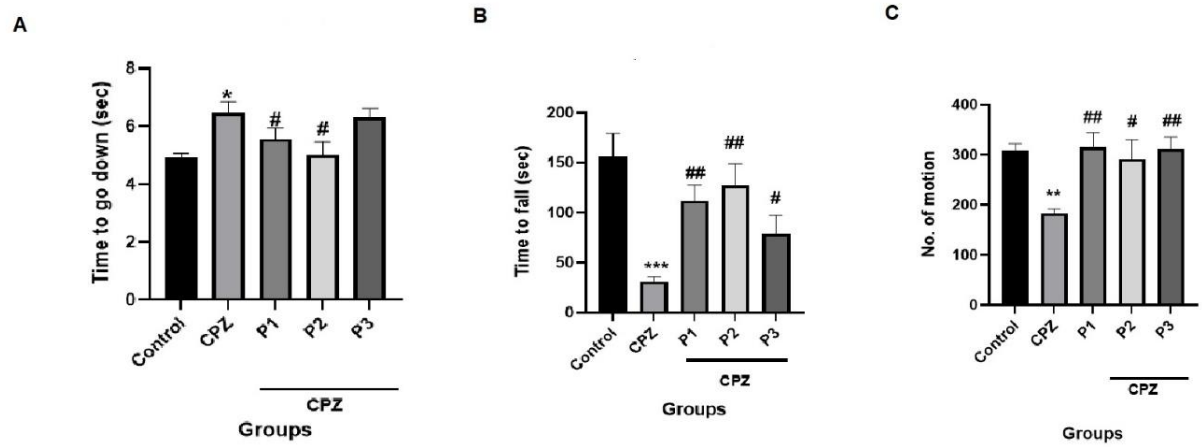

Fig. 2. Behavioral tests (n = 7). A: The pole test, the graph shows the time to reach the floor. B: The rotarod test, the graph demonstrates the latency to fall. C: The open field test, Number of motions is shown. CPZ: CPZ group; CPZ + P1: *P. oleracea* extract 100 mg/kg treated-CPZ group; CPZ + P2: *P. oleracea* extract 200 mg/kg treated-CPZ group; CPZ + P3: *P. oleracea* extract 300 mg/kg treated-CPZ group. #P < 0.05 compared with CPZ group; *P < 0.05 versus the control group.

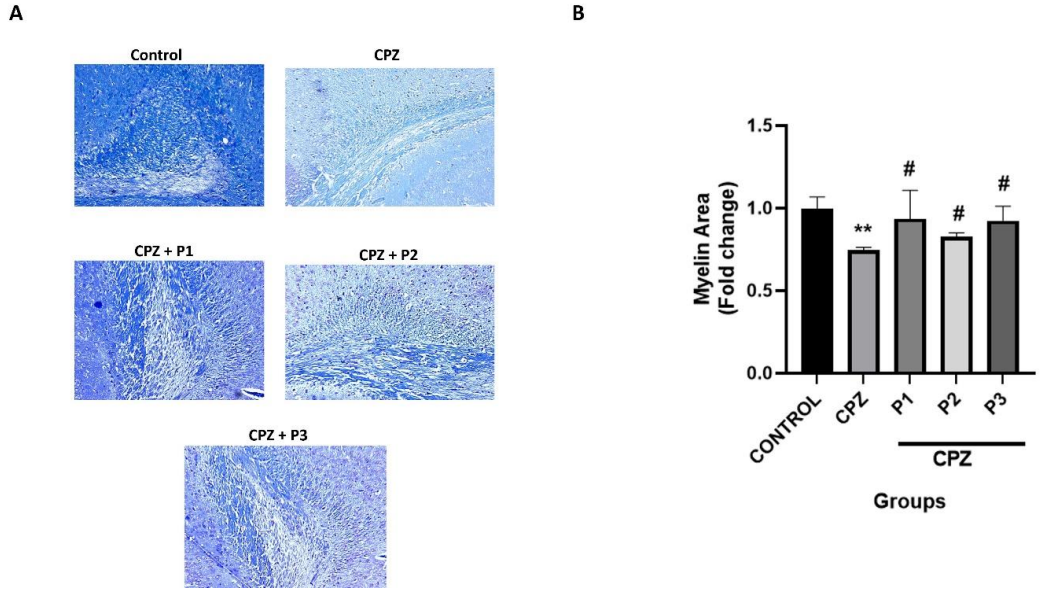

Fig. 3. LFB staining of the corpus callosum (× 100). CPZ causes demyelination, which results in diminished blue color intensity, whereas normal myelin is observed in the corpus callosum in the control and CPZ + P groups (increased blue intensity color). CPZ: CPZ group; CPZ+P1: *P. oleracea* extract 100 mg/kg treated-CPZ group; CPZ+P2: *P. oleracea* extract 200 mg/kg treated-CPZ group; CPZ+P3: *P. oleracea* extract 300 mg/kg treated-CPZ group. #P < 0.05; compared with CPZ group; **P < 0.01 versus control group.

3.4. Hematoxylin and eosin staining (H&E)

Cortical H&E staining was done to evaluate histological alterations involving neurons, oligodendrocytes, and tissue architecture. In the perspective of histological characteristics, according to Figure 4 the cerebral cortex's detrimental consequences of CPZ, including myelin degradation, chromatolysis, aberrant Nissl granules, hyperchromatic nuclei, and vacuolated neurons, were diminished by injection of *P. oleracea* extract, which also revealed near-normal features like what is observed in the control group. In contrast to the CPZ group, the prefrontal cortex morphology, numbers of oligodendrocyte, and myelin density are all normal in the control group.

3.5. Immunohistochemistry assay of HO-1, NQO-1, p-Nrf2 and NF-κB p65

Immunohistochemical staining was performed to examine CPZ-associated changes and the effects of *P. oleracea* treatment to observe the protein expression of HO-1, NQO-1, NF-κB p65, and p-Nrf2 in the corpus callosum of animals' brain.

HO-1 ($F(4, 10) = 5.557$, $P < 0.05$), NQO-1 ($F(4, 14) = 7.417$, $P < 0.001$) and p-Nrf2 ($F(4, 14) = 6.500$, $P < 0.01$) expression in the CPZ group was considerably reduced compared to the control group ($P < 0.05$); Meanwhile, consumption of the *P. oleracea* extract (100 and 200 mg/kg doses) recovered the expression reduction of HO-1 and there was a significant difference compared to the CPZ group ($P < 0.05$) (Figure 5). Moreover, consumption of the extract (100 and 200 mg/kg doses) recovered the expression reduction of NQO-1 compared to CPZ group ($P < 0.001$, $P < 0.05$ respectively) (Figure 6), and also the expression reduction of p-Nrf2 was recovered after consumption of the extract (100 and 200 mg/kg doses) versus to CPZ group (0.1, 0.05 respectively) (Figure 7). In contrast, the corpus callosum NF-κB p65 expression in the CPZ group, was significantly higher than versus the control group ($F(4, 21) = 10.96$, $P < 0.001$). The elevated levels of NF-κB p65 expression noticeably declined after the consumption of *P. oleracea* extract (100 and 200 mg/kg doses) compared CPZ group ($P < 0.01$) (Figure 8).

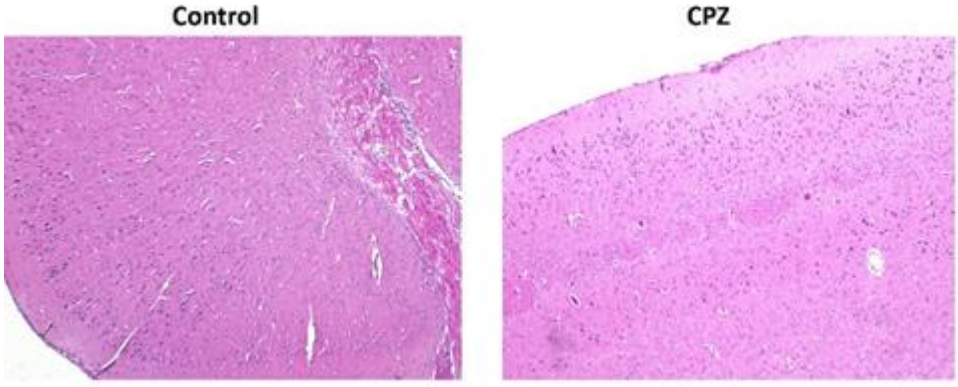

Fig. 4. Photomicrograph of cortex H & E (hematoxylin and eosin staining) (× 100). CPZ causes abnormalities in Nissl substance and neurons whereas the control group and CPZ + P treatment groups show normal structure. CPZ: CPZ group; CPZ+P1: *P. oleracea* extract 100 mg/kg treated-CPZ group; CPZ + P2: *P. oleracea* extract 200 mg/kg treated-CPZ group; CPZ+P3: *P. oleracea* extract 300 mg/kg treated-CPZ group.

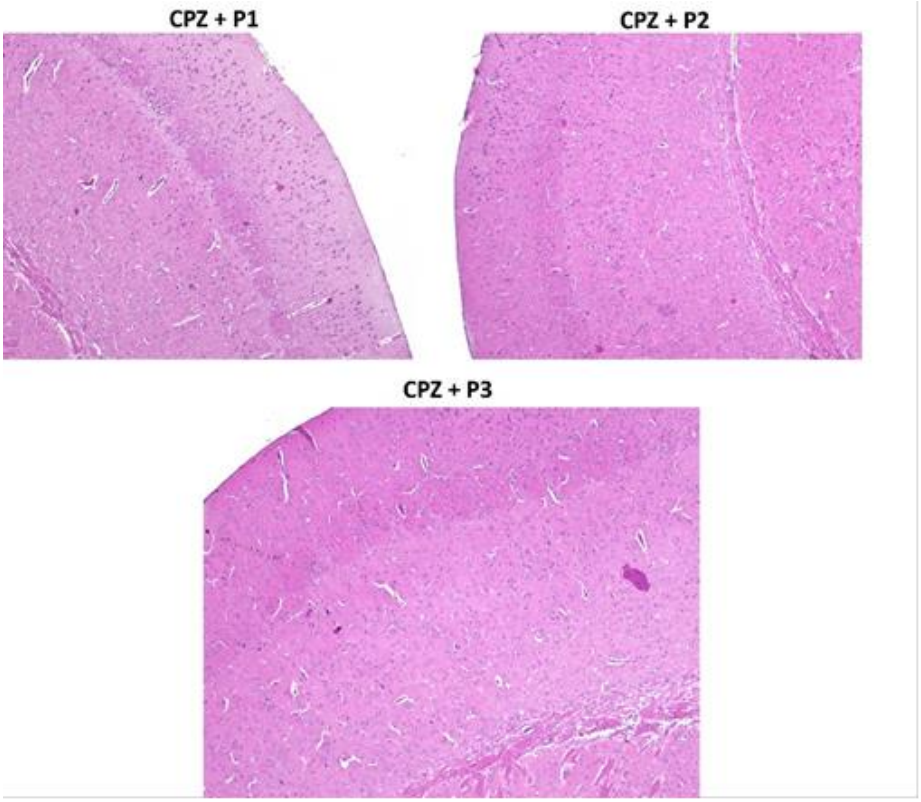

Fig. 4. Photomicrograph of cortex H & E (hematoxylin and eosin staining) (× 100). CPZ causes abnormalities in Nissl substance and neurons whereas the control group and CPZ + P treatment groups show normal structure. CPZ: CPZ group; CPZ+P1: *P. oleracea* extract 100 mg/kg treated-CPZ group; CPZ + P2: *P. oleracea* extract 200 mg/kg treated-CPZ group; CPZ+P3: *P. oleracea* extract 300 mg/kg treated-CPZ group (continued).

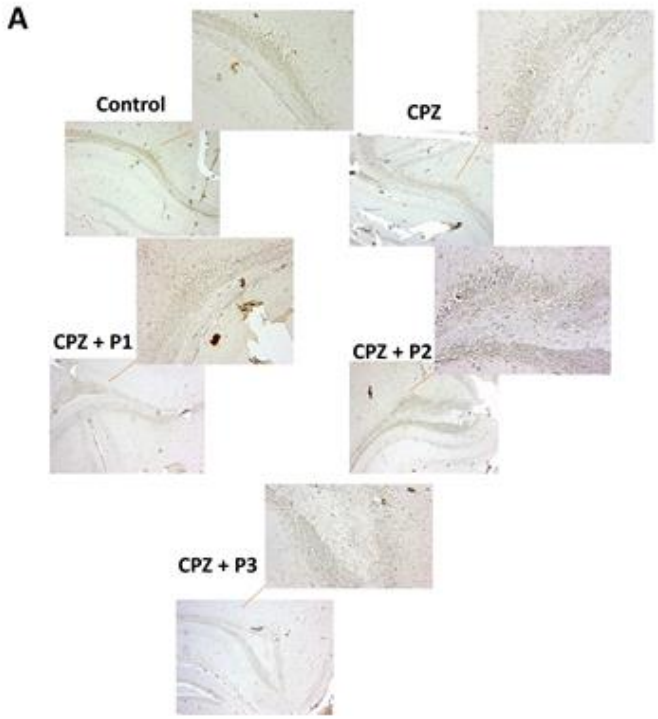

Fig. 5. A

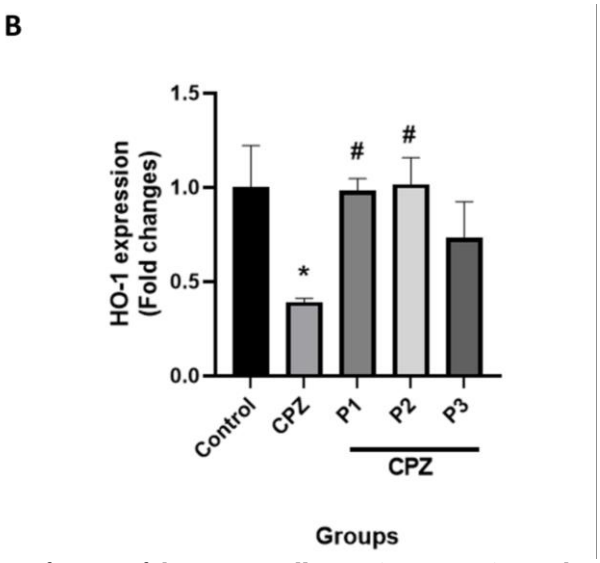

Fig. 5. A: Immunohistochemistry of HO-1 of the corpus callosum (×40, ×100). B: The quantified intensity of HO-1 staining by ImageJ. CPZ: CPZ group; CPZ + P1: *P. oleracea* extract 100 mg/kg treated-CPZ group; CPZ + P2: *P. oleracea* extract 200 mg/kg treated-CPZ group; CPZ + P3: *P. oleracea* extract 300 mg/kg treated-CPZ group. #P < 0.05; compared with CPZ group; *P < 0.05 versus the control group.

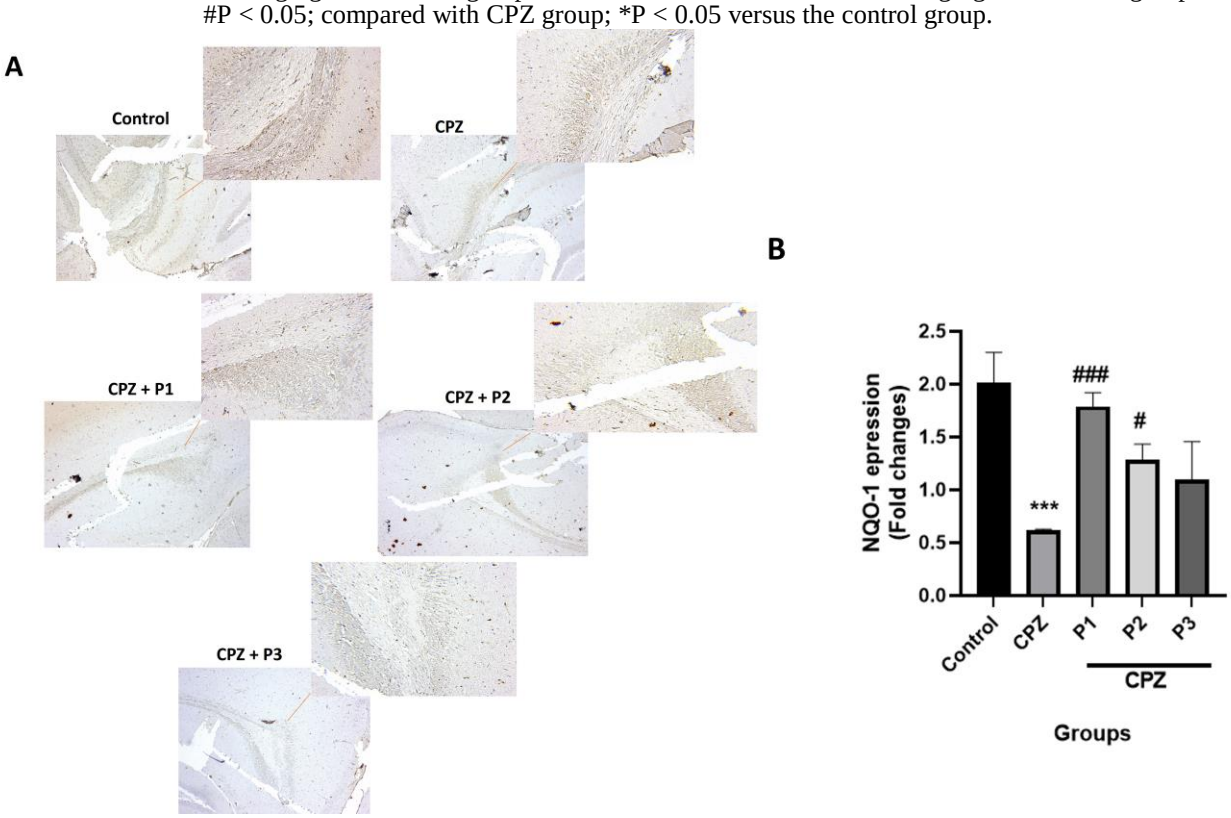

Fig. 6. A: Immunohistochemistry of NQO-1 of the corpus callosum (× 40, × 100). B: The quantified intensity of NQO-1 staining by ImageJ. CPZ: CPZ group; CPZ + P1: *P. oleracea* extract 100 mg/kg treated-CPZ group; CPZ + P2: *P. oleracea* extract 200 mg/kg treated-CPZ group; CPZ + P3: *P. oleracea* extract 300 mg/kg treated-CPZ group. $^{\#}P < 0.05$; $^{\#\#\#}P < 0.001$ compared with CPZ group; $^{***}P < 0.001$ compared with control group.

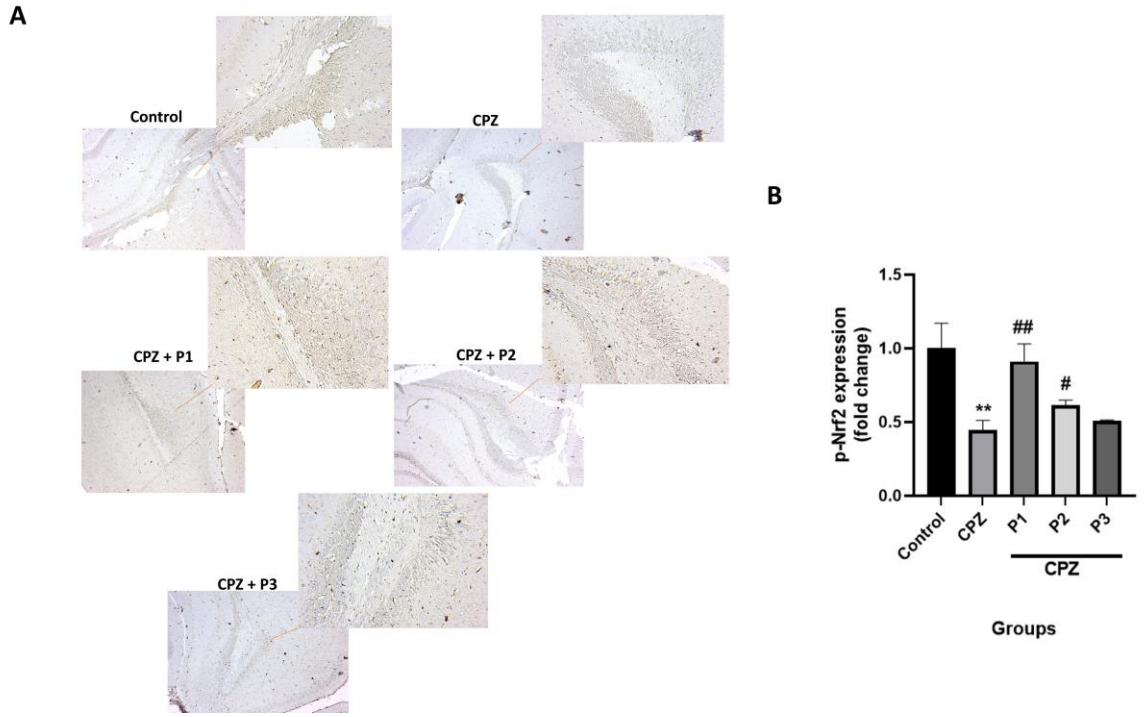

Fig. 7. A: Immunohistochemistry of p-Nrf2 of the corpus callosum (×40, ×100). B: The quantified intensity of p-Nrf2 staining by ImageJ. CPZ: CPZ group; CPZ + P1: *P. oleracea* extract 100 mg/kg treated-CPZ group; CPZ + P2: *P. oleracea* extract 200 mg/kg treated-CPZ group; CPZ + P3: *P. oleracea* extract 300 mg/kg treated-CPZ group. #P < 0.05; ##P < 0.01 compared with CPZ group; **P < 0.01 versus control group.

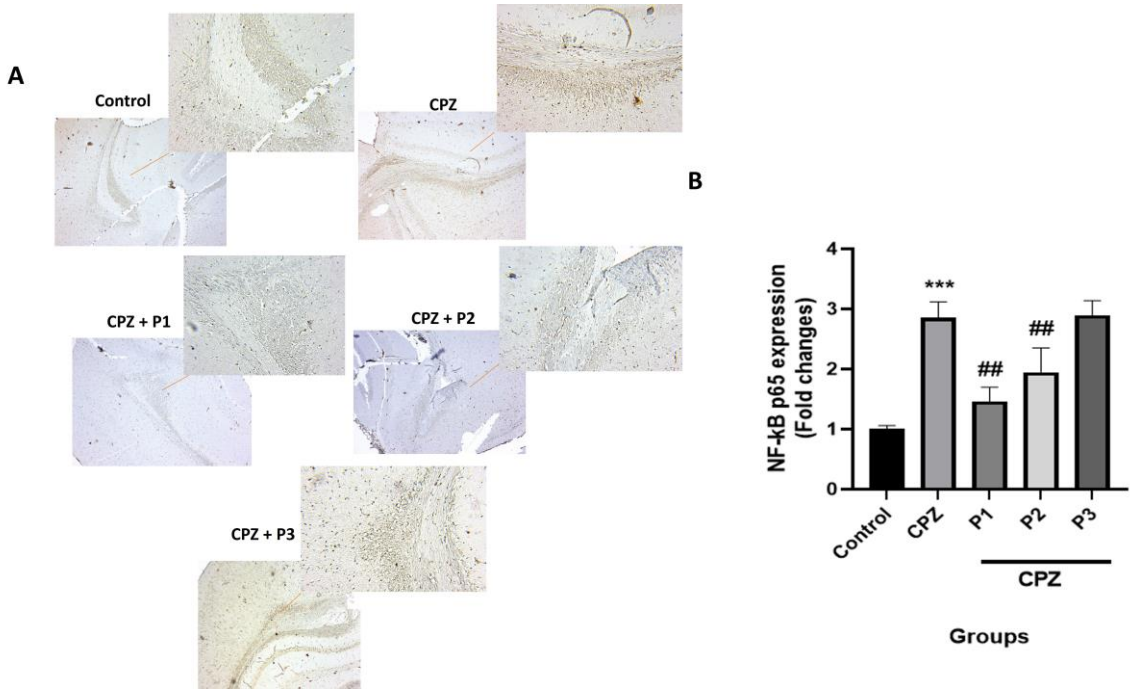

Fig. 8. A: Immunohistochemistry of NF-kB p65 of the corpus callosum (× 40, × 100). B: The quantified intensity of NF-kB p65 staining by ImageJ. CPZ: CPZ group; CPZ + P1: *P. oleracea* extract 100 mg/kg treated-CPZ group; CPZ + P2: *P. oleracea* extract 200 mg/kg treated-CPZ group; CPZ + P3: *P. oleracea* extract 300 mg/kg treated-CPZ group. ##P < 0.01 compared with CPZ group; ***P < 0.001 versus control group.

4. Discussion

Ms is a long-term immune-mediated CNS disorder in which inflammatory demyelination and progressive neurodegenerative processes occur. It is associated with a cascade of pathological events, such as oxidative stress, apoptosis, axonal damage, and gliosis, leading to motor and behavioral impairments [48]. There are numerous animal models, including CPZ, for MS research [49]. By interfering with copper-dependent mitochondrial enzymes, CPZ promotes oxidative stress and oligodendrocyte injury. The resulting cellular damage can contribute to axonal inflammation and functional impairment in demyelinating disorders [25]. In several CPZ animal model studies, results have reported behavioral and motor changes in the CPZ group that were proven by various tests such as rotarod, open field, and pole [45, 50]. Moreover, CPZ reduces the body weight [44]. In the present study, we investigated the capability of *P. oleracea* to ameliorate the dysfunction of behavioral motor and to protect myelin in a CPZ-induced demyelination model. Interestingly, our study's outcomes indicate that consumption of the *P. oleracea* extract led to the compensation of the lost weight. In this study, the 100- and 200-mg/kg doses of *P. oleracea* improved locomotor performance and motor coordination ($P < 0.05$ and $P < 0.01$), whereas the 300 mg/kg dose showed a milder or non-significant effect in certain tasks. These behavioral improvements reflect the extract's ability to reverse neurological damage, potentially by enhancing myelin integrity. Previous evidence suggests that *P. oleracea* can modulate Nrf2 signaling and reduce oxidative cellular injury [51]. Previous research results have shown that demyelination in the mouse brain leads to behavioral dysfunction [52]. Exposure of animals to CPZ has an effective role in increasing the number of demyelinating fibers. Nevertheless, *P. oleracea* consumption significantly reduced these histological changes, which shows the effectiveness of *P. oleracea* in improving the remyelination process. Earlier in vivo findings have associated more extensive CPZ-induced demyelination with greater body-weight loss. Therefore, the attenuation of weight loss observed after *P. oleracea* treatment may reflect partial protection against demyelinating injury [53]. The outcomes of this research showed that CPZ diet leads to the induction of demyelinated areas in the brain which is in accordance with the results of prior studies [45]. *P. oleracea* has been reported to suppress NF-κB/MAPK signaling, limit p65 phosphorylation, and reduce inflammatory mediator production, reduces NO, TNF-, and IL-6 production, and that its anti-inflammatory and antioxidant activities are linked to the Nrf2/HO-1/ NF-κB pathway [54]. In the present study, *P. oleracea* counteracted the CPZ-associated reduction in HO-1, NQO-1, and p-Nrf2 expression and lowered the elevated NF-κB level. This pattern is compatible with antioxidant protection involving Nrf2/HO-1 signaling. It also agrees with previous reports of reduced HO-1 expression during MS exacerbation and the contribution of NF-κB activation to neuroinflammation through immune and glial-cell responses [14-18, 22-24]. In the present work, NF-kB p65 levels were meaningfully higher in the CPZ group. Nevertheless, PO decreased the NF-kB expression [44]. Histological assessments using luxol fast blue and H&E staining confirmed severe demyelination and neuronal damage following CPZ administration ($P < 0.01$). Treatment with *P. oleracea* notably reduced the extent of these alterations ($P < 0.05$), preserving myelin structure and restoring near-normal cellular architecture, demonstrating the effectiveness of *P. oleracea* treatment in enhancing the process of remyelination.

5. Conclusion

This study confirmed that CPZ exposure produced demyelination and movement-related

impairment in mice. P. oleracea improved behavioral performance and reduced histological evidence of myelin injury. The accompanying increase in Nrf2-related antioxidant markers and reduction in NF-κB expression suggest possible antioxidant and anti-inflammatory mechanisms. Further mechanistic and preclinical studies are required before clinical relevance in MS can be considered.

Author contributions

SS Conceptualization, Methodology, Writing - original draft, Writing - review & editing & Supervision. SDA, SZH and SK Data curation, Writing- Original draft preparation. AMF Validation, Investigation & Writing - review & editing. TN & NH Visualization, Investigation & Writing - review & editing.

Conflicts of interest

The authors have no conflict of interest.

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