Curcumin attenuates delayed-onset muscle soreness and muscle function deficits following a soccer match in male professional soccer players

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https://doi.org/10.1123/ijspp.2022-0283

PUBLISHER

Human Kinetics

VERSION

AM (Accepted Manuscript)

PUBLISHER STATEMENT

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Title: Curcumin attenuates delayed-onset muscle soreness and muscle function deficits following a soccer match in male professional players

Submission style: Original investigation

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Key words: curcumin, (poly)phenols, team sports, muscle damage, recovery.

Running head: Curcumin and exercise recovery in soccer

Word count: 3455

Tables: 2

Figures: 1

Abstract

Purpose: To examine the effects of acute curcumin supplementation on recovery from a soccer match in male professional players. **Methods:** In a randomised, placebo-controlled, crossover design, 11 players from the under-23 team of an English Premier League club (age 19 ± 1 y, body mass 79.4 ± 7.9 kg, height 180.8 ± 5.7 cm) consumed 500 mg of curcumin or a control (Medium Chain Triglycerides) (CON) immediately, 12 and 36 h after a 90-min match. Countermovement jump height (CMJ), reactive strength index (RSI), delayed onset of muscle soreness (DOMS, 0-200 mm), and subjective wellbeing were measured before, 12, 36, and 60 h post-match. Global positioning systems (GPS) measured external load during matches and dietary intake was recorded across the testing period. **Results:** GPS and dietary intake did not differ between conditions ($P \geq 0.246$). Curcumin accelerated the recovery of CMJ ($P \leq 0.004$), and RSI ($P \leq 0.001$), and reduced DOMS ($P \leq 0.004$) at all post-match time-points (except 60 h-post for RSI). The greatest difference between control and curcumin was 12 h-post for CMJ ($P < 0.001$, 1.91 ± 4.40 cm, 95%CI: 1.25 to 2.57, $g = 0.36$) and RSI ($P = 0.003$, 0.40 ± 0.41 AU, 95%CI: 0.17 to 0.63, $g = 0.90$), and 36 h-post for DOMS ($P < 0.001$, 47 ± 23 mm, 95%CI: -67 to -27, $g = 2.12$). **Conclusions:** Curcumin intake $<$36 h after a soccer match attenuated DOMS and muscle function deficits, suggesting curcumin may aid recovery in professional male soccer players.

Key words: curcumin, polyphenols, team sports, muscle damage, recovery.

Introduction

Strenuous or unaccustomed exercise can damage skeletal muscle and the surrounding extracellular matrix[1,2]. This ultrastructural damage activates cell signalling pathways that induce an inflammatory response to repair the tissues[1]. Although necessary, the inflammatory cascade that proceeds, largely driven through the cyclooxygenase and nuclear factor kappa beta (NF-κB) pathways[1,3], may precipitate symptoms of delayed onset of muscle soreness (DOMS) and impair muscle force, at least in the short term[1,2]. Indeed, deficits in muscle force and DOMS can last >96 h following this type of exercise[1], impacting exercise performance in the subsequent days. Several studies have shown that soccer, an intense intermittent sport, evokes deficits in muscle function and DOMS that can last for 72 h following matches[4]. As soccer players often have limited recovery time between matches (48–120 h) and even less between training, their performance, wellbeing and even health could be compromised. One strategy to alleviate these symptoms and accelerate recovery processes, is the use of pharmacological drugs or nutritional dietary supplements[4].

Non-steroidal anti-inflammatory drugs (NSAIDs) are often used to enhance muscle function and reduce DOMS after exercise[5]. Although NSAIDs have attenuated DOMS in some studies, findings in soccer players remain equivocal and there are concerns that NSAIDs could impair muscle regeneration[5]. Despite medical departments and the International Federation of Association Football (FIFA) warning against their use, NSAIDs are still commonly consumed to support recovery in soccer[4]. As NSAIDs may have deleterious side effects, including gastrointestinal stress, and impaired central nervous system function[5], there is a growing interest in the efficacy of nutritional supplements on DOMS and muscle force recovery in soccer players.

Several nutritional supplements rich in (poly)phenols (chemical compounds especially abundant in plant foods[6]) have been examined for their potential benefits on markers of recovery following exercise. One (poly)phenol consistently shown to modulate exercise recovery is curcumin, a constituent of the spice turmeric[7]. The recovery enhancing effects of curcumin are believed to stem from its antioxidant and anti-inflammatory properties[7]. Indeed, curcumin can downregulate the pro-inflammatory cyclooxygenase-2 (COX-2)[8] and NF-κB pathways that are thought to propagate EIMD[9]. Curcumin has also been shown to decrease the secretion of pro-inflammatory cytokines such as IL-8 and TNF-α[8,10,11] that mediate DOMS severity following exercise.

To date, studies showing that acute curcumin supplementation attenuates muscle force deficits and DOMS following exercise are limited to sub-elite populations where exercise has been experimentally induced in a laboratory environment[7]. As such, there is little evidence that the beneficial effects observed in these studies translate to professional athletes after real-world competitions[7,12]. Thus, the aim of the present study was to examine the effects of acute curcumin supplementation on the recovery of muscle function and DOMS following a soccer match in professional male players. We hypothesised that acute curcumin supplementation would accelerate the recovery of muscle function, as measured by our primary outcome, countermovement jump (CMJ) height, a secondary outcome, reactive strength index (RSI), as well as attenuate DOMS and positively influence subjective wellbeing (secondary outcomes) following a match.

Method

Trail design

This study utilised a randomised, double-blind, placebo controlled, crossover design. After two competitive league fixtures participants were supplemented with either curcumin (CURC) or a placebo control (CON). Due to changes in team selection, 4 matches were required to collect data for 11 players. Two days prior to matches, baseline measures of the dependent variables (DOMS, countermovement jump height [CMJ], reactive strength index [RSI], and subjective wellbeing) were recorded. These measures were repeated 12, 36 and 60 h following matches and collected prior to training in a fasted state (~09:00–09:30). The trial was pre-registered with the Open Science Framework (https://osf.io/9k72s/).

Study population

A convenience sample of eleven male professional soccer players from the under-23 squad of a Category 1 English Premier League football club (age 19 ± 1 y, body mass 79.4 ± 7.9 kg, height 180.8 ± 5.7 cm) provided written informed consent for this study. All matches took place at the squad's home venue (19:00 kick off) in the southeast of England between November 2021 and January 2022. The two matches for each participant were separated by >7 days, as dictated by team selection, match location and injuries. Players completed a health history questionnaire to evaluate contraindications to the study procedures (e.g., injury, recent medication use, allergies to the supplements); none were excluded on this basis. The study received ethical approval from Loughborough University (reference: 5842) and was conducted according to the Declaration of Helsinki 7th revision, 2013 (Fortaleza, Brazil).

Study interventions

Players consumed 500 mg/day of a curcumin supplement (Elite Opti-Turmeric, Health Span, UK) or 1000 mg/day of medium chain triglyceride (MCT) oil, which served as the control for the study. As we could not procure a placebo supplement that was batch tested for prohibited substances, we used a low dose (1000 mg/day; 1/6th of recommended) of MCT oil (Now, IL, US) as a placebo. In addition to being batch tested, MCT was selected because; 1) it had a similar appearance to the curcumin capsules; 2) there is no research or mechanistic rationale to suggest MCT, especially at the low dose provided, would affect recovery processes after exercise.

Study outcomes

Our primary outcome measure was CMJ height. Secondary outcomes were RSI, DOMS, and subjective wellbeing. CMJ height and RSI were measured with an optoelectrical system (Optojump, Bolzano, Italy), as in our previous work[13]. For CMJ, participants stood with their feet shoulder width apart and jumped vertically with maximal force. For RSI, participants performed a drop jump (DJ), stepping off a 30 cm high box, landing on both feet, and jumping vertically. Players were instructed to jump with maximal effort and minimise ground contact time. RSI was calculated as jump height (cm)/contact time (ms). For both sets of jumps (CMJ and DJ), players were instructed to keep their hands fixed to their hips and had three attempts separated by 60 s of recovery, with the mean used for data analysis. Participants routinely completed these measures as part of clubs monitoring processes and were thus familiarised to such procedures. Inter-day coefficients of variation were 0.9% and 1.7% for CMJ and RSI, respectively.

DOMS were assessed by visual analogue scale (VAS), during which players were asked to rate the level of muscle soreness they felt in their legs during a squat to 90° knee flexion[13]. Participants marked this on a 0-200 mm VAS from 0 mm "no soreness" to 200 mm "unbearably painful", which was subsequently measured to the nearest mm, as previously administered by the group[13].

Subjective wellbeing was assessed using an in-house questionnaire that the players routinely complete as part of their monitoring programme. At each time-point (baseline, 12, 36 and 60 h), participants rated each of the following questions on a scale of 1 (positive) to 5 (negative): 1) How sore do your muscles feel today? 2) How fatigued do you feel today? 3) How well did you sleep last night? 4) How is your mood today? 5) How stressed do you feel today? The sum of the five responses per participant was used for data analysis; a higher score indicates worse wellbeing.

Participants wore Global Positioning Satellite (GPS) accelerometer units (OptimEye S5B, Version 7.18; Catapult Innovations, Melbourne, Australia) during matches to estimate physical load output (total distance, explosive distance and high-speed running, see Table 1 for further details) and were asked to record their dietary intake for the duration of each testing phase. Participants were told not to consume any other dietary supplements during the trials, but they could continue using other putative recovery practices (e.g., active recovery) if they were consistently used in both trials. These were monitored and recorded by the research team; two players consistently used a foam roller post-match; nine players employed no specific strategies. Participants also recorded their dietary intakes with online food diaries on match day (MD), match day +1 (MD+1; 12 h post) and match day + 2 (MD+2; 36 h post). Diaries were subsequently analysed for energy and macronutrient intake using online software (Nutritics, Dublin, IR); the average of the three days was used for data analysis.

Sample size

Our sample was size was determined by the time and resources available. The number of participants we could recruit for this research was limited by number of players in the squad, to those who are picked to play the matches, and various other extraneous variables such as loans to other clubs and injuries. As our sample size was unavoidably limited, no formal sample size calculation was performed. However, the research was deemed useful as, to our knowledge, no other study had examined the effects of curcumin on recovery from a soccer match in professional athletes and therefore the data and effect sizes will provide new insights in to how its application in real-world sporting scenarios.

Randomization and blinding

The order of trials was determined by simple randomisation using a computer-generated list (sealedenvelope.com) by an investigator not involved in data collection. Although the supplements were not identical in taste and appearance, players were blinded to the aims of the trials and only told that they were testing the effects of two different antioxidant supplements. This was effective as according to a post-trial exit survey only two (18%) players correctly guessed which supplement they received on each trial. The supplements were provided as two capsules in opaque envelopes and consumed immediately post-match (~21:00-21:30) and then on MD+1 and MD+2 after the dependent variables were collected each morning (three days in total).

Statistical Analysis

Data were analysed using IBM SPSS Statistics for Windows, Version 27.0 (Armonk, NY: IBM Corp) and are displayed as mean ± standard deviation (SD). Normal distribution of data was checked by inspecting histograms and the Shapiro-Wilk test ($P > 0.05$ = normal distribution). CMJ, RSI, DOMS and wellbeing were analysed using a 2 (supplement) x 4 (time-point) repeated measures ANOVA. As wellbeing data was not normally distributed according to the Shapiro-Wilk test, the data was log-transformed and although this did not alter the result of the Shapiro-Wilk test, visual inspection of histograms suggested the data now approximated a normal distribution. The same ANOVAs were performed to examine for any trial order effects. If the ANOVA indicated significant differences for main effects, *post-hoc* tests with Bonferroni corrections were performed to identify the location of differences. Paired t-tests were used to assess differences in dietary intake and GPS variables between intervention groups. TD, duration and protein data were not normally distributed (Shapiro-Wilk: $P > 0.05$) and therefore Wilcoxon signed-rank tests were used for analysis. For all tests, statistical significance was set at $P < 0.05$. Hedge's g effect sizes were calculated for paired t-tests (g) (small, 0.2 -0.40; medium, 0.5-0.79; large, ≥ 0.8)[14].

Results

GPS data was not different between interventions across all parameters, indicating that matches resulted in similar external loads (Table 1). Average daily energy (kcal) and macronutrient (g) intake was also not different between interventions (Table 2). There were no trial order effects for CMJ, RSI, DOMS, or wellbeing (all group and interaction effects were $P \geq 0.244$).

Dependent variables are presented in Figure 1. CMJ, RSI, DOMS and subjective wellbeing all exhibited time effects following matches ($P < 0.001$). For each variable, the greatest difference from baseline occurred at 12 h-post ($P \leq 0.001$). There were intervention effects for CMJ, RSI and DOMS (CMJ and DOMS: $P \leq 0.001$; RSI: $P = 0.024$), but not for wellbeing ($P = 0.052$). All outcome variables displayed significant interaction effects: CMJ and RSI ($P \leq 0.001$), DOMS ($P = 0.003$) and wellbeing ($P = 0.006$).

At all post-match time-points except 60 h-post for RSI, CMJ and RSI were significantly higher in the curcumin condition compared to control (CMJ: $P \leq 0.003$, 95%CI: 0.53 – 1.25 to 2.13 – 2.57, g = 0.25-0.36; RSI: $P \leq 0.004$, 95%CI: 0.13 – 0.17 to 0.35 – 0.63, g = 0.58-0.98; Figure 1). These differences between conditions peaked at 12 h-post, where CMJ and RSI were higher with curcumin than control (CMJ: $P < 0.001$, 1.91 ± 4.40 cm, 95%CI: 1.25 to 2.57, $g = 0.36$; RSI: $P = 0.003$, 0.40 ± 0.41 AU, 95%CI: 0.17 to 0.63, $g = 0.90$).

DOMS was greater than baseline at 12 h ($P < 0.001$, 70 ± 18 mm, 95%CI: 42 to 98, $g = 3.57$) and 36 h-post ($P = 0.004$, 53.55 ± 22.55, 95%CI: 17 to 89, $g = 2.32$) in the control condition, but not in the curcumin condition ($P \geq 0.175$; Figure 1). At all post-match time-points DOMS was significantly lower in the curcumin condition compared to control (12 h- and 36 h-post: $P < 0.001$, 95%CI: -68 to -24 and -67 to -27, g = 1.67 and 2.12, respectively; 60 h-post: $P \leq 0.004$, 95%CI: -45 to -11, $g = 1.40$; Figure 1).

Following the matches, wellbeing was rated worse at 12 and 36 h-post in the control condition ($P < 0.001$, 95%CI: 2.96 to 6.86 and 1.47 to 4.71, g = 2.08 and 1.40, respectively; Fig. 1), but no changes were observed from baseline in the curcumin condition ($P \geq 0.087$). At 12 h and 60 h-post match, wellbeing was greater (lower score) with curcumin supplementation ($P \leq 0.034$, 95%CI: -3.65 to -0.17 and -3.47 to -0.53, g = 0.76 and 1.17, respectively; Figure 1).

Discussion

The main finding of this study was that acute curcumin supplementation accelerated the recovery of muscle function attenuated DOMS in the 60h following a competitive soccer match in professional male players. This is the first study to examine the effects of curcumin supplementation on elite-level team-sport athletes using match-play as an ecologically valid model of exercise-induced muscle damage (EIMD).

In the present study, DOMS (and deficits in CMJ and RSI) were lower after curcumin supplementation at all post-match time-points, except 60h-post for RSI. These findings are consistent with studies that report expedited muscle function recovery after curcumin supplementation in untrained/moderately trained cohorts[11,15,16] and animals[3]. They also agree with, to our knowledge, the only other study in well-trained athletes, where curcumin and piperine supplementation attenuated deficits in 6-s sprint performance 12 h-post muscle damage induced by single-leg downhill hopping in rugby players[12]. In other studies, curcumin supplementation has also mitigated DOMS after EIMD[3,17] and in particular after resistance-exercise induced muscle damage[7]. Nonetheless, not all studies report analgesic effects with curcumin[12,15,16]. Although in Jager et al.[16] eight-weeks of curcumin supplementation reduced DOMS by 26% in the days after muscle damage, this was not statistically significant. Likewise, Tanabe et al.[15] did not observe any significant effects of curcumin on DOMS after a 150 mg dose of curcumin immediately before and 12 h after exercise. These findings are perhaps a consequence of the dosing strategies employed, which ceased before[16] or 12 h[15] after the EIMD protocols. Like other (poly)phenols, plasma levels of curcumin metabolites peak within the first few hours after intake, after which they are metabolised and eliminated from the body[18]. Thus, for substantial analgesic effects, it may be essential to consume higher doses of curcumin throughout the recovery process following EIMD.

The mechanisms by which curcumin may modify symptoms of EIMD remain unclear and examining these was beyond the scope of this trial. However, the effects in this study are likely associated with the bioactive effects of curcumin; curcumin interacts with multiple redox and inflammatory pathways[16] and several human and animal studies demonstrate that curcumin downregulates NF-κB[9,19]. Down-regulating NF-κB suppresses pro-inflammatory cytokines (such as IL-6, IL-8 and TNF-α) and modulates oxidative damage, which can impair muscle contractile function and sensitize pain receptors[9]. The suppression of pro-inflammatory cytokines with curcumin supplementation has been demonstrated in both humans and animals [10,11]. Antagonising NF-κB may also attenuate muscle function deficits post-EIMD by supporting myoblast proliferation and differentiation[20]. Specific to DOMS, curcumin may exert its beneficial effects by supressing the production of algogenic substances such as cyclooxygenase[8] and prostaglandin E_2[21].

A further plausible mechanism by which curcumin may enhance recovery from EIMD is the activation of nuclear factor erythroid 2-related factor 2 (Nrf2), a redox sensitive transcription factor. Nrf2 upregulates cytoprotective redox enzymes such as catalase, glutathione peroxidase and superoxide dismutase, which can modulate oxidative damage[22] and, theoretically, DOMS and impairments in muscle function associated with excess oxidant generation. Although curcumin activates Nrf2[23], this effect has not been reported alongside markers of muscle damage in humans. Animal data support this theoretical mechanism as curcumin ingestion increased Nrf2 and antioxidant gene expression while concurrently decreasing markers of muscle damage (creatine kinase, lactate dehydrogenase) and oxidative stress (malondialdehyde) subsequent to exhaustive exercise in rats[19]. Moreover, a recent study with (poly)phenol-rich cherry juice reported upregulation of antioxidant enzymes and gene expression in human skeletal muscle coinciding with enhanced recovery of MIVC 48 h post-eccentric exercise[24]. We were unable to collect biological samples in this study and thus can only postulate that supressing NF-κB and/or activating Nrf2 were mechanisms responsible for curcumins effects in this study.

We have previously reported decreased subjective wellbeing in soccer players in the days after a match[25], likely due to fatigue, muscle soreness and stressors related to elite performance and sleep loss. In the current study, curcumin supplementation improved subjective wellbeing in the days post-match compared to control, which contrasts to our previous work with tart-cherry juice supplementation, which is also high in (poly)phenols[13]. Sciberas et al.[26] reported similar findings; participants felt better with the causes and symptoms of psychological stress as assessed by the Daily Analysis of Life Demands on Athletes (DALDA) after consuming 500 mg/day of curcumin 4-days prior to exercise. However, participants undertook this trial glycogen depleted, and the DALDA is a retrospective means of measurements, increasing its risk of recall bias. Whether the improved wellbeing in our study is a direct effect of curcumin or an indirect effect of reduced DOMS and muscle function impairments is unclear. Lending support to the former, several previous studies in older adults have suggested that curcumin's anti-inflammatory and neuroprotective properties may enhance mood and improve cognitive function[27,28]. However, these studies did not give an acute dose like ours, instead supplementing curcumin chronically (> 4 weeks[27,28]).

Previously, curcumin supplementation ameliorated symptoms of EIMD with doses between 150 mg and 6 g/day[7]. We administered a dose of 500 mg/day on three consecutive days starting immediately after exercise. The curcumin formulation contained 500 mg of NovaSOL® curcuminoids and 20mg Vitamin C delivered in a water-soluble and pH stable form, which enhances its bioavailability[29]. Although this formulation is shown as bioavailable[29], we were unable to quantify circulatory curcumin concentrations in the present study. Interestingly, the dose in the present study is lower than that used by Delecroix and colleagues[12] who gave elite rugby players 6 g of curcumin and 60 mg of piperine/day from 48 h pre-exercise to 48 h post-exercise. Thus, our study suggests well-trained athletes may only require small acute doses of curcumin to enhance recovery from EIMD and only up to MD+1 (36 h post-match). To our knowledge, curcumin intake at these doses are safe, and no side effects were reported in our study. However, further research is required to determine if regular doses of curcumin affect exercise adaptations; indeed, some, but not all studies, suggest interfering with inflammatory or antioxidant pathways may impede exercise adaptations[30]. While the evidence for such effects are weak[30], especially with (poly)phenols, further research should examine whether longer-term or higher doses influence exercise adaptations.

A key limitation of this study was our inability to interrogate the mechanisms by which curcumin could attenuate markers of EIMD; ideally, future studies would incorporate markers of oxidative damage, redox status, and inflammation. Finally, our sample size is inherently constrained due to the limited number of players in a soccer squad. As such, our findings may be more susceptible to type II errors and should be interpreted as such. Future studies could increase statistical power by repeating the procedures with the same participants. Despite these limitations, this study has many strengths, as it was the first to show that curcumin may alleviate symptoms of muscle damage in professional soccer players after a competitive match. These findings therefore have real-world practical application. Future research should seek to confirm these findings in further applied studies with elite athletes and in lab-based studies that concurrently investigate the underlying mechanisms.

Practical Applications

This study suggests that 500 mg/day of curcumin may enhance functional recovery in professional soccer players. As some studies suggest high doses of supplements with antioxidant features can impair exercise adaptations[30], until further research is conducted it may be prudent to supplement curcumin when recovery and not training adaptations are a priority (e.g. pre-season, tournaments). Indeed, curcumin could be taken when recovery time between competitive matches is limited to <72h, adaptations are not a priority, and/or players are still experiencing DOMS or impairments in muscle function.

Conclusion

Our findings are consistent with most studies in untrained populations using different models of EIMD and suggest that curcumin might be an effective recovery aid in elite team-sport players. Although these findings need to be confirmed with additional studies, they suggest players recovery could be enhanced with curcumin supplementation, and therefore supplementation should be considered during periods of fixture congestion

Acknowledgements

The authors would like to thank the players who participated in the present study and the support staff from the soccer club who aided data collection.

Author contributions: TC, WA, EH, LJ and JS designed the study and sought ethical approval. Data collection was undertaken by WA and AB. EH and TC completed data analysis and a draft of the manuscript. All listed authors edited the manuscript draft and contributed to the final manuscript submission.

Conflicts of Interest

The authors declare no conflicts of interest.

Figure captions

Figure 1 – (A) Countermovement-jump (CMJ) height, (B) reactive strength index (RSI), (C) delayed-onset muscle soreness (DOMS), and (D) subjective wellbeing before and 12, 36, and 60-hours post-match in the curcumin (solid dots) or control (open dots) trials. ¥ Signifies a difference between conditions at this time-point ($P < 0.05$); # Signifies a difference compared to baseline (pre-match) at this time-point ($P < 0.05$). Data are presented as % change from baseline for illustrative purposes only. Values are mean ± SD. N = 11. AU indicates arbitrary units.

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