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Research Article

Exploration of Neuroprotective Effect of Vanillin on Cobalt Induced Neurotoxicity in Rat Model

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Abstract:
Background: Cobalt chloride ($CoCl_2$) induces neurotoxicity by stabilizing hypoxia-inducible factor-1 alpha (HIF-1α), leading to oxidative stress, neuroinflammation, mitochondrial dysfunction, and cognitive impairment. Vanillin (4-hydroxy-3-methoxybenzaldehyde), a naturally occurring phenolic aldehyde isolated from Vanilla planifolia, possesses antioxidant, anti-inflammatory, anti-apoptotic, and neuroprotective properties (Arya et al., 2021; Iannuzzi et al., 2023).
Objective: To investigate the neuroprotective potential of vanillin against $CoCl_2$-induced neurotoxicity in Sprague Dawley rats.
Material and Methods: Male Sprague Dawley rats (170–200 g; n=6/group) were divided into four groups: normal control, negative control ($CoCl_2$ 40 mg/kg/day p.o. for 14 days), $CoCl_2$ + vanillin 100 mg/kg/day, and $CoCl_2$ + vanillin 200 mg/kg/day. Behavioral assessments included Morris Water Maze (MWM), Elevated Plus Maze (EPM)
Results:$CoCl_2$ significantly increased escape latency (71 ± 1.2 s; $p < 0.01$) and reduced retention time (13 ± 1.4 s; $p < 0.01$) in the MWM, and elevated transfer latency (68.9 ± 3.4 s; $p < 0.01$) in the EPM, confirming impaired spatial memory and anxiety-like behaviour. Vanillin treatment dose-dependently reversed these deficits; the 200 mg/kg dose maximally restored escape latency (27 ± 0.75 s), retention time (30 ± 1.4 s), and transfer latency (27.8 ± 1.8 s) compared to the negative control (all $p < 0.01$).
Conclusion: Vanillin demonstrated significant dose-dependent neuroprotective effects against $CoCl_2$-induced neurotoxicity through antioxidant, anti-inflammatory, and anti-apoptotic mechanisms. These findings support the potential therapeutic role of vanillin in oxidative stress-mediated neurodegenerative disorders.
Keywords: Vanillin; Cobalt chloride; Neurotoxicity; Neuroprotection; HIF-1α

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1. Introduction

Neurodegenerative disorders including Alzheimer's disease (AD), Parkinson's disease (PD), Huntington's disease, and amyotrophic lateral sclerosis affect hundreds of millions worldwide, characterised by progressive neuronal loss leading to cognitive and motor disability (Lamptey et al., 2022). Key pathological mechanisms include excessive ROS generation, mitochondrial dysfunction, neuroinflammation, and apoptotic cascade activation (Gadhave et al., 2024).

Among environmental neurotoxicants, cobalt exerts profound toxicity at elevated concentrations from industrial exposure, dietary contamination, and orthopaedic implant degradation (Leyssens et al., 2017). Cobalt stabilises HIF-1α by inhibiting prolyl hydroxylase domain (PHD) enzymes, inducing chemical hypoxia that drives ROS overproduction, glutathione depletion, and accumulation of amyloid-beta

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and hyperphosphorylated tau, culminating in hippocampal neurodegeneration and cognitive impairment (Tang et al., 2023; Gomez-Arnaiz et al., 2022; Akinrinde et al., 2023).

Vanillin (4-hydroxy-3-methoxybenzaldehyde), a phenolic compound from Vanilla planifolia, is recognised as safe for human use (Ho et al., 2011; Arya et al., 2021). It modulates NF-κB signalling, regulates the Bcl-2/Bax pathway, preserves mitochondrial integrity, and crosses the blood-brain barrier (Bezerra-Filho et al., 2019; Iannuzzi et al., 2023). Neuroprotective efficacy has been demonstrated across multiple models including rotenone-, bromate-, iron-, aluminium chloride-, and isoproterenol-induced neurotoxicity, as well as spinal cord injury and Alzheimer's pathology (Dhanalakshmi et al., 2015; Ben Saad et al., 2017; Salau et al., 2020; Afolabi et al., 2025; Abdelghafour et al., 2025; Chen et al., 2019; Iannuzzi et al., 2023).

However, vanillin's neuroprotective efficacy against cobalt-induced neurotoxicity remains unexplored. The present study therefore aimed to evaluate the protective effect of vanillin against $CoCl_2$-induced neurotoxicity in rats and elucidate its possible mechanisms of action.

2. Materials And Methods

2.2 In Vivo Study

2.2.1 Animals

Healthy male Sprague Dawley rats weighing 170–200 g and aged 8 weeks were obtained and maintained in polypropylene cages under controlled laboratory conditions, including a 12-hour light/dark cycle, temperature of 25 ± 2°C, and relative humidity of 60 ± 5%. The animals were provided with standard pellet feed and water freely throughout the study.The rats were housed and treated according to the rules and regulations of CCSEA and IAEC. The protocol for all the animal study was approved by Institutional Animal Ethics Committee (IAEC) with research project number 650/Po/Re/S-2002/2026/CCSEA/09.

2.2.2 Experimental Design

A total of 24 rats were randomly divided into four groups, with six animals in each group..

- **Group 1 – Normal Control:** Received distilled water orally for 14 days.
- **Group 2 – Negative Control:** Received $CoCl_2$ 40 mg/kg/day p.o for 14 consecutive days to induce neurotoxicity (Oria et al., 2023).
- **Group 3 – $CoCl_2$ + Vanillin 100 mg/kg:** Received $CoCl_2$ 40 mg/kg/day + vanillin 100 mg/kg/day p.o. for 14 days (Tripathi et al., 2022).
- **Group 4 – $CoCl_2$ + Vanillin 200 mg/kg:** Received $CoCl_2$ 40 mg/kg/day + vanillin 200 mg/kg/day p.o. for 14 days (Tripathi et al., 2022).

Baseline behavioural assessments were conducted on Day 0 for all animals prior to treatment initiation. Cobalt chloride induces neurotoxicity by stabilising HIF-1α and generating excessive ROS, mimicking hypoxic neurodegeneration. Vanillin doses were selected based on established experimental literature demonstrating neuroprotective efficacy (Tripathi et al., 2022; Arya et al., 2021).

2.2.3 Behavioural Assessments

a) **Morris Water Maze (MWM):** Spatial learning and memory were evaluated using a circular water maze with a hidden submerged platform. Escape latency and time spent in the target quadrant were recorded to assess hippocampal-dependent memory (Morris, 1984; Vorhees & Williams, 2006).

b) **Elevated Plus Maze (EPM):** Anxiety and memory were assessed using an elevated plus-shaped maze with open and closed arms. Transfer latency from open to closed arm was recorded on Day 0 and Day 14 using Image EP software (Pellow et al., 1985; Walf & Frye, 2007).

2.2.6 Statistical Analysis

All experimental results were presented as Mean ± SD. Statistical comparisons among groups were carried out using one-way analysis of variance (ANOVA) followed by Dunnett's multiple comparison test. Differences were considered statistically significant at $p < 0.01$. Data analysis was performed using GraphPad Prism software.

3. Results

3.2 In Vivo Behavioral Results

3.2.1 Morris Water Maze (MWM)

Table No 2.Effect of Cobalt Chloride and Vanillin in the Morris Water Maze (MWM) Test in Rats

Group	Escape Latency Day 0 (s)	Escape Latency Day 14 (s)	Retention Time Day 0 (s)	Retention Time Day 14 (s)
Normal Control	50±0.5	42±2.45**	44±1.4	44±1.4
Negative Control ($CoCl_2$)	52±1.9ns	71±1.2@	42±1.8	13±1.4@
$CoCl_2$+Vanillin 100 mg/kg	52±1.4 ns	38±2.3**	42±1.8	22±1.4**
$CoCl_2$+Vanillin 200 mg/kg	52±1.4ns	27±0.75**	43±2.5	30±1.4**

Escape Latency :-Retention Time:-

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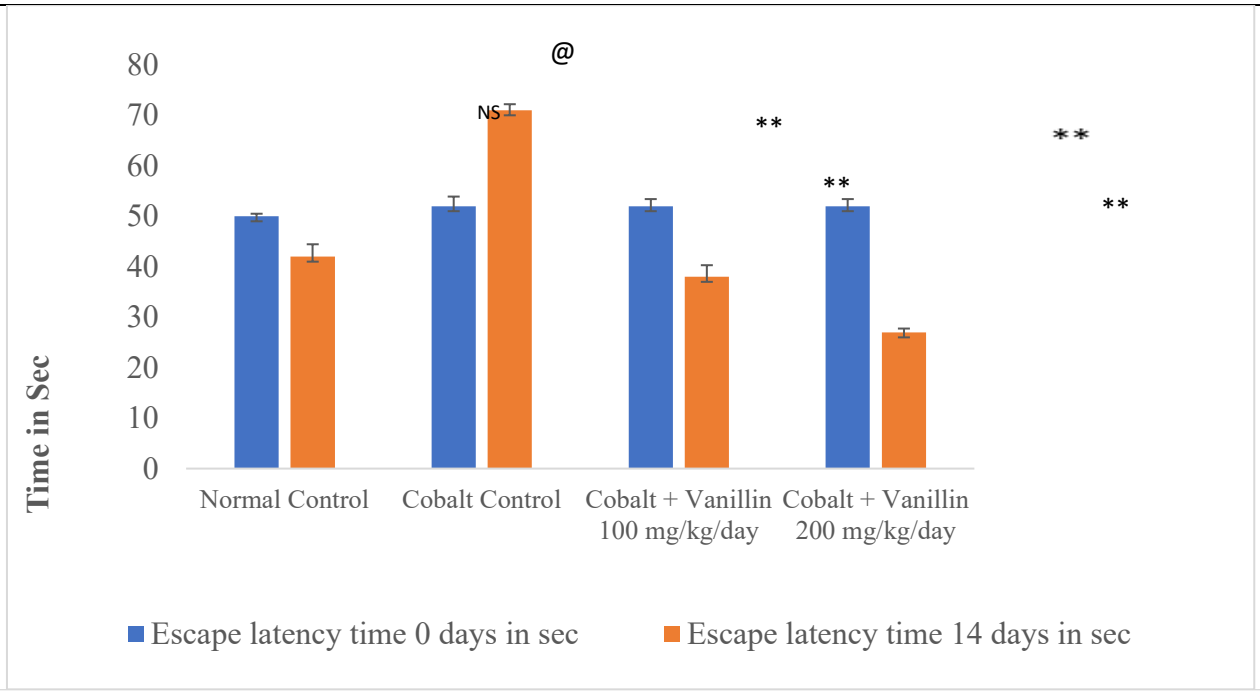

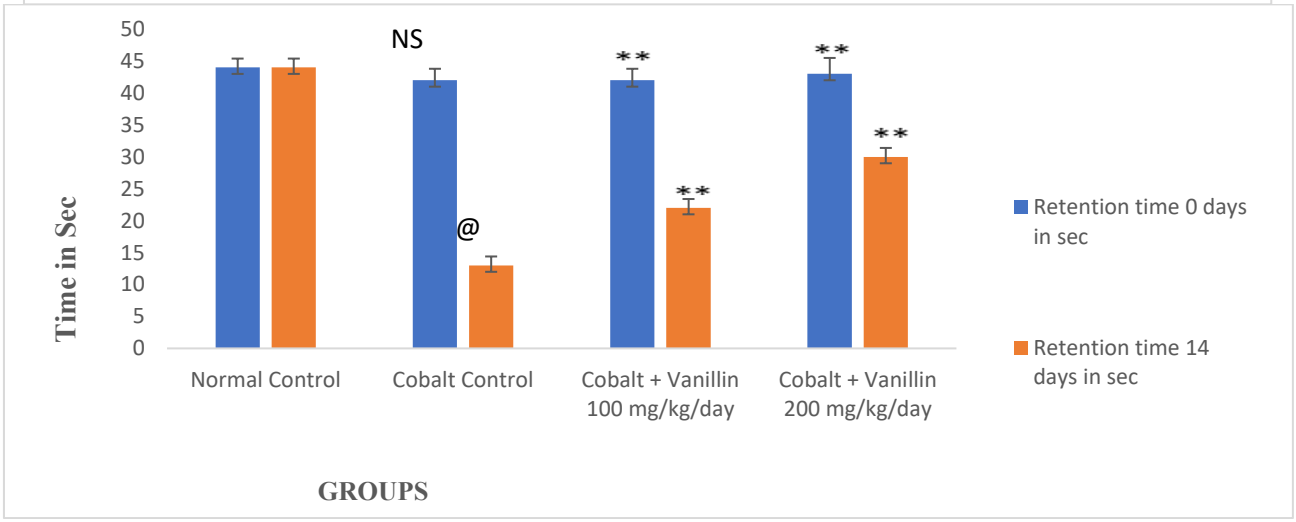

Table no 2. Effect of vanillin on MWM parameters. Values = Mean ± SD. NS = Non-significant ($p>0.05$); @$p<0.01$ vs. Normal Control; **$p<0.01$ vs. Negative Control.

No significant difference (NS; $p>0.05$) was observed among groups on Day 0. $CoCl_2$ significantly ($p<0.01$) increased escape latency from (52±1.9 to 71±1.2) and reduced retention time from (42±1.8 to 13±1.4) , indicating impaired spatial learning and memory. Vanillin treatment significantly and dose-dependently improved these deficits. The 200 mg/kg dose showed maximum improvement with escape latency of (27±0.75) and retention time of (30±1.4) , indicating restoration of hippocampal-dependent memory.

3.2.2 Elevated Plus Maze (EPM)

Table No 3.Effect of Cobalt Chloride and Vanillin on Transfer Latency in the Elevated Plus Maze (EPM) Test in Rats

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Transfer Latency

Group	Transfer Latency Day 0 (s)	Transfer Latency Day 14 (s)
Normal Control	45±3.2	41.8±1.6
Negative Control ($CoCl_2$)	49.1±2.3 NS	68.9±3.4@
$CoCl_2$+Vanillin 100 mg/kg	49.1±2.3 ns	39.5±2.3**
$CoCl_2$+Vanillin 200 mg/kg	49.0±2.8 ns	27.8±1.8**

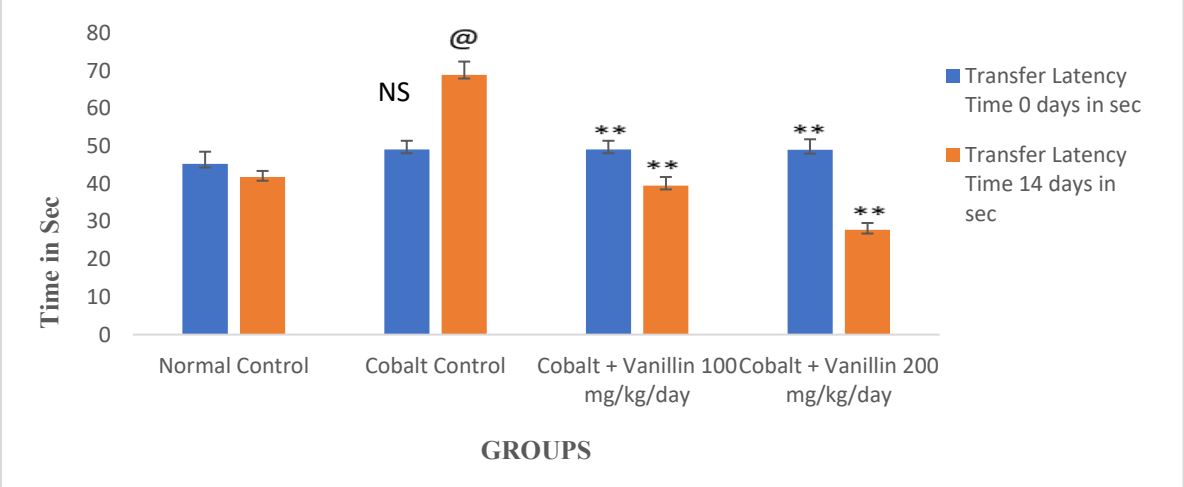

Table no 3.Effect of vanillin on EPM transfer latency. Values = Mean ± SD. NS = Non-significant ($p>0.05$); @$p<0.01$ vs. Normal Control; **$p<0.01$ vs. Negative Control.

No significant difference (NS; $p>0.05$) was observed among groups on Day 0. $CoCl_2$ significantly ($p<0.01$) increased transfer latency from 49.1±2.3 to 68.9±3.4 , indicating impaired memory and anxiety-like behaviour. Vanillin treatment significantly and dose-dependently reduced transfer latency at 100 mg/kg (39.5±2.3) and 200 mg/kg (27.8±1.8), demonstrating improved memory consolidation and anxiolytic activity.

4. Discussion

Neurons are post-mitotic, metabolically active cells highly vulnerable to oxidative injury due to their elevated lipid content and limited regenerative capacity (Uttara et al., 2009). Neuronal damage occurs through lipid peroxidation, mitochondrial dysfunction, and caspase-dependent apoptosis (Mattson &Kriegler, 2000; Orrenius et al., 2003). These mechanisms ultimately result in synaptic loss, axonal degeneration, and behavioral impairment (Coleman & Freeman, 2010). Several experimental neurotoxicity models, including heavy metal-induced, oxidative stress-induced, and chemically induced neuronal injury models, have been established to study neurodegeneration and evaluate neuroprotective agents in rodents (Vorhees & Williams, 2006; Costa & Giordano, 2007). Among these, cobalt chloride ($CoCl_2$)-induced neurotoxicity is a widely accepted model for investigating oxidative stress-mediated neuronal damage and cognitive dysfunction.

Cobalt is a well-established neurotoxic heavy metal capable of generating ROS through redox cycling and Fenton-like oxidative reactions, initiating neuronal lipid peroxidation and protein oxidation (Valko et al., 2005; Leyssens et al., 2017). Cobalt stabilizes hypoxia-inducible factor-1 alpha (HIF-1α) by inhibiting prolyl hydroxylase domain (PHD) enzymes. Accumulated HIF-1α activates pro-oxidant and pro-apoptotic genes including

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BNIP3, driving ROS overproduction, glutathione depletion, and mitochondrial apoptosis (Semenza, 2003; Tang et al., 2023). This establishes a self-amplifying oxidative feed-forward loop that perpetuates neuronal damage (Nanduri et al., 2013).

Adult male Sprague Dawley rats were used due to their established sensitivity toward hippocampal neurotoxicity and behavioral impairments (Vorhees& Williams, 2006). Cobalt chloride ($CoCl_2$) was administered to induce experimental neurotoxicity, a widely used animal model for studying oxidative stress-mediated neuronal injury and memory dysfunction. Vanillin (4-hydroxy-3-methoxybenzaldehyde) was administered orally at doses of 100 mg/kg and 200 mg/kg to evaluate its neuroprotective potential against cobalt-induced neuronal damage.

Several established experimental studies have shown that cobalt chloride ($CoCl_2$)-induced neurotoxicity leads to marked deficits in cognition and behavior in rodents, primarily due to oxidative stress and neuronal damage (Rani et al., 2014). Behavioral paradigms such as the Morris Water Maze and Elevated Plus Maze are widely accepted and validated methods for evaluating learning, memory, and anxiety-like behavior in neurotoxicity studies (Vorhees & Williams, 2006).

In the present study, behavioral assessments were performed to evaluate the protective effect of vanillin against cobalt-induced neurotoxicity in male Sprague Dawley rats. The Morris Water Maze (Morris, 1984) was used to assess hippocampal-dependent spatial learning and memory. Cobalt-exposed rats showed significantly increased escape latency and reduced time spent in the target quadrant, indicating impaired learning and memory (Rani et al., 2014). The Elevated Plus Maze (Pellow et al., 1985) demonstrated anxiety-like behavior in cobalt-treated animals through decreased open-arm entries and reduced time spent in open arms.

Treatment with vanillin at doses of 100 mg/kg and 200 mg/kg significantly improved behavioral performance in the experimental paradigms. Vanillin-treated animals exhibited reduced escape latency, increased target quadrant retention, and improved open-arm exploration compared with the cobalt-treated group. The 200 mg/kg dose demonstrated greater neuroprotective efficacy, suggesting dose-dependent amelioration of cobalt-induced neurobehavioral deficits.

Vanillin, a naturally occurring phenolic aldehyde derived from vanilla beans, exerts neuroprotection through antioxidant, anti-inflammatory, and anti-apoptotic mechanisms (Iannuzzi et al., 2023). Vanillin inhibits pro-inflammatory cytokines such as TNF-α, IL-1β, and IL-6 (Bezerra et al., 2019). Preservation of mitochondrial membrane integrity and ATP synthesis further contributes to its neuroprotective activity (Dhanalakshmi et al., 2015; Iannuzzi et al., 2023).

5. Conclusion

The present study demonstrates that vanillin exerts significant dose-dependent neuroprotective effects against cobalt chloride-induced neurotoxicity in Sprague Dawley rats. Vanillin treatment significantly improved recognition memory, spatial learning, anxiety-associated behavior, and motor coordination in cobalt-exposed animals. The neuroprotective effects are likely mediated through antioxidant, anti-inflammatory, anti-apoptotic, and mitochondrial protective mechanisms. These findings support the

therapeutic potential of vanillin in oxidative stress-mediated neurodegenerative disorders and warrant further biochemical and molecular investigations

References

1. Abdelghafour, A. M., Mahrous, M., & Zaher, M. E. (2025). Vanillin alleviates oxidative stress-mediated neuronal pyroptosis induced in rats by isoproterenol via SIRT1/NOX4/ROS/TXNIP/NLRP3 signaling pathway. Food & Function, 16(13), 5312–5325.
2. Afolabi, O. B., Jaiyesimi, K. F., Olasehinde, O. R., Olaoye, O. A., Ekakitie, L. I., Adetunji, A. E., & Oloyede, O. I. (2025). Caffeine, vanillin and their combination modulate purinergic enzyme activities, mRNA expressions of some synaptic-entry proteins and histomorphological status of hippocampal tissue in aluminum chloride-induced neurotoxicity in rats. Pharmacological Research – Natural Products, 6, 100201.
3. Akinrinde, A., Adigun, K., & Mustapha, O. (2023). Cobalt-induced neuro-behavioral alterations are accompanied by profound Purkinje cell and gut-associated responses in rats. Environmental Analysis, Health and Toxicology, 38, e2023010.
4. Antunes, M., & Biala, G. (2012). The novel object recognition memory: Neurobiology, test procedure, and its modifications. Cognitive Processing, 13(2), 93–110.
5. Arya, S. S., Rookes, J. E., Cahill, D. M., & Lenka, S. K. (2021). Vanillin: A review on the therapeutic prospects of a popular flavouring molecule. Advances in Traditional Medicine, 21(3), 1–17.
6. Ben Saad, H., Kharrat, N., Driss, D., Gargouri, M., Marrakchi, R., Jammoussi, K., et al. (2017). Effects of vanillin on potassium bromate-induced neurotoxicity in adult mice: impact on behavior, oxidative stress, genes expression, inflammation and fatty acid composition. Archives of Physiology and Biochemistry, 123(3), 165–174.
7. Bezerra-Filho, C. S., Barboza, J. N., Souza, M. T., Sabry, P., Ismail, N. S., & de Sousa, D. P. (2019). Therapeutic potential of vanillin and its main metabolites to regulate the inflammatory response and oxidative stress. Mini-Reviews in Medicinal Chemistry, 19(20), 1681–1693.
8. Block, M. L., Zecca, L., & Hong, J. S. (2007). Microglia-mediated neurotoxicity: uncovering the molecular mechanisms. Nature Reviews Neuroscience, 8(1), 57–69.
9. Chen, H., Zheng, J., & Ma, J. (2019). Vanillin ameliorates changes in HIF-1α expression and neuronal apoptosis in a rat model of spinal cord injury. Restorative Neurology and Neuroscience, 37(1), 21–29.
10. Coleman, M. P., & Freeman, M. R. (2010). Wallerian degeneration, axonal degeneration, and neuronal death. Cold Spring Harbor Perspectives in Biology, 2(1), a001735.
11. Costa, L. G., & Giordano, G. (2007). Developmental neurotoxicity: Some old and new issues. ISRN Toxicology, 2007, 814795.
12. Daina, A., Michielin, O., & Zoete, V. (2019). SwissTargetPrediction: updated data and new features for efficient prediction of protein targets of small molecules. Nucleic Acids Research, 47(W1), W357–W364.
13. Deacon, R. M. J. (2013). Measuring motor coordination in mice. Journal of Visualized Experiments, 75, e2609.

14. Dhanalakshmi, C., Manivasagam, T., Nataraj, J., Justin Thenmozhi, A., & Essa, M. M. (2015). Neurosupportive role of vanillin, a natural phenolic compound, on rotenone induced neurotoxicity in SH-SY5Y neuroblastoma cells. Evidence-Based Complementary and Alternative Medicine, 2015, 626028.
15. Dunham, N. W., & Miya, T. S. (1957). A note on a simple apparatus for detecting neurological deficit in rats and mice. Journal of the American Pharmaceutical Association, 46(3), 208–209.
16. Ennaceur, A., & Delacour, J. (1988). A new one-trial test for neurobiological studies of memory in rats. Behavioural Brain Research, 31(1), 47–59.
17. Gadhave, D. G., Sugandhi, V. V., Jha, S. K., Nangare, S. N., Gupta, G., Singh, S. K., et al. (2024). Neurodegenerative disorders: Mechanisms of degeneration and therapeutic approaches with their clinical relevance. Ageing Research Reviews, 99, 102357.
18. Gella, A., & Durany, N. (2009). Oxidative stress in Alzheimer disease. Cell Adhesion & Migration, 3(1), 88–93.
19. Gomez-Arnaiz, S., Tate, R. J., & Grant, M. H. (2022). Cobalt neurotoxicity: Transcriptional effect of elevated cobalt blood levels in the rodent brain. Toxics, 10(2), 59.
20. Gulcin, I. (2012). Antioxidant activity of food constituents: an overview. Archives of Toxicology, 86(3), 345–391.
21. Ho, K., Yazan, L. S., Ismail, N., & Ismail, M. (2011). Toxicology study of vanillin on rats via oral and intra-peritoneal administration. Food and Chemical Toxicology, 49(1), 25–30.
22. Hopkins, A. L. (2008). Network pharmacology: The next paradigm in drug discovery. Nature Chemical Biology, 4(11), 682–690.
23. Iannuzzi, C., Liccardo, M., &Sirangelo, I. (2023). Overview of the role of vanillin in neurodegenerative diseases and neuropathophysiological conditions. International Journal of Molecular Sciences, 24(3), 1817.
24. Kafali, M., Finos, M. A., &Tsoupras, A. (2024). Vanillin and its derivatives: A critical review of their anti-inflammatory, anti-infective, wound-healing, neuroprotective, and anti-cancer health-promoting benefits. Nutraceuticals, 4(4), 522–561.
25. Kandel, E. R., Koester, J. D., Mack, S. H., & Siegelbaum, S. A. (2021). Principles of Neural Science (6th ed.). McGraw-Hill.
26. Kroemer, G., Galluzzi, L., & Brenner, C. (2007). Mitochondrial membrane permeabilization in cell death. Physiological Reviews, 87(1), 99–163.
27. Lamptey, R. N., Chaulagain, B., Trivedi, R., Gothwal, A., Layek, B., & Singh, J. (2022). A review of the common neurodegenerative disorders: Current therapeutic approaches and the potential role of nanotherapeutics. International Journal of Molecular Sciences, 23(3), 1851.
28. Leyssens, L., Vinck, B., Van Der Straeten, C., Wuyts, F., & Maes, L. (2017). Cobalt toxicity in humans—A review of the potential sources and systemic health effects. Toxicology, 387, 43–56.
29. Li, S., & Zhang, B. (2013). Traditional Chinese medicine network pharmacology: theory, methodology and application. Chinese Journal of Natural Medicines, 11(2), 110–120.

30. Lin, M. T., & Beal, M. F. (2006). Mitochondrial dysfunction and oxidative stress in neurodegenerative diseases. Nature, 443(7113), 787–795.
31. Mattson, M. P., & Kriegler, T. B. (2000). Apoptotic and anti-apoptotic mechanisms in neurons. Journal of Cell Science, 113, 457–469.
32. Morris, R. (1984). Developments of a water-maze procedure for studying spatial learning in the rat. Journal of Neuroscience Methods, 11(1), 47–60.
33. Nanduri, J., et al. (2013). HIF-1α activation by intermittent hypoxia requires NADPH oxidase stimulation. Antioxidants & Redox Signaling, 18, 1595–1604.
34. Ohkawa, H., Ohishi, N., & Yagi, K. (1979). Assay for lipid peroxides in animal tissues by thiobarbituric acid reaction. Analytical Biochemistry, 95(2), 351–358.
35. Oria, R. B., et al. (2023). Neurological and cognitive consequences of cobalt exposure: experimental models and mechanistic insights. Neurotoxicology, 98, 45–60.
36. Orrenius, S., Zhivotovsky, B., & Nicotera, P. (2003). Regulation of cell death: the calcium-apoptosis link. Nature Reviews Molecular Cell Biology, 4(7), 552–565.
37. Pellow, S., Chopin, P., File, S. E., & Briley, M. (1985). Validation of open:closed arm entries in an elevated plus-maze as a measure of anxiety in the rat. Journal of Neuroscience Methods, 14(3), 149–167.
38. Poewe, W., Seppi, K., Tanner, C. M., Halliday, G. M., Brundin, P., Volkmann, J., et al. (2017). Parkinson disease. Nature Reviews Disease Primers, 3, 17013.
39. Rani, A., et al. (2014). Cobalt chloride-induced behavioural and neurochemical alterations in rats. Experimental and Toxicologic Pathology, 66, 137–143.
40. Semenza, G. L. (2003). Targeting HIF-1 for cancer therapy. Nature Reviews Cancer, 3(10), 721–732.
41. Simonsen, L. O., Harbak, H., & Bennekou, P. (2012). Cobalt metabolism and toxicology—a brief update. Science of the Total Environment, 432, 210–215.
42. Tang, Z., He, D., Miao, J., et al. (2023). Cobalt chloride-induced chemical hypoxia promotes accumulation of amyloid-β and hyperphosphorylated-tau via autophagic flux impairment. Aging, 15(12), 5671–5695.
43. Tripathi, A.S., Awasthi, S., Maurya, R.K., Yasir, M., Mohapatra, L., & Srivastav, V. (2022). Protective effect of vanillin on the management of cecal ligation and puncture induced sepsis rat model. Microbial Pathogenesis, 165, 105493.
44. Uttara, B., Singh, A. V., Zamboni, P., & Mahajan, R. T. (2009). Oxidative stress and neurodegenerative diseases: A review of upstream and downstream antioxidant therapeutic options. Current Neuropharmacology, 7(1), 65–74.
45. Valko, M., Morris, H., & Cronin, M. T. D. (2005). Metals, toxicity and oxidative stress. Current Medicinal Chemistry, 12(10), 1161–1208.

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46. Vorhees, C. V., & Williams, M. T. (2006). Morris water maze: Procedures for assessing spatial and related forms of learning and memory. Nature Protocols, 1(2), 848–858.

47. Walf, A.A., & Frye, C.A. (2007). The use of the elevated plus maze as an assay of anxiety-related behavior in rodents. Nature Protocols, 2, 322–328. DOI: 10.1038/nprot.2007.44

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