Asian J Sports Med. 2026 March; 17(1): e171233 https://doi.org/10.5812/asjsm-171233

Published Online: 2026 March 31 **Research Article**

MDA Response to Ergocycle HIIT and Post-exercise Curcumin Supplementation in Badminton Athletes: A Quasi-Experimental Approach

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Received: 7 February, 2026; **Revised:** 1 March, 2026; **Accepted:** 18 March, 2026

Abstract

Background: Badminton involves repeated high-intensity efforts that may increase reactive oxygen species production and lipid peroxidation during recovery. Malondialdehyde (MDA) is commonly used as a marker of lipid peroxidation. Curcumin has been investigated as a nutritional intervention for exercise-induced oxidative stress; however, evidence in badminton athletes after acute high-intensity interval training (HIIT) remains limited.

Objectives: This study aimed to compare changes in plasma MDA levels between the curcumin and placebo groups during the 24-hour recovery period following acute ergocycle HIIT in male badminton athletes.

Methods: This quasi-experimental pretest-posttest control-group study was conducted at the Physiology Laboratory, Universitas Brawijaya, from August to September 2025. Thirteen male badminton athletes or students aged 18 - 25 years with a normal Body Mass Index completed the protocol and were allocated to the curcumin group (500 mg without piperine; n = 6) or the placebo group (n = 7). After a 12-hour fast, participants completed a single 20-minute ergocycle HIIT session at approximately 90% of maximal heart rate, consisting of repeated 10-second bouts at 100 rpm followed by 50 seconds of active recovery at 45 - 55 rpm. The first blood sample (T1) was collected immediately after HIIT and before capsule ingestion. The second sample (T2) was collected 24 hours after supplementation, following an approximately 10-hour fast. Plasma MDA was measured using a commercial assay kit. Between-group differences at T2 were analyzed using an analysis of covariance adjusted for T1 MDA.

Results: Plasma MDA increased from T1 to T2 in both groups. In the curcumin group, MDA increased from 0.65 ± 0.13 to 1.16 ± 0.44 nmol/mL, whereas in the placebo group, it increased from 1.03 ± 0.58 to 1.37 ± 0.47 nmol/mL. No significant between-group difference in the change was observed, and the Time × Group interaction was not significant (P = 0.163). In an additional baseline-adjusted analysis, the Group × T1 MDA term was significant (P = 0.001), indicating that the baseline-to-follow-up relationship differed between groups and that standard analysis of covariance without an interaction term was inappropriate for primary inference.

Conclusions: In this preliminary sample, a single 500 mg dose of curcumin did not produce a consistent between-group effect on the 24-hour plasma MDA response. The baseline-adjusted sensitivity analysis suggested that the association between baseline and follow-up MDA differed by group, indicating substantial uncertainty in baseline-adjusted between-group comparisons. Further studies with larger samples, repeated dosing, a pre-exercise baseline assessment, and additional recovery time points are warranted.

Keywords: Badminton, Curcumin, High-intensity Interval Training, Malondialdehyde, Oxidative Stress

1. Background

As an intermittent high-intensity sport, badminton involves repeated acceleration and deceleration, abrupt changes in direction, jumping, and dynamic stroke execution (1, 2). These demands necessitate repeated intensive training sessions within a microcycle to maintain physical capacity and technical performance, thereby increasing the need for adequate recovery before the subsequent session (3-5).

Strenuous exercise increases oxygen utilization and metabolic activity, thereby stimulating the generation of reactive oxygen species (ROS) (6). When endogenous antioxidant systems cannot neutralize ROS, oxidative stress develops and may promote lipid peroxidation (7). As a primary marker of lipid peroxidation, MDA is

How to Cite: Endra Vigriawan G, Herawati L, Yunus M, Syamsudin F, Moh Yudha Isnaini L, et al. MDA Response to Ergocycle HIIT and Post-exercise Curcumin Supplementation in Badminton Athletes: A Quasi-Experimental Approach. Asian J Sports Med. 2026;17(1):e171233. doi: https://doi.org/10.5812/asjsm-171233

widely used to evaluate oxidative stress responses during exercise and post-exercise recovery (8, 9).

Nutritional interventions have received attention in sports science as strategies to reduce post-exercise oxidative stress. Curcumin, the principal bioactive constituent of *Curcuma longa*, has documented antioxidant and anti-inflammatory effects through the modulation of inflammatory pathways and antioxidant defenses and may support recovery after intense exercise (10, 11). However, oxidative stress biomarker responses to supplementation may vary according to dose, duration, participant characteristics, and exercise protocol (12).

High-intensity interval training is an efficient and relevant model for intermittent sports because it involves repeated high-intensity work-recovery intervals. On an ergocycle, HIIT can be standardized using a target heart rate, such as 90% of maximal heart rate, and controlled cadence parameters, thereby providing a reproducible physiological stimulus (13).

Current evidence regarding the effectiveness of a single 500 mg dose of curcumin in badminton athletes after an acute ergocycle HIIT session remains limited, particularly when oxidative stress outcomes are assessed during recovery, such as 24 hours after exercise (14-16). Immediate post-exercise administration was selected to determine whether curcumin intake during early recovery could modulate the subsequent oxidative stress response, particularly the changes in MDA observed 24 hours after the standardized HIIT stimulus. This information is needed to clarify whether acute post-exercise curcumin supplementation can meaningfully influence oxidative stress recovery in badminton athletes.

2. Objectives

This study evaluated whether changes in plasma MDA levels from immediately after exercise and before supplementation (T1) to 24 hours after supplementation (T2), following a single ergocycle HIIT session at 90% of maximal heart rate, differed between the curcumin and placebo groups. Given the acute design and small preliminary sample, the study was intended to provide initial evidence regarding the 24-hour MDA response to post-exercise curcumin supplementation rather than definitive conclusions about the broader efficacy of curcumin in reducing exercise-induced oxidative stress.

3. Methods

This quasi-experimental pretest-posttest control-group study examined the effect of curcumin supplementation on plasma MDA levels during the 24-hour recovery phase after HIIT. The protocol was approved by the Health Research Ethics Committee of Universitas Negeri Malang (KEPK UM) under approval code 27.08.10/UN32.14.2.8/LT/2025. Written informed consent was obtained from all participants.

3.1. Participants and Group Allocation

The study was conducted at the Physiology Laboratory, Universitas Brawijaya, from August to September 2025. Participants were recruited from a university badminton club. The final analysis included 13 male badminton athletes or students aged 18 - 25 years: 6 participants in the group receiving 500 mg of curcumin without piperine and 7 participants in the placebo group. As this was a preliminary acute intervention study, no formal a priori sample size calculation was performed; all eligible participants available during the study period were recruited. Participants had a normal Body Mass Index (BMI), with comparable BMI values between groups, and none were classified as overweight.

The inclusion criteria were male sex, age 18 - 25 years, regular participation in badminton training, apparently healthy status, no current musculoskeletal injury, normal BMI, and the ability to complete the ergocycle-based HIIT protocol. Participants were excluded if they had a history of cardiovascular, metabolic, hepatic, renal, or other chronic disease; were currently taking antioxidant, anti-inflammatory, herbal, turmeric, or curcumin supplements; had a recent acute illness or injury; were unable to complete the exercise protocol; or declined to provide written informed consent. Eligibility was confirmed through interview-based screening, a health history assessment, and a baseline non-exercise assessment.

3.2. Exercise Protocol

Before the intervention session, participants completed a 12-hour fast and then performed a single HIIT session on an ergocycle. The session lasted 20 minutes and was performed at approximately 90% of maximal heart rate. Maximal heart rate was estimated using the formula 220 - age, and heart rate was monitored throughout the session (17, 18).

The HIIT protocol consisted of repeated 10-second high-intensity cycling bouts at 100 rpm followed by 50 seconds of active recovery at 45 - 55 rpm. This cycle was repeated continuously until the total exercise duration reached 20 minutes.

3.3. Supplementation and Blood Sampling

The first blood sample (T1) was collected immediately after the HIIT session and before capsule ingestion. Thus, T1 represented post-exercise plasma MDA levels before supplementation. After T1 blood sampling, participants consumed a capsule according to their group allocation: either 500 mg of curcumin without piperine or placebo. The placebo capsules were prepared to resemble the curcumin capsules in physical appearance to reduce expectancy-related bias. During the 24-hour recovery period, participants were instructed not to perform additional exercise or strenuous physical activity.

The second blood sample (T2) was collected 24 hours after capsule ingestion following an approximately 10-hour fast. Thus, T2 represented plasma MDA levels during the 24-hour recovery phase after HIIT and supplementation (19). At each sampling point, 3 mL of venous blood was collected into ethylenediaminetetraacetic acid tubes and processed to obtain plasma. Plasma MDA levels were analyzed using a commercially available MDA assay kit from BT LAB, Shanghai Korain Biotech Co., Ltd., Shanghai, China (catalog No. 1007/96S), according to the manufacturer's protocol. Results were expressed in nmol/mL.

3.4. Statistical Analysis

Statistical analyses were performed using analysis of covariance (ANCOVA) within a general linear model. MDA at T2 was the dependent variable, treatment group was the between-subject factor, and MDA at T1 was the covariate. This approach compared MDA levels during the 24-hour recovery phase between the curcumin and placebo groups while controlling for post-exercise, pre-supplementation MDA. The homogeneity-of-regression-slopes assumption was assessed using the interaction between group and T1 MDA. Results were reported using F values, P values, partial eta squared (ηp^2), and adjusted means. Statistical significance was set at $\alpha = 0.05$.

4. Results

Thirteen male badminton athletes aged 18 - 25 years completed the acute protocol and provided complete MDA data at T1 and T2. Participants were allocated to the 500 mg curcumin group (n = 6) or the placebo group (n = 7). No missing data or adverse events were recorded during the 24-hour follow-up. As shown in Table 1, MDA increased from T1 to T2 in both groups, and within-group tests indicated significant increases in both groups.

Figure 1 shows the mean MDA at T1 and T2 for each group.

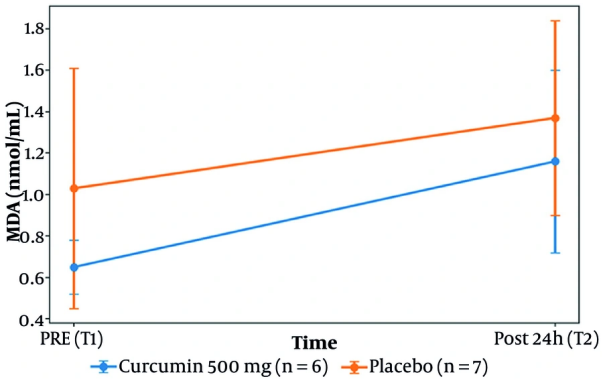

Figure 1. Mean (± SD) MDA at T1 and T2 for Each Group

Figure 2 shows the mean change in MDA for each group.

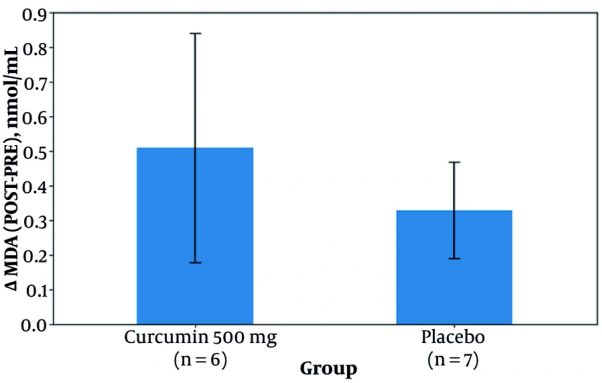

Figure 2. Mean (± SD) Change in MDA (Δ = T2 - T1) for Each Group

Between-group analyses showed no significant difference in the change in MDA between the curcumin and placebo groups. The mean difference in change was +0.17 nmol/mL (95% CI, -0.17 to +0.52), and neither the Welch test (P = 0.268) nor the Mann-Whitney test (P = 0.445) was significant (Table 2; Figure 3). The Time × Group interaction was also not significant (P = 0.163); therefore, these data provide no strong evidence that a single 500 mg dose of curcumin administered after exercise altered the magnitude of the MDA increase during the 24-hour recovery period. A baseline-adjusted

Table 1. Malondialdehyde Levels at T1 and T2 and Within-Group Changes [a]

Group	n	T1	T2 at 24 h	Mean Change	P Value, Paired t Test	P Value, Wilcoxon Test	Cohen dz
Curcumin, 500 mg	6	0.65 ± 0.13	1.16 ± 0.44	0.51 (0.16 - 0.86)	0.0127	0.0313	1.55
Placebo	7	1.03 ± 0.58	1.37 ± 0.47	0.33 (0.20 - 0.46)	0.00068	0.0156	2.36

[a] Values are expressed as mean ± SD or 95%(CI).

Table 2. Primary Between-Group Inference and Baseline-Adjusted Sensitivity Analysis

Analysis	Result	P Value	Effect Size	Interpretation
Difference in change (curcumin - placebo)	+0.17 nmol/mL (95% CI, -0.17 to +0.52)	Welch P = 0.268; Mann-Whitney P = 0.445	Hedges g = 0.66	Not significant
Time × Group interaction (mixed ANOVA)	-	0.163	-	Not significant
Group × baseline interaction	F(1, 9) = 25.826	0.001	Partial η^2 = 0.742	Significant; standard ANCOVA without an interaction term was not appropriate
Baseline covariate (T1 MDA)	F(1, 9) = 70.800	< 0.001	Partial η^2 = 0.887	Significant covariate

sensitivity analysis was conducted with T2 MDA as the dependent variable, group as the fixed factor, and T1 MDA as the covariate. The Group × T1 MDA interaction was significant, $F(1, 9) = 25.826$, $P = 0.001$, partial $\eta^2 = 0.742$, indicating a violation of the homogeneity-of-regression-slopes assumption. Therefore, a standard ANCOVA model without an interaction term was not considered appropriate for primary inference, and no single overall adjusted group effect was interpreted. In the same model, T1 MDA was a significant covariate, $F(1, 9) = 70.800$, $P < 0.001$, partial $\eta^2 = 0.887$.

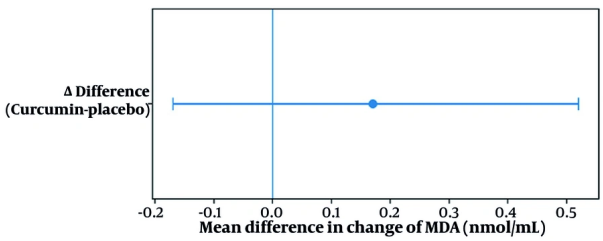

Figure 3. Between-Group Difference in MDA Change With 95% CI

5. Discussion

The present study evaluated whether a single 500 mg dose of curcumin administered immediately after acute ergocycle HIIT was associated with a different plasma MDA response during the 24-hour recovery period in badminton athletes. MDA increased from T1 to T2 in both groups, and no inferential evidence supported a between-group difference in the change in MDA (Table 2). In this preliminary sample, acute post-exercise curcumin supplementation had no detectable effect on the 24-hour MDA response.

The elevation in MDA 24 hours after exercise indicates that oxidative stress likely persisted during recovery. Acute high-intensity exercise substantially increases adenosine triphosphate turnover, oxygen flux, and mechanical loading, which may promote ROS formation in working skeletal muscle. When endogenous antioxidant defenses are insufficient to counter this oxidative challenge, ROS can damage polyunsaturated fatty acids in cell membranes and trigger lipid peroxidation. Because MDA is a downstream product of this process, its elevated concentration 24 hours after exercise supports the interpretation that the HIIT session induced a measurable oxidative disturbance rather than only a short-lived metabolic response (20).

The biological relevance of curcumin derives from its reported ability to regulate redox-related mechanisms, including nuclear factor kappa B and nuclear factor erythroid 2-related factor 2, thereby exerting antioxidant and anti-inflammatory effects. However, the present results suggest that the oxidative load induced by the HIIT session was not detectably altered by a single 500 mg dose administered only after exercise. The timing of supplementation may not have coincided optimally with the onset of lipid peroxidation, and the low oral bioavailability of curcumin without an absorption enhancer may have limited its systemic

effect. Thus, in this preliminary sample, acute post-exercise curcumin at this dose and timing had no detectable effect on the 24-hour oxidative stress response reflected by MDA (21, 22).

This finding is consistent with previous literature showing heterogeneous effects of curcumin on acute exercise responses (23). Several studies reporting beneficial effects have used different supplementation strategies, including administration before exercise or repeated dosing over several days, which may provide greater biological exposure than a single post-exercise dose (24). Evidence concerning oxidative stress markers is also more limited than that concerning inflammatory or muscle-damage markers. Curcumin effects may be more difficult to detect for oxidative outcomes because these outcomes are strongly influenced by sampling time, analytical approach, and the exercise protocol.

A notable methodological issue was the lower T1 MDA value in the curcumin group than in the placebo group. A baseline-adjusted sensitivity analysis was therefore conducted. However, the significant Group × T1 interaction indicated that the relationship between T1 and T2 MDA differed by group, violating the homogeneity-of-regression-slopes assumption required for a standard ANCOVA without an interaction term. This finding increases uncertainty in the interpretation of adjusted between-group comparisons in this small preliminary sample and supports cautious interpretation of the results (25).

From a practical perspective, these findings do not support recommending a single 500 mg dose of curcumin as a stand-alone strategy to attenuate the 24-hour MDA response after intense interval exercise. Future studies should examine larger samples, repeated or preload supplementation strategies, and broader biomarker panels.

5.1. Study Limitations

Several limitations should be acknowledged, including the small sample, the absence of a pre-exercise baseline measurement, and the use of a single biomarker. Additional sampling points, including a pre-exercise baseline and 48 hours after exercise, would help clarify the temporal pattern of the MDA response.

Footnotes

AI Use Disclosure: For the purpose of Text Editing and Translation, the Chatgpt and Deepl were used Minor, Minor in the Introduction and Introduction section.

Authors' Contribution: Study concept and design: G. V., L. H., and M. Y.; Acquisition of data: G. V., L. Y. I., and H. F.; Analysis and interpretation of data: G. V., L. H., M. Y., F. S., and N. A.; Drafting of the manuscript: G. V.; Critical revision of the manuscript for important intellectual content: L. H., M. Y., F. S., N. A., and L. Y. I.; Statistical analysis: G. V. and L. H.; Administrative, technical, and material support: L. Y. I. and H. F.; Study supervision: L. H. and M. Y. All authors read and approved the final manuscript.

Conflict of Interests Statement: The authors do not declare any conflicts of interests for this study.

Data Availability: The data presented in this study are uploaded during submission as a supplementary file and are openly available for readers upon request. Dataset name: Raw Data of Malondialdehyde (MDA) Levels in Badminton Athletes Following Acute Ergocycle HIIT with Curcumin Supplementation; File type: PDF.

Ethical Approval: This study was approved by the Health Research Ethics Committee of Universitas Negeri Malang (KEPK UM) under ethical approval code 27.08.10/UN32.14.2.8/LT/2025. The details of the ethical approval are available at: https://drive.google.com/file/d/1ulAZjZtb56cyq0w3MjsHgR-LZ3fkD8tc/view?usp=sharing. Written informed consent was obtained from all participants prior to their inclusion in the study.

Funding/Support: The study was supported by institutional resources from the Laboratory of Physiology, Universitas Brawijaya, including the use of laboratory facilities, equipment, and standard materials necessary for data collection and analysis. The institution had no role in the study design, data collection, data analysis, interpretation of data, decision to publish, or preparation of the manuscript.

Informed Consent: Written informed consent was obtained from all participants prior to their inclusion in the study after a full explanation of the study procedures, potential risks, and benefits. Participants were informed of their right to withdraw from the study at any time without any consequences.

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