



Research Paper

Antinociceptive Role of β -alanine in Hot Plate-induced Pain in Mice



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ABSTRACT

Introduction: Pain is a distressing sensation that arises as a consequence of damage to bodily tissues, whereas β -alanine is an amino acid that is both nonessential and non-proteinogenic, functioning as an inhibitory neurotransmitter. Hence, the purpose of this investigation was to ascertain the analgesic role of β -alanine in the context of pain induced by exposure to a hot plate in mice.

Materials & Methods: A total of 85 male NMRI mice were employed in five separate experiments. In the initial experiment, the mice were administered saline, β -alanine at doses of 15 mg/kg, 30 mg/kg, and 45 mg/kg, as well as morphine at a dose of 5 mg/kg. In the second experiment, the mice were given saline, β -alanine at a dose of 30 mg/kg once daily for a duration of 7 days, naloxone at a dose of 2 mg/kg, and naloxone in combination with β -alanine at a dose of 30 mg/kg. For experiments 3-5, the mice were subjected to flumazenil (5 mg/kg), L-NAME (10 mg/kg), and 6-hydroxydopamine (100 mg/kg) instead of naloxone. Importantly, the mice received β -alanine once daily for a period of 7 days, whereas all the antagonists were administered 30 minutes prior to the respective tests. Subsequently, the hot plate test was employed to measure pain responses, both prior to and at 10, 15, 20, 25, and 30 minutes following the injections, by recording the response latency time. At the end of the experiments, blood samples were obtained and used to determine the levels of serum malondialdehyde (MDA), superoxide dismutase (SOD), glutathione peroxidase (GPx), total antioxidant status (TAS), and nitric oxide (NO).

Results: The findings revealed that morphine led to a significant increase in the latency time ($P < 0.05$), similarly, β -alanine resulted in a notable increase in the latency time ($P < 0.05$). Interestingly, pretreatment with β -alanine followed by naloxone resulted in a decrease in the latency time ($P < 0.05$). Similarly, pretreatment with β -alanine followed by flumazenil

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significantly reduced the latency time on the hot plate ($P<0.05$). Furthermore, pretreatment with β -alanine followed by L-NAME led to an increase in the latency time ($P<0.05$). Administration of β -alanine resulted in a decrease in serum NO and MDA levels, and an increase in SOD, GPx, and TAS levels ($P<0.05$).

Conclusion: Collectively, these findings suggest that the antinociceptive activity of β -alanine is mediated through GABAergic mechanisms and NO production, and possibly through its antioxidant properties, in the context of pain induced by exposure to a hot plate in mice.

1. Introduction

The sensation of pain serves as a defensive mechanism that has evolved to safeguard tissues against actual or potential harm, thereby playing a crucial role in the survival of various animal species. Moreover, pain also manifests as a symptom in numerous diseases, serving as an indicator that there is an underlying issue within the organism [1]. Nevertheless, the persistence of pain can potentially lead to the development of chronic conditions and result in alterations in both the central nervous system and peripheral tissues [2]. Dysfunction in nociceptive signaling at different levels of the nervous system can be identified as the primary cause of pathological pain. Extensive documentation has confirmed that the opioidergic, GABAergic, dopaminergic, and nitrgergic systems are responsible for providing relief from pain within the spinal cord [3]. Despite the widespread prescription of opioids and nonsteroidal anti-inflammatory drugs for pain relief, reports of side effects associated with their long-term use have surfaced [3].

β -alanine, a nonessential and non-proteinogenic amino acid, is produced as the end product of carnosine metabolism in the human body. This amino acid plays a critical role in intracellular buffering and effectively delays the accumulation of lactic acid [4]. Numerous physiological functions have been attributed to β -alanine, including anticancer and antioxidant activities, as well as the enhancement of muscle function and exercise performance [5]. While the mechanisms through which β -alanine exerts its positive effects on the brain have not been fully elucidated, its structural similarities to γ -aminobutyric acid (GABA) and glycine enable it to bind to their receptors and function as an inhibitory neurotransmitter [6]. Furthermore, β -alanine has been found to positively influence spatial memory, as evidenced by its ability to increase levels of this amino acid in the hippocampus following the performance of the Morris water maze test [7]. In individuals diagnosed with schizophrenia, β -alanine supplementation has been shown to improve cognitive function through its antioxidant properties [5].

Supplementation with β -alanine has been found to decrease lipid peroxidation and the production of reactive oxygen species (ROS), while simultaneously enhancing levels of glutathione peroxidase (GPx), superoxide dismutase (SOD), reduced glutathione (GSH), and catalase (CAT) in rats with myocardial ischemia-reperfusion injury [4]. Despite an extensive review of the literature, no reports have been found regarding the anti-nociceptive properties of β -alanine. Therefore, the objective of this study is to investigate the potential antinociceptive role of β -alanine and its potential interaction with the opioidergic, GABAergic, dopaminergic, and nitrgergic systems in the context of hot plate-induced pain.

2. Materials and Methods

2.1. Animals and grouping

In this investigation, a total of 85 male NMRI mice with a weight range of 25–30 g were housed in a controlled environment with a room temperature of $23\pm1^\circ\text{C}$ and a 12-hour light/dark cycle. The mice were kept in standard cages, with six mice in each cage. They had unrestricted access to fresh water and chow pellets. The first test involved the intraperitoneal (IP) injection of different substances into each mouse. These substances included saline, β -alanine at three different doses (15 mg/kg, 30 mg/kg, and 45 mg/kg), and morphine (5 mg/kg). It should be noted that the mice received β -alanine once a day for a period of 7 days, while morphine was injected only 30 minutes before the test. In the second test, the mice were again intraperitoneally injected with different substances. These substances included saline, β -alanine (30 mg/kg) once a day for 7 days, naloxone (2 mg/kg), and a combination of naloxone and β -alanine (30 mg/kg). The third test followed a similar pattern, with the mice receiving different injections. These injections included saline, β -alanine (30 mg/kg) once a day for 7 days, flumazenil (5 mg/kg), and a combination of flumazenil and β -alanine (30 mg/kg). In the fourth test, the mice were injected with saline, β -alanine (30 mg/kg) once a day for 7 days, L-NAME (10 mg/kg), and a com-



Figure 1. The hot plate procedure

bination of L-NAME and β -alanine (30 mg/kg). The fifth test involved the IP injection of saline, β -alanine (30 mg/kg) once a day for 7 days, 6-hydroxydopamine (100 mg/kg), and a combination of 6-hydroxydopamine and β -alanine (30 mg/kg). Similar to the first test, the mice received β -alanine once a day for 7 days, while all the antagonists were injected 30 minutes before the test.

2.2. Hot plate test

The thermal noxious stimuli antinociceptive activity of β -alanine was evaluated using Harvard's hot plate, which was set at a temperature of $52 \pm 2^\circ\text{C}$ [8]. The mice were placed on the heated surface, and the time elapsed between placement and specific responses, such as jumping, withdrawal of the paw(s), or licking of the forepaws, was recorded as the response latency time. These recordings were made before the injection and at 10, 15, 20, 25, and 30 minutes after the injections. A cut-off time of 20 seconds was used to determine analgesia and prevent tissue damage [8] (Figure 1).

2.3. Biochemical evaluations

At the end of the tests, blood samples were collected and serum MDA, SOD, GPx, and TAS were determined using Zell Bio GmbH (Germany) assay kits. The Greiss colorimetric method determined nitric oxide (NO) concentration in the blood serum. An ELISA reader measured the samples' optical density (OD) at the wavelength of 540 nm [9].

2.4. Statistical analysis

SPSS 22.0 statistical was used for data analysis using a one-way analysis of variance (ANOVA), and results were shown as the Mean $\pm$ SE. Tukey post hoc test was applied for the main effect of ANOVA ($P < 0.05$).

3. Results

The figures presented in the study demonstrate the antinociceptive properties of β -alanine as measured by the hot plate test. In Figure 2, it can be observed that morphine significantly increased the latency time in the hot plate test compared to the control group ($P < 0.05$). On the other hand, β -alanine at a dosage of 15 mg/kg had no significant effect on latency time ($P > 0.05$). However, at dosages of 30 and 45 mg/kg, β -alanine significantly increased the latency time in the hot plate test compared to the control group ($P < 0.05$).

As shown in Figure 3, it is evident that naloxone at a dosage of 2 mg/kg did not elicit an antinociceptive response in the hot plate test compared to the control group ($P > 0.05$). Conversely, β -alanine at a dosage of 30 mg/kg significantly increased the latency time in the hot plate test compared to the control group ($P < 0.05$). Moreover, when β -alanine was administered prior to naloxone (2 mg/kg), the latency time in the hot plate test was significantly decreased ($P < 0.05$).

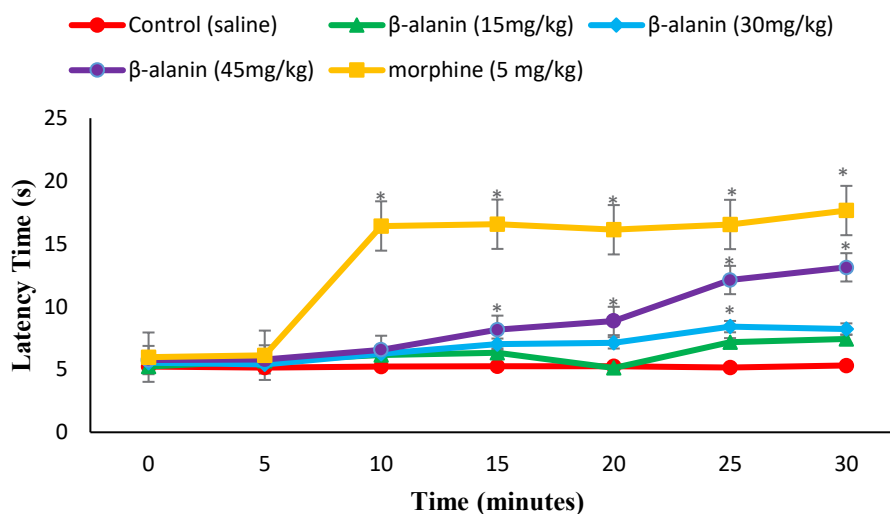


Figure 2. Effect of β -alanine on latency time in the hot plate test in mice (Mean $\pm$ SE, $P < 0.05$)

Figure 4 reveals that flumazenil at a dosage of 5 mg/kg did not produce any antinociceptive response in the hot plate test compared to the control group ($P > 0.05$). In contrast, β -alanine at a dosage of 30 mg/kg significantly increased the latency time in the hot plate test compared to the control group ($P < 0.05$). Furthermore, when β -alanine was administered prior to flumazenil (5 mg/kg), the latency time in the hot plate test was significantly reduced ($P < 0.05$).

As presented in Figure 5, it can be observed that the administration of L-NAME at a dosage of 10 mg/kg had no effect on the latency time in the hot plate test compared to the control group ($P > 0.05$). However, β -alanine at a dosage of 30 mg/kg significantly increased the latency

time in the hot plate test compared to the control group ($P < 0.05$). Additionally, when β -alanine was administered prior to L-NAME (10 mg/kg), the latency time in the hot plate test was significantly increased ($P < 0.05$).

Figure 6 demonstrates that 6-hydroxydopamine at a dosage of 100 mg/kg did not elicit an antinociceptive response in the hot plate test compared to the control group ($P > 0.05$). Conversely, β -alanine at a dosage of 30 mg/kg significantly increased the latency time in the hot plate test compared to the control group ($P < 0.05$). Notably, no significant effect was observed on the latency time in mice pretreated with β -alanine (30 mg/kg) followed by 6-hydroxydopamine ($P > 0.05$).

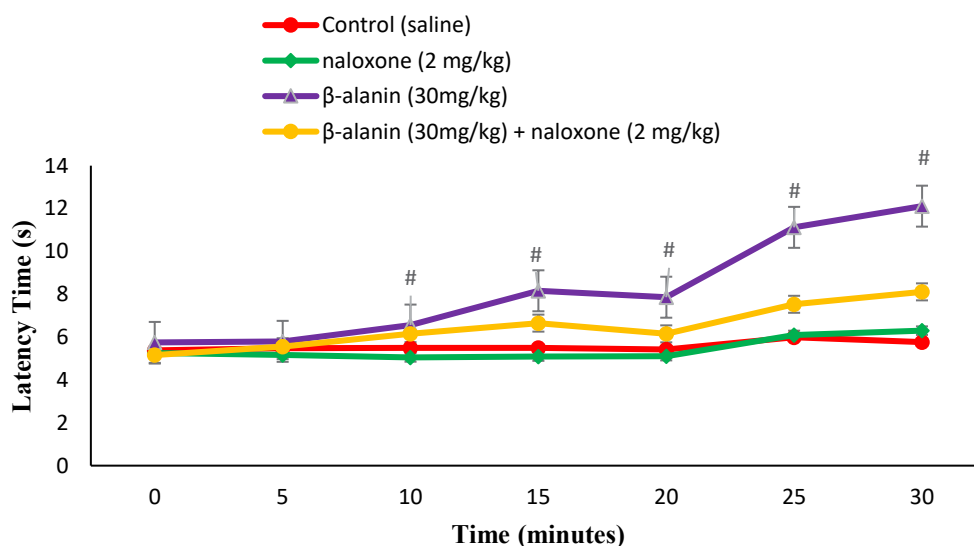


Figure 3. Effect of β -alanine, naloxone and their co-injection on latency time in the hot plate test in mice (Mean $\pm$ SE, $P < 0.05$)

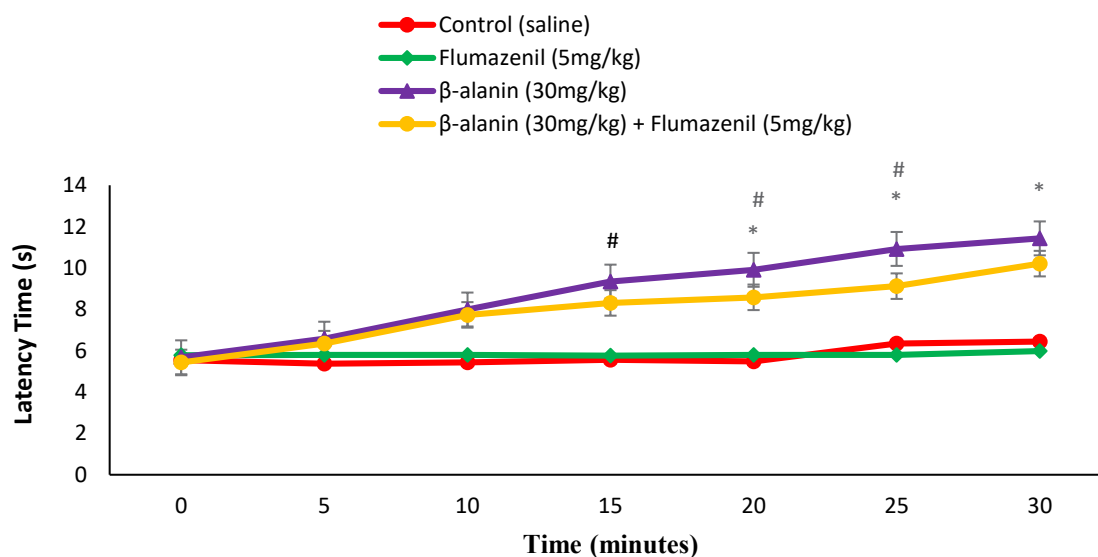


Figure 4. Effect of β -alanine, flumazenil and their co-injection on latency time in the hot plate test in mice (Mean $\pm$ SE, $P<0.05$)

Figures 7, 8, 9, 10, and 11 illustrate the effects of β -alanine on serum biochemicals. In Figure 7, it can be observed that a single dose of morphine had no significant effect on serum MDA levels compared to the control group ($P>0.05$). However, administration of β -alanine significantly decreased serum MDA levels compared to control mice ($P<0.05$). There was no significant difference between the dosages of 30 and 45 mg/kg of β -alanine ($P>0.05$).

As depicted in Figure 8, it is evident that morphine had no significant effect on serum SOD levels compared to control mice ($P>0.05$). Conversely, treatment with β -alanine significantly increased serum SOD levels

compared to control mice ($P<0.05$). There was no significant difference between the dosages of 30 and 45 mg/kg of β -alanine ($P>0.05$).

In this study, it was observed that the administration of morphine did not have any discernible impact on the levels of serum GPx compared to the control group ($P>0.05$). On the other hand, treatment with β -alanine led to a significant increase in the levels of serum GPx in comparison to the control group ($P<0.05$). Furthermore, there was no notable distinction between the 30 and 45 mg/kg doses of β -alanine ($P>0.05$) (Figure 9).

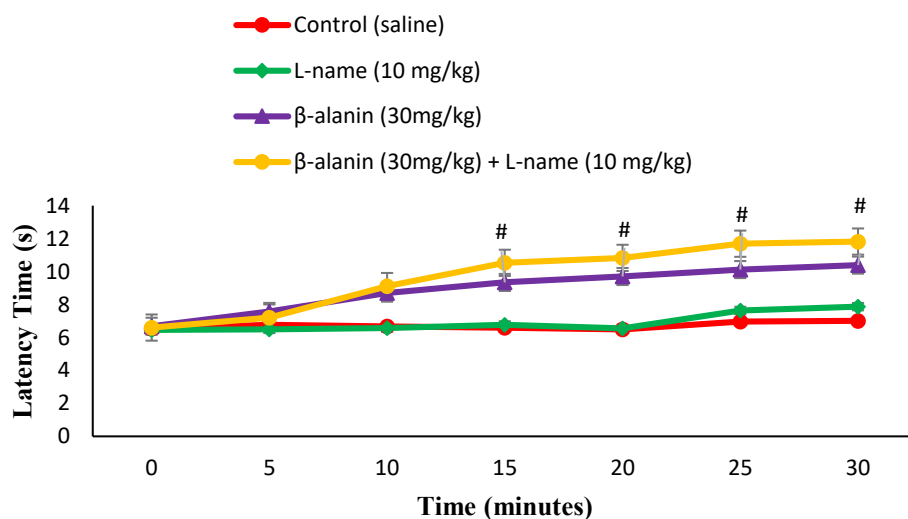


Figure 5. Effect of β -alanine, L-NAME and their co-injection on latency time in the hot plate test in mice (Mean $\pm$ SE, $P<0.05$)

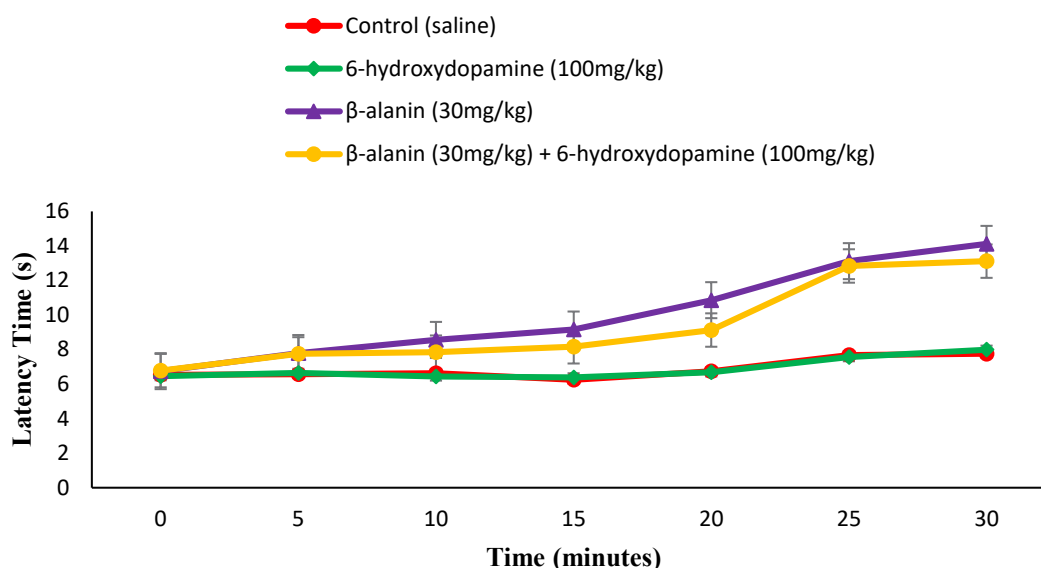


Figure 6. Effect of β -alanine, 6-hydroxydopamine and their co-injection on latency time in the hot plate test in mice (Mean $\pm$ SE, $P < 0.05$)

Results revealed that the administration of morphine did not exert any influence on the levels of total antioxidant status (TAS) in the serum compared to the control group ($P > 0.05$). Conversely, treatment with β -alanine resulted in a significant increase in serum TAS levels compared to the control group ($P < 0.05$). Moreover, there was no significant distinction between the 30 and 45 mg/kg doses of β -alanine ($P > 0.05$) (Figure 10).

Based on the findings illustrated in Figure 11, it was observed that a single dose of morphine did not have any noticeable impact on the concentration of NO in the serum compared to the control group ($P > 0.05$). Con-

versely, treatment with β -alanine led to a significant decrease in serum NO concentration compared to the control group ($P < 0.05$). Furthermore, there was no significant difference between the 30 and 45 mg/kg doses of β -alanine ($P > 0.05$).

4. Discussion

Based on the principal finding of the present investigation, the administration of β -alanine resulted in an increase in the duration of latency. Subsequent pretreatment with β -alanine, followed by the administration of an opioid antagonist, led to a decrease in latency time. Furthermore, pretreatment

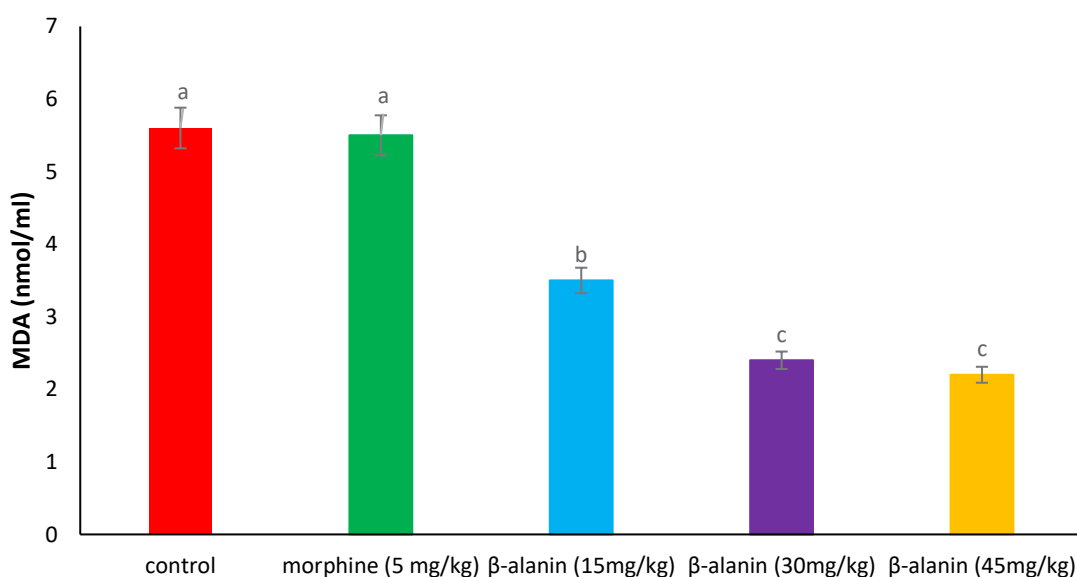


Figure 7. Effect of β -alanine on serum MDA levels in mice (Mean $\pm$ SE, $P < 0.05$)

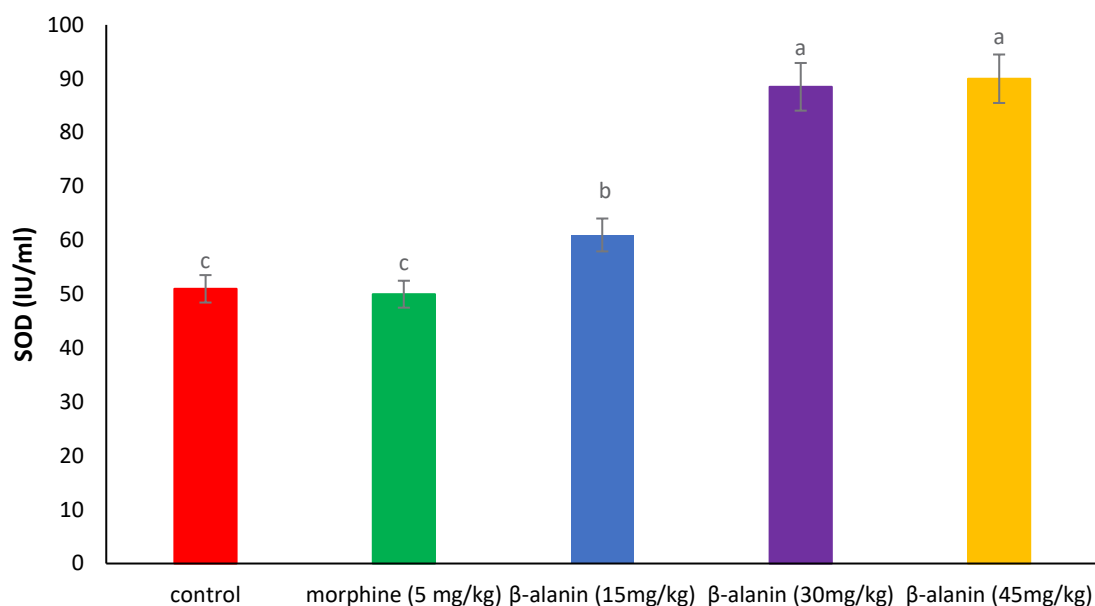


Figure 8. Effect of the β -alanine on SOD levels in mice (Mean $\pm$ SE, $P < 0.05$)

with β -alanine, followed by a GABA antagonist, resulted in a reduction in latency time on the hot plate. Additionally, pretreatment with β -alanine, followed by an inhibitor of NO synthesis, caused an increase in latency time. β -alanine is classified as an endogenous β -amino acid and, although it is not utilized in the synthesis of proteins or enzymes, it does demonstrate physiological significance. β -alanine is present within the central nervous system as a neuromodulator [10]. It has been reported that pretreatment with naloxone

blocked the antinociceptive effects during the threshold period in hot plate tests [11]. There exists a correlation between the synthesis of β -alanine and the GABA system facilitated by malonic semialdehyde. GABA-T exhibits comparable reactivity towards both β -alanine and GABA. Consequently, the endogenous concentration and release of β -alanine are significantly influenced by GABA-T, suggesting that this enzyme is also involved in regulating the synthesis of β -alanine within the central nervous system [12].

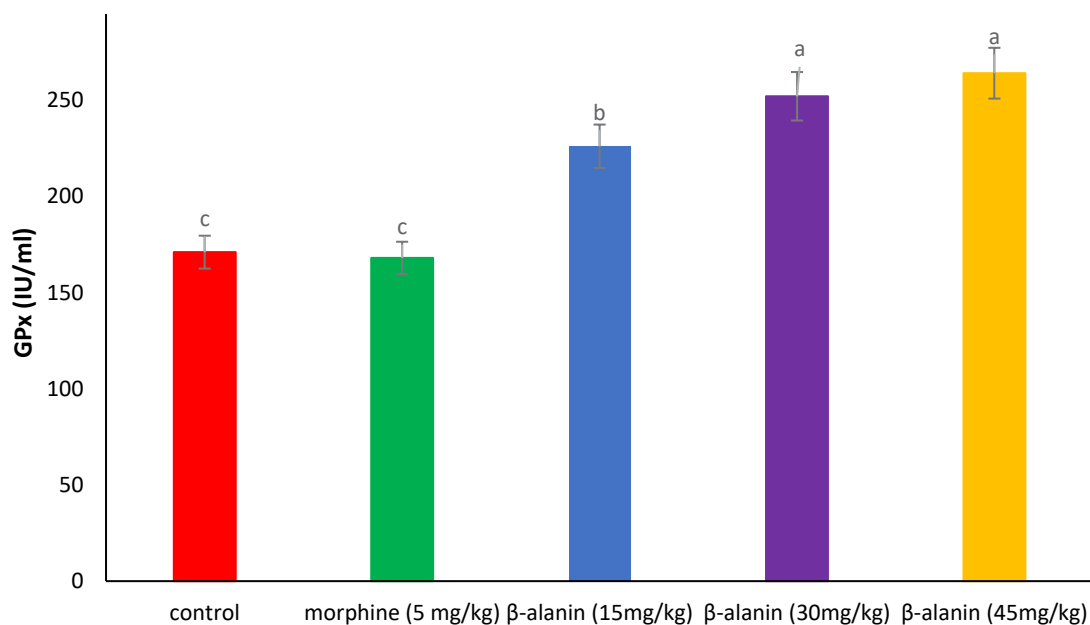


Figure 9. Effect of β -alanine on serum GPx levels in mice (Mean $\pm$ SE, $P < 0.05$)

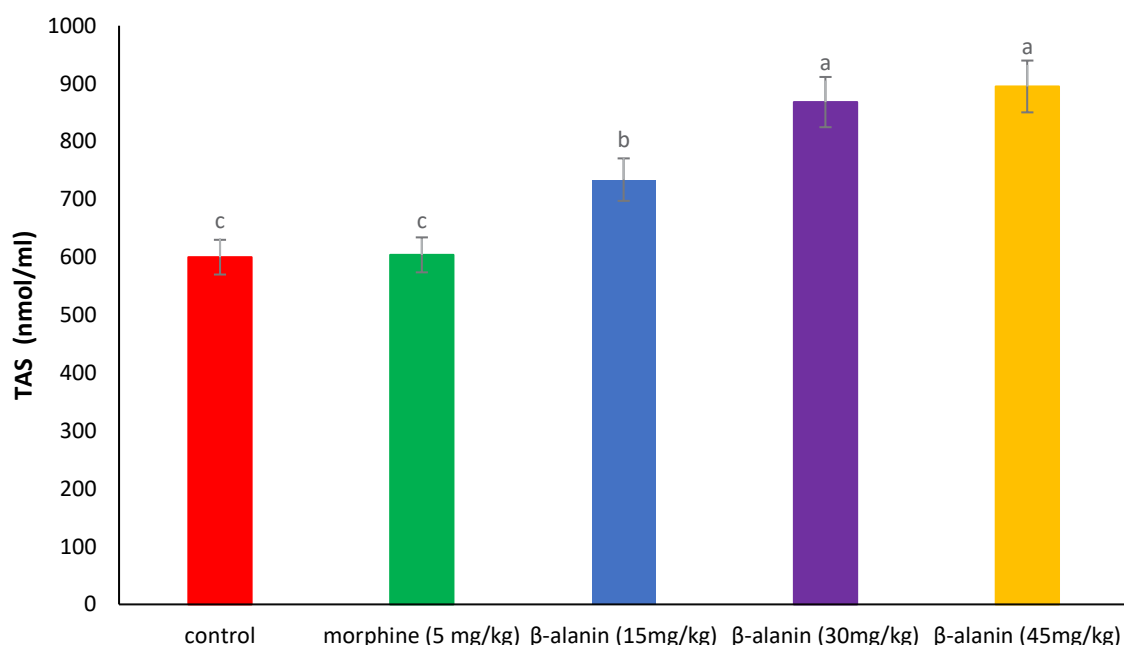


Figure 10. Effect of β -alanine on serum TAS in mice (Mean $\pm$ SE, $P<0.05$)

NO can induce peripheral hyperalgesia by modulating the expression of cyclooxygenase [13]. The subplantar injection of formalin results in an elevation of NO levels at the site of injection, and pretreatment with L-NAME mitigates pain in mice [14, 15]. β -alanine has the capability to bind to GABA and glycine receptors, as well as the N-methyl-D-aspartate (NMDA) receptor complex. Within the central nervous system, β -alanine is localized in both neurons and glia, specifically within the brainstem and spinal cord [16]. Electrical stimulation triggers the release of β -alanine,

which then interacts with binding sites and inhibits neuronal excitability [17]. Activation of NMDA receptors by glutamate leads to an increase in the release of NO and PGE2, subsequently enhancing glutamate levels within the dorsal horn neurons and promoting central sensitization [18]. Conversely, glycine receptors suppress neuronal firing within the spinal cord, and pretreatment with cyclooxygenase inhibitors reduces pain [19]. Presumably, the antinociceptive activity of β -alanine is mediated through the involvement of the NO and GABAergic systems.

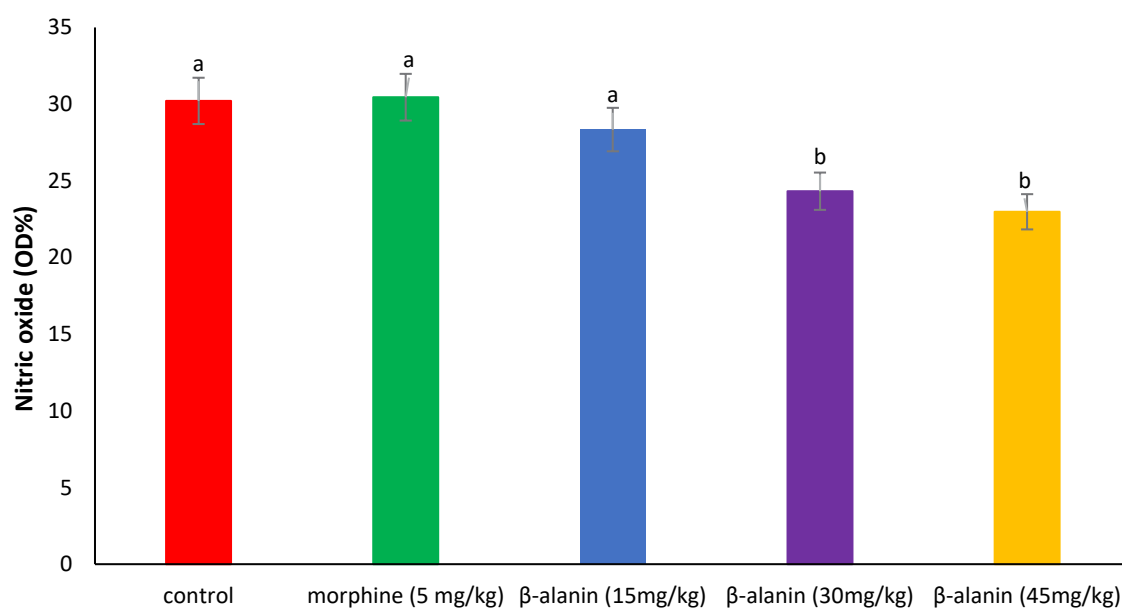


Figure 11. Effect of the β -alanine on serum NO concentration in mice (Mean $\pm$ SE, $P<0.05$)

As observed, the administration of β -alanine resulted in a decrease in serum levels of NO and MDA, while simultaneously increasing levels of SOD, GPx, and TAS. These findings suggest that the antinociceptive activity of β -alanine is mediated through the GABAergic and NO production pathways, and potentially through its antioxidant activity in the context of hot plate-induced pain in mice. The antioxidant properties of β -alanine have been reported in previous studies. Supplementation with β -alanine (at doses ranging from 300-1200 mg/kg) resulted in reduced serum levels of immunoglobulin G and immunoglobulin M, as well as an upregulation of SOD and GPx expression in weaned piglets [20]. Furthermore, β -alanine has been demonstrated to alleviate oxidative stress by decreasing MDA levels, increasing SOD levels, and mitigating muscle fatigue in mice [21].

5. Conclusion

Based on novel discoveries from the recent investigation, β -alanine exhibits an antinociceptive function and interacts with the opioidergic, GABAergic, and nitrergic systems in relation to hot plate-induced pain in mice. Furthermore, β -alanine ameliorates oxidative stress through the reduction of MDA levels and the augmentation of SOD, GPx, and TAS levels in the context of hot plate-induced pain in mice.

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Compliance with ethical guidelines

This study was approved by the Biomedical Research Ethics Committee of the Science and Research Branch, Islamic Azad University, Tehran, Iran (Code: IR.IAU.SRB.REC.1402.141).

Data availability

The data supporting the findings of this study are available upon request from the corresponding author.

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Authors' contributions

Conceptualization, study design, analysis, data interpretation analysis, statistical analysis, review and editing: Shahin Hassanpour; Data acquisition and writing the original draft: Aida Abbasi; Project administration, technical, and material support: Shahin Hassanpour and Ehsan Khaksar.

Conflict of interest

The authors declared no conflict of interest.

References

- [1] Zendehdel M, Beizae S, Taati M, Bashiri A. Antinociceptive mechanisms of Rosmarinus officinalis extract in mice using writhing test. Iran J Vet Med. 2011; 5(4):240-6. [Link]
- [2] Nikjooy N, Asghari A, Hassanpour S, Arfaee F. Study of anti-nociceptive role of the manna of hedysarum and the neurotransmitter systems involved in mice. Iran J Vet Med. 2022; 16(3). [Link]
- [3] Regalado AI, Mancebo B, Paixão A, López Y, Merino N, Sánchez LM. Antinociceptive Activity of Methanol Extract of Tabebuia hypoleuca (C. Wright ex Sauvalle) Urb. Stems. Med Princ Pract. 2017; 26(4):368-74. [DOI:10.1159/000478015] [PMID]
- [4] Hou X, Sun G, Guo L, Gong Z, Han Y, Bai X. Cardioprotective effect of taurine and β -alanine against cardiac disease in myocardial ischemia and reperfusion-induced rats. Electron J Biotechnol. 2020; 45:46-52. [DOI:10.1016/j.ejbt.2020.04.003]
- [5] Bhattacharya TK, Pence BD, Ossyra JM, Gibbons TE, Perez S, McCusker RH, et al. Exercise but not (-)-epigallocatechin-3-gallate or β -alanine enhances physical fitness, brain plasticity, and behavioral performance in mice. Physiol Behav. 2015; 145:29-37. [DOI:10.1016/j.physbeh.2015.03.023] [PMID]
- [6] Yeung AWK, Tzvetkov NT, El-Tawil OS, Bungu SG, Abdel-Daim MM, Atanasov AG. Antioxidants: Scientific literature landscape analysis. Oxid Med Cell Longev. 2019; 2019:8278454. [DOI:10.1155/2019/8278454] [PMID]
- [7] Sase A, Dahanayaka S, Höger H, Wu G, Lubec G. Changes of hippocampal beta-alanine and citrulline levels are paralleling early and late phase of retrieval in the Morris water maze. Behav Brain Res. 2013; 249:104-8. [DOI:10.1016/j.bbr.2013.04.033] [PMID]
- [8] Ong HM, Mohamad AS, Makhtar N, Khalid MH, Khalid S, Perimal EK, et al. Antinociceptive activity of methanolic extract of Acmella uliginosa (Sw.) Cass. J Ethnopharmacol. 2011; 133(1):227-33. [DOI:10.1016/j.jep.2010.09.030] [PMID]

- [9] Jalili C, Ahmadi S, Roshankhah S, Salahshoor M. Effect of Genistein on reproductive parameter and serum nitric oxide levels in morphine-treated mice. *Int J Reprod Biomed*. 2016; 14(2):95-102. [DOI:10.29252/ijrm.14.2.95] [PMID]
- [10] Hoffman JR, Emerson NS, Stout JR. β -alanine supplementation. *Curr Sports Med Rep*. 2012; 11(4):189-95. [DOI:10.1249/JSR.0b013e3182604983] [PMID]
- [11] Llorca-Torralba M, Pilar-Cuellar F, da Silva Borges G, Mico JA, Berrocoso E. Opioid receptors mRNAs expression and opioids agonist-dependent G-protein activation in the rat brain following neuropathy. *Prog Neuropsychopharmacol Biol Psychiatry*. 2020; 99:109857. [DOI:10.1016/j.pnpbp.2019.109857] [PMID]
- [12] Saunders B, Elliott-Sale K, Artioli GG, Swinton PA, Dolan E, Roschel H, et al. β -alanine supplementation to improve exercise capacity and performance: A systematic review and meta-analysis. *Br J Sports Med*. 2017; 51(8):658-69. [DOI:10.1136/bjsports-2016-096396] [PMID]
- [13] Ping CP, Tengku Mohamad TAS, Akhtar MN, Perimal EK, Akira A, Israf Ali DA, et al. Antinociceptive effects of cardamonin in mice: Possible involvement of TRPV $\square$, glutamate, and opioid receptors. *Molecules*. 2018; 23(9):2237. [DOI:10.3390/molecules23092237] [PMID]
- [14] Chen L, Zhong Y, Ouyang X, Wang C, Yin L, Huang J, et al. Effects of β -alanine on intestinal development and immune performance of weaned piglets. *Anim Nutr*. 2022; 12:398-408. [DOI:10.1016/j.aninu.2022.10.008] [PMID]
- [15] Kaboutari J, Ghorbani M, Karimi B, Javdai M, Khosraviyan P. Effects of the Slow-release curcumin-loaded selenium nanoparticles on experimental peritonitis. *Iran J Vet Med*. 2024; 18(4):555-66. [DOI:10.32598/ijvm.18.4.1005414]
- [16] Khodabakhshi Rad A, Kazemi Mehrjerdi H, Pedram MS, Azizzadeh M, Amanollahi S. Clinical evaluation of the effect of methylprednisolone sodium succinate and meloxicam in experimental acute spinal cord injury. *Iran J Vet Med*. 2023; 17(2):129-38. [DOI:10.32598/IJVM.17.2.1005246]
- [17] Parthasarathy A, Savka MA, Hudson AO. The synthesis and role of β -alanine in plants. *Front Plant Sci*. 2019; 10:921. [DOI:10.3389/fpls.2019.00921] [PMID]
- [18] Azarhosh M, Ghashghaei A, Pooyanmehr M, Maleki A, Alimohammadi S. Evaluating immunomodulatory effects and cytokine changes by propranolol following surgical stress in male rats. *Iran J Vet Med*. 2024; 18(3):415-28. [DOI:10.32598/ijvm.18.3.1005374]
- [19] Bhat AS, Tandan SK, Kumar D, Krishna V, Prakash VR. The interaction between inhibitors of nitric oxide synthase and cyclooxygenase in formalin-induced pain in mice: An isobolographic study. *Anesth Analg*. 2008; 106(3):978-84. [DOI:10.1213/ane.0b013e318163f71b] [PMID]
- [20] Chen Y, Boettger MK, Reif A, Schmitt A, Üçeyler N, Sommer C. Nitric oxide synthase modulates CFA-induced thermal hyperalgesia through cytokine regulation in mice. *Mol Pain*. 2010; 6:13. [DOI:10.1186/1744-8069-6-13] [PMID]
- [21] Ma YL, Yang Y, Thakur K, Cespedes-Acuña CL, Zhang JG, Wei ZJ. Evaluation of spatial memory and anti-fatigue function of long-term supplementation of β -alanine and confirmation through cAMP-PKA and apoptosis pathways in mice. *eFood*. 2021; 2(4):185-92. [DOI:10.53365/efood.k/144395]