

RESEARCH

Open Access



Sweet relief: a randomised controlled trial of the effectiveness of dark chocolate for managing menstrual cycle-related symptoms in female athletes

Sara Chica-Latorre^{1*} , Tamara M. Grant¹ , Andrew J. McKune^{1,2,3}, Martin R. Lindley⁴ and Michelle Minehan¹

Abstract

Background Female athletes frequently report menstrual cycle-related symptoms (MCS), which impact wellbeing, training and perceived performance, prompting exploration of strategies to support symptom management. Dark chocolate is rich in cocoa polyphenols and other bioactive compounds that may influence inflammatory, oxidative stress, mood- and pain-related pathways implicated in MCS. This study evaluated dark chocolate as a strategy to manage MCS in female athletes. Twenty-five athletes consumed 40 g of 70% dark ($n = 13$) or 25% milk ($n = 12$) chocolate daily for eight days (-4 to +4 days from bleeding onset) across two menstrual or hormonal contraceptive cycles, following a two-cycle baseline. Primary outcomes were MCS frequency and severity, brain fog, and high sensitivity C-reactive protein. Exit interviews captured expectations and perceptions.

Results Over 70% of participants reported moderate baseline MCS severity. Among nine MCS clusters, the dark chocolate group showed the largest, albeit non-significant, declines in negative affect ($\Delta = -1.21$, $p = 0.06$) and pain ($\Delta = -0.65$, $p = 0.07$); changes in the milk chocolate group were small ($|\Delta| \leq 0.64$). Linear mixed models revealed no significant effects of time, group, or interaction ($p > 0.97$) on primary outcomes. Interviews indicated (1) mixed expectations, (2) perceived but hard-to-isolate symptom relief, (3) enjoyment/adherence, and (4) benefits from symptom tracking and communication.

Conclusions Eight days of chocolate produced no group-level effects, yet the intervention was feasible and associated with individual perceptions of comfort and modest relief. Larger trials with higher doses and longer exposure are warranted.

Trial registration ANZCTR.org.au. Trial registration ID: ACTRN12624000029594. Date of registration: 15/01/2024.

Keywords Female athlete, Menstrual cycle, Symptoms, Symptom management, Chocolate

*Correspondence:

Sara Chica-Latorre
sara.chicalatorre@canberra.edu.au

¹University of Canberra, Research Institute for Sport and Exercise,
Canberra, ACT 2617, Australia

²Functional Foods and Nutrition Research (FFNR) Laboratory, University of
Canberra, Canberra, ACT 2617, Australia

³Discipline of Biokinetics, Exercise and Leisure Sciences, School of Health
Sciences, University of KwaZulu-Natal, Durban, KwaZulu-Natal
4000, South Africa

⁴School of Health Sciences, Faculty of Medicine and Health, University of
New South Wales, Sydney, NSW 2052, Australia



© The Author(s) 2026. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

Background

The menstrual cycle (MC) has potential to influence health and athletic performance, yet the influence of the MC on athletes is understudied [9, 16]. Quantitative investigations indicate that MC and hormonal contraceptive (HC) use have unclear impacts on sports performance [22, 45], however athletes themselves perceive their capacity to train and perform is affected by the MC or HC use [11]. Menstrual cycle-related symptoms (MCS) are common with over 80% of active individuals reporting symptoms [3, 10, 42, 44]. The extent to which MCS affect individuals is highly varied and their aetiology is not fully understood [10, 44, 57]. Nevertheless, it is recognised that MCS affect physiology, psychology, and quality of life, making this a focal issue in terms of athletic health and performance [12, 42, 56].

Events of the MC (i.e., menstruation, ovulation) cause tissue damage and inflammatory responses in the uterus [50]. There is a well-recognised crosstalk between the immune and reproductive systems, where a degree of inflammation is essential to fulfil normal menstrual function [51]. Nevertheless, alterations to immune-mediated inflammatory responses likely play a role in the occurrence of MCS [4, 32]. During a natural MC, progesterone withdrawal before menstruation triggers inflammatory processes, which have been linked to negative symptoms [24]. Specifically, increases in pro-inflammatory mediators (i.e., chemokines, cytokines, growth factors and prostaglandins) trigger leukocyte recruitment, which release more pro-inflammatory factors, attracting further leukocytes to the endometrium, worsening inflammation and causing uterine hypercontractility, hypoxia, ischemia, and pain [24]. Studies in healthy, naturally cycling (NC), non-athletic individuals show that C-reactive protein levels (CRP; an acute-phase protein and a marker of systemic inflammation), including high-sensitivity CRP assays (hsCRP), are positively correlated with the severity of self-reported MCS. These symptoms include mood- and pain-related symptoms [30, 52], cravings and appetite changes [1], and fluctuations in MC characteristics such as cycle length [34]. Similarly, some HC formulations can induce local (i.e., reproductive organs) and systemic immune changes, including increased inflammation and CRP levels, which may exacerbate symptoms [20, 38]. However, regular training induces complex physiological adaptations that generally support a lower baseline inflammatory state [29], which may modify the expression and sensitivity of biomarkers like CRP in athletic populations [26], and potentially alter their relationship with MCS.

Diet has the potential to directly or indirectly affect inflammation and immune-health outcomes [13]. Polyphenols are plant-derived phytonutrients widely studied for their antioxidant and anti-inflammatory health

benefits. They are abundant in herbs, fruits, berries, tea, coffee, red wine, and cocoa products, including dark chocolate [19]. Cocoa is particularly rich in the polyphenols epicatechins and procyanidins, which potentially neutralise reactive oxygen species, limiting oxidative stress and preventing the activation of nuclear factor-kappa B (NF- κ B), an important transcription factor that promotes the release of inflammatory cytokines such as interleukin-6 (IL-6) and tumour necrosis factor- α (TNF- α) [2, 53]. Given that the hepatic production of CRP is induced by these cytokines [18], modulation of this inflammatory signalling pathway might be implicated in MCS severity reduction (Fig. 1). Additionally, dark chocolate contains other bioactive components like theobromine, which may influence mood and pain perception [53]. Studies have investigated the effect of dark chocolate on reducing MCS in relatively healthy, young, non-athlete individuals, with findings suggesting reduced menstrual pain following short-term dark chocolate protocols. These included 40 g per day of 60% cocoa dark chocolate for three days before menstruation and on the first day of menstruation, 40 g per day of dark chocolate with unspecified cocoa content during the first three days of menstruation, and a single 35 g dose of 70% cocoa dark chocolate on the first day of menstruation [39, 41, 49]. Nevertheless, there is little research in female athletes, with only a singular sports-specific study (i.e., CrossFit®) evaluating 30 g per day of dark chocolate (85% cocoa) over three consecutive days, reporting physical and cognitive improvements during the late luteal phase [55]. As most evidence supporting dark chocolate's benefits for MCS management stem from non-athletes, the applicability of these findings to athletic cohorts remains unclear.

Importantly, an increased desire (craving) for chocolate around menstruation and withdrawal bleeding, is commonly reported by athletes and non-athletes [12, 37, 40]. Yet, individuals' views on chocolate cravings are usually shaped by maladaptive eating and weight attitudes, promoting conflicts between feelings such as contentment and guilt [37]. Negative attitudes might be more pronounced for types of chocolates not associated with health benefits, driven by a "personal health responsibility", as is the case with milk chocolate compared to dark chocolate [46]. Hence, despite an increased desire for chocolate, athletes can experience uncertainty and guilt about consuming different types of chocolate [12].

Chocolate could offer an opportunity to manage MCS. Particularly, high polyphenol (dark) chocolate might modulate pro-inflammatory mediators related to MCS, offering adjunct dietary management for athletes. Therefore, this study aimed to assess the effectiveness of dark (70% cocoa) versus milk (25% cocoa) chocolate in reducing MCS in athletes, and to examine its relationship

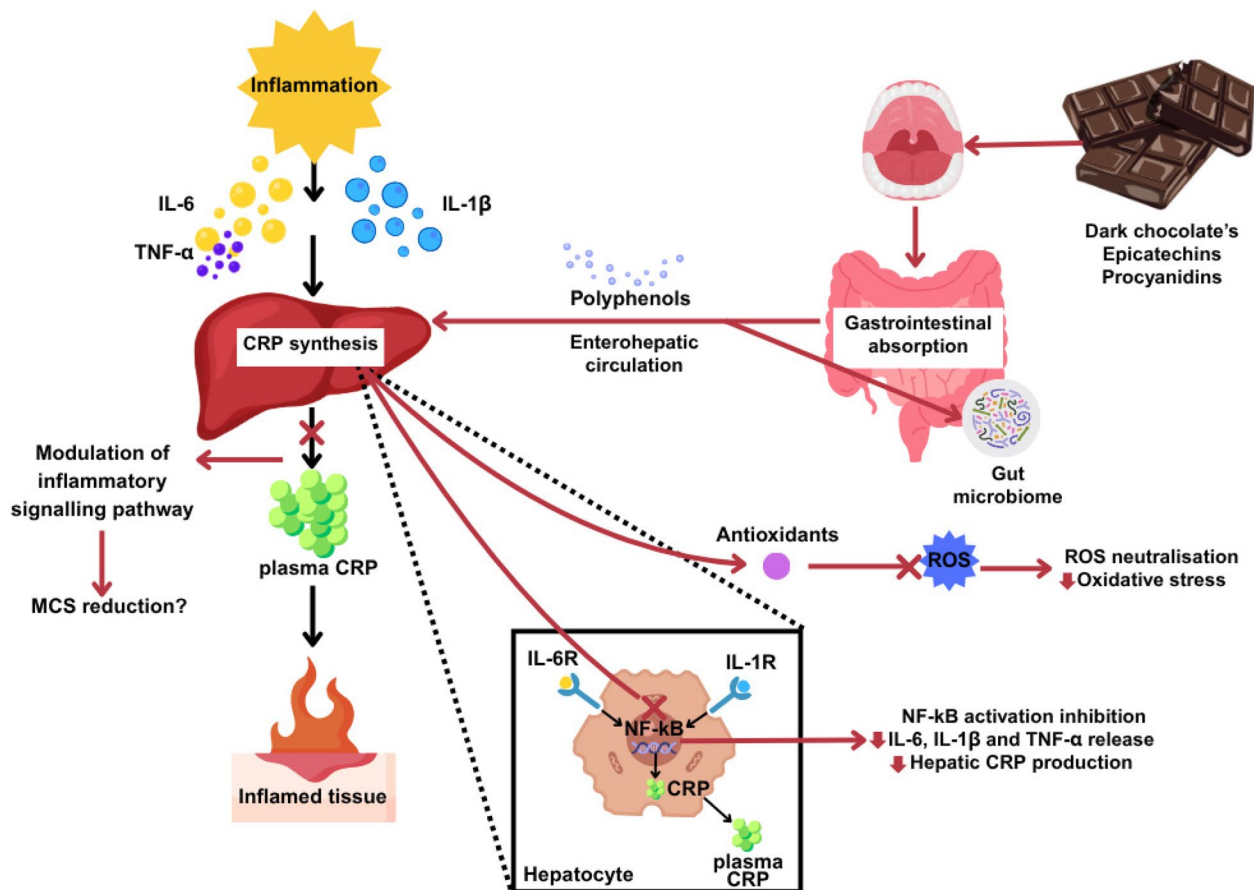


Fig. 1 Anti-inflammatory effects of dark chocolate-derived polyphenols (epicatechins and procyanidins) through their inhibition of the nuclear factor-kappa B (NF- κ B) mediated C-reactive protein (CRP) synthesis and inflammatory pathway, and reactive oxygen species (ROS) neutralisation. Note. IL-6=interleukin 6; IL-1 β =interleukin 1 beta; TNF- α =tumour necrosis factor alpha. Synthesised and redrawn by the authors, based on data and concepts from previous work [2, 18, 53]

with hsCRP as an indicator of systemic inflammation. We hypothesised that consuming dark chocolate during symptomatic days would result in greater reductions in (1) overall MCS severity and frequency, (2) brain fog, and (3) hsCRP levels.

Methods

Study design

A randomised controlled trial (RCT) monitored athletes for four consecutive MC or HC cycles. Athletes were recruited from January to September 2024. All participants provided written informed consent. This study was approved by the Human Research Ethics Committee of the University of Canberra (HREC – 13591) and is reported according to CONSORT (participant flow-chart in Fig. 2) [36]. A sample size of 24 was estimated based on an a priori power analysis (Cohen's f effect size of 0.25, with α 0.05 and power of 0.80) for a two-group $\times$ four-time-point (cycles) repeated measures and within-between interactions analyses of variance calculated through G-power 3.1 statistical software [25]. Given that

no prior chocolate and MCS, or inflammatory-marker and MCS study closely matched the present study's design, population, and outcomes, a medium effect size (Cohen's f =0.25) was adopted as the most appropriate pragmatic estimate, consistent with established conventions for health research where this value represents a medium effect [14].

Participants and recruitment

Athletes (18–40 yrs) living in the Australian Capital Territory and New South Wales (Australia), who were training to participate in sport competitions and experienced regular menstrual bleeding or withdrawal bleeding (frequent and between 21 to 35 days long), were recruited. Regular menstrual or withdrawal bleeding was confirmed prior to study commencement through a three-month cycle tracking diary provided by participants recorded using their preferred tracking app. Purposive sampling was used to recruit participants who described experiencing negative MCS for at least the past three cycles, irrespective of HC use. Athletes were excluded if they

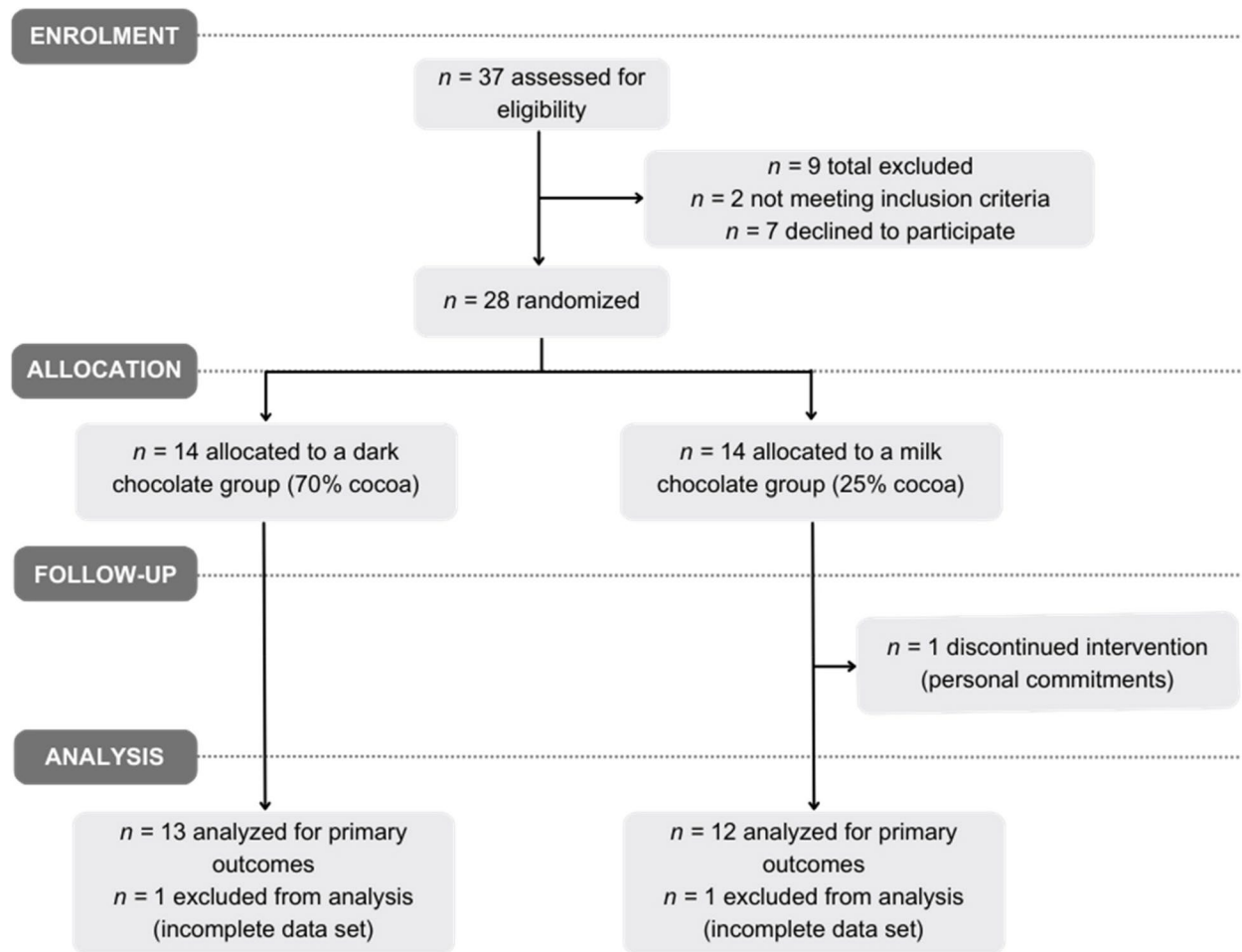


Fig. 2 CONSORT flowchart of participant progress through the randomised controlled trial

reported (1) being pregnant or lactating, (2) any diagnoses of chronic illness, including MC-related conditions (e.g., Polycystic Ovarian Syndrome (PMOS), endometriosis), or (3) being intolerant or allergic to chocolate. Eligible athletes were also excluded if unwilling to refrain from using anti-inflammatory medication or supplements during the study.

Definition of female athlete

Female athletes in this study are ‘any individual who identifies with a particular sport, actively trains to enhance their athletic skills to meet competitive standards, whether recreational or professional, and experiences menstruation or withdrawal bleeding.’ Hence, all participants were classified as Tier 2 or higher according to McKay et al., [43]. While all participants experienced menstruation or withdrawal bleeding, they represented diverse gender identities, and not all identified as women or female.

Method

This study consisted of a two-cycle baseline stage and a two-cycle intervention stage. Eligible participants identified initially as either naturally cycling (NCathletes) or HC users (HCathletes) and were randomly allocated to consume 40 g of 70% (dark chocolate group) or 25% (milk chocolate group) cocoa chocolate during the intervention stage. Block randomisation was used. Blinding was not feasible; however, participants were blinded to other possibilities of group allocation (i.e., participants did not know if and which types of chocolate were allocated to other participants). Participants began the study four days prior to the onset of their next menstrual or withdrawal bleed, which was prospectively identified using a three-month cycle tracking diary provided by participants upon recruitment. An eight day intervention was selected to span the anticipated symptomatic window surrounding bleeding onset, from the late luteal onset of MCS to the early bleeding phase. Four dependent variables, MCS frequency, MCS severity, brain fog, and hsCRP levels, were evaluated each cycle.

Menstrual cycle-related symptoms assessment

Menstrual cycle-related symptoms (MCS) were assessed with the 46-item Menstrual Distress Questionnaire (MDQ) Form T (today) [47]. Eight symptom clusters: pain, concentration, water retention, behaviour change, negative affect, autonomic/metabolic, arousal, and control are covered. The MDQ Form T was adapted to include an additional symptom cluster (six items: including cravings, and changes in appetite, taste preference and bowel habits, relating to common symptoms experienced by athletes in previous studies [10] tallying to nine symptom clusters and 52 total items.

The MDQ was administered at each cycle for eight consecutive days starting four days before the expected onset of bleeding and concluding after the fourth day of bleeding. Daily severity of MCS was rated using a 5-point scale from “No experience of symptom” (0) to “Present, Severe” (4) and was calculated as the daily sum of the total scores for each symptom cluster with a maximum value of 208, where higher scores reflected greater severity of MCS. Symptom frequency was the count of items ≥ 1 (maximum value 52). To compare symptom severity scores, raw scores were converted to standard scores (mean 50, standard deviation 10) [47], enabling categorisation of participants into low-, moderate-, or high-MCS severity.

Symptoms related to brain fog (e.g., confusion, forgetfulness, concentration issues) were studied using a 23-item Brain Fog Scale (BFS) [17], administered every two weeks across the length of the study. The biweekly administration of this questionnaire ensured coverage of the full MC or HC cycle, as each round was designed to retrospectively capture participants' experiences over the previous two weeks. Items were rated in a 5-point scale from “Never” (0) to “Nearly all the time” (4), with total BFS score calculated as the sum of items, ranging from 0–92, higher values denoting worse brain fog.

High sensitivity C-reactive protein levels assessment

hsCRP was measured as an exploratory marker of low-grade systemic inflammation to examine its association with MCS and to assess whether chocolate consumption, particularly polyphenol-rich dark chocolate, was accompanied by changes in systemic inflammation. This was based on previous links between hsCRP and MCS severity in non-athletic individuals, and the proposed anti-inflammatory properties of cocoa polyphenols [30, 52, 53]. Venous blood samples (5–10 ml) were assessed for hsCRP using the Cardiac C-Reactive Protein (Latex) High Sensitive assay (CRPHS), a particle-enhanced immunoturbidimetric assay (PETIA), on Roche/Hitachi cobas c system compatible with cobas c 303/c 503 analyses (Roche Diagnostics GmbH, Mannheim, Germany). Manufacturer-reported precision ranged from 0.4–8.4%

CV, depending on analyte concentration. Samples were collected between 6 am and 12 pm and processed by an external provider (Intelligent Screening Pty Ltd). Participants refrained from exercise at least 12 h prior. Samples were collected on the first, second, or third day of bleeding (menstruation or withdrawal bleed). Timing of hsCRP testing was established to capture a raise in CRP, based on previous research on healthy NC individuals showing a peak in CRP during menstruation [28], a 17% increase during menstruation [59], and a positive correlation between CRP levels and MCS [52].

Menstrual cycle state confirmation

NCathletes confirmed their MC status by detecting a urinary luteinising hormone (LH) surge (Pregmate®) to confirm ovulation. Testing began on day eight for cycles 21–27 days long, and on day ten for cycles ≥ 28 days long, continuing until a positive result or until day 18 of the cycle [23]. Seven to nine days post-ovulation confirmation, serum progesterone was sampled between 6 am and 12 pm and analysed using the Atellica® IM Progesterone (PRGE) assay, a competitive immunoassay using direct chemiluminescent technology, on the Atellica IM Analyser (Siemens Healthineers). Manufacturer-reported within-laboratory precision ranged from 2.9–12.9% CV, depending on analyte concentration. Analyses were performed by an external provider (Intelligent Screening Pty Ltd). Progesterone concentrations ≥ 16 nmol/L were used to confirm mid-luteal phase status and the absence of luteal phase deficiency [23]. This was used to further characterise NCathletes as eumenorrhoeic (EUathletes) [23]. Hence, NCathletes were defined as participants reporting naturally occurring MCs and no HC use, whereas EUathletes represented the subgroup of NCathletes with confirmed ovulation and mid-luteal progesterone ≥ 16 nmol/L during the baseline cycles. HCathletes also had their progesterone concentrations established approximately seven to nine days before a predicted withdrawal bleeding to characterise endogenous progesterone status at the time of sampling. These values were used descriptively and were not used to confirm luteal phase status or to classify HCathletes as eumenorrhoeic.

Chocolate intake

Commercially available milk (25% cocoa) and dark (70% cocoa) chocolates were used. Milk chocolate was selected as a near-isocaloric, lower-cocoa, lower-polyphenol active comparator that offered a similar food matrix to dark chocolate. This allowed for the partial control of the non-specific effects of chocolate consumption, including palatability and the behavioural aspects of receiving a dietary intervention, while allowing to test a dose–response relationship between cocoa content and MCS

relief. Detailed composition information is stated in Supplementary Material 1.

Participants received 640 g (pre-portioned) of 25% or 70% cocoa chocolate to be consumed in batches of 40 g per day for eight consecutive days. The dark chocolate dose (40 g per day) provided approximately 28 mg of epicatechin, 8 mg of catechin, and 25 mg of total procyanidins (*Supplementary 1*). This phenolic dose reflects realistic, food-based intake and aligns with dark chocolate doses from previous research (35–40 g) showing symptom relief in non-athletic and athletic populations [39, 49, 55]. Hence, our pragmatic dosing approach aimed to balance physiological relevance with practical consumption in athletic settings.

Chocolate consumption started four days before the expected onset of bleeding and ceased four days after the onset of bleeding, overlapping with the expected onset of MCS and rise in CRP levels in non-athletic NC individuals [28, 52, 59]. Participants were required to avoid any pain-relief medication, particularly anti-inflammatory analgesics, during the eight monitoring days (Fig. 3).

Assessment of dietary intake, training load and body composition

Participants completed daily food diaries and physical activity logs from four days before to four days after the expected onset of bleeding. These coincided with daily records of MCS and chocolate intake during the intervention.

Dietary intake (i.e., kilocalories (kcal)), macronutrients, micronutrients and food groups, were assessed using Easy Diet Diary™ (Xyris Software Australia Pty Ltd) and FoodWorks (Version 9, Xyris Software, Canberra, Australia), a method validated in female athletes [15]. Participants were instructed on how to record their food and fluid intake using audiovisual and verbal guidance

and received daily text message reminders during recording periods to enhance compliance. Participants were instructed to maintain their usual diet and avoid the introduction of new foods or supplements, when possible, across the study length. All food records were reviewed by a trained sports dietitian, with follow-up for clarification on food entries as needed. Under-reporting was screened with the Goldberg cut-off method [5]. This approach accounts for intra-individual variation in energy intake ($CV_{wEI}=23\%$) and basal metabolic rate ($CV_{wB}=8.5\%$), with total variation (CV_{tP}) of 15%, and applies a 95% confidence interval ($[CI] Z=2.0$) and physical activity level (PAL) of 1.55, reflecting moderate activity levels. Implausibly low intake was therefore defined as reported energy intake falling below the participant-specific lower Goldberg cut-off for plausible energy intake relative to estimated basal metabolic rate, rather than by a fixed kcal threshold. Days with implausibly low reported energy intake were excluded.

Participants completed training logs recording session duration (in minutes) and Rating of Perceived Exertion (RPE; 0–10). A session-RPE (sRPE) was calculated as the product of session duration and RPE, as a proxy for training load [27]. Higher sRPE values were interpreted as reflecting greater internal training load. This method was selected as a pragmatic approach to compare training load across heterogeneous sports modalities. Body composition was assessed using dual-energy X-ray absorptiometry (DXA, GE Lunar Prodigy), analysed using GE enCORE software (enCORE Version 17, GE Healthcare). Participants were measured in the morning following standardised conditions: eight-hour fast, normal hydration, and wearing light clothing free of metal objects. Positioning was as described by Nana et al., [48]. The coefficient of variation (CV) for lean body mass was 0.7%,

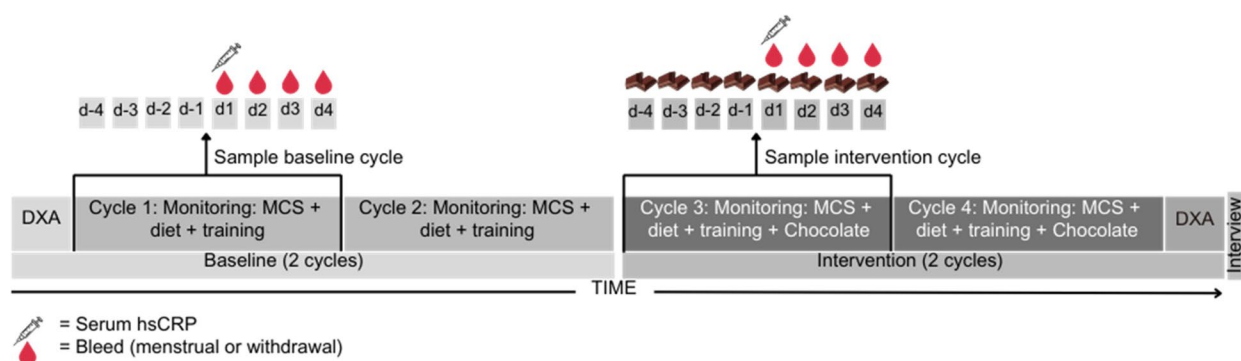


Fig. 3 Schematic overviewed of the study methodology. Note. Menstrual cycle-related symptoms (MCS), dietary intake, and training loads (frequency and perceived exertion) were monitored for eight days (−4 days to +4 days from onset of menstrual or withdrawal bleed) across two baseline cycles and two intervention cycles. Additionally, across the two intervention cycles 40 g of dark (70% cocoa) or milk (25% cocoa) chocolate were consumed. Serum high sensitivity C-reactive protein (hsCRP) was assessed at the onset of menstrual or withdrawal bleed, Dual-energy X-ray Absorptiometry (DXA) scans took place before commencing the study and after completing the intervention, and participants were interviewed (15–30 min) about their experiences after completing the intervention

with a least significant change (LSC, 95% CI) of 1.9%. For fat mass, the CV was 1.3%, LSC (95% CI) of 3.7%.

Statistical analysis

Frequencies and percentages were used to summarise categorical participant characteristics, such as sport modalities (endurance-based, strength/power-based, or hybrid/team sport), MC characteristics (NCathletes, EUathletes or HCathletes), and athlete calibre (Tier 2–3). Means, standard deviation (SD), and ranges were reported for continuous variables, including age, body composition, dietary intake, training load, and the main outcomes hsCRP, MCS severity and frequency, and brain fog, within each chocolate group at baseline and during the intervention.

Independent samples *t*-tests and one way Analysis of Variance (ANOVA) were used to compare baseline body composition, dietary patterns and training load between chocolate groups and across sport modalities, MC characteristics and athlete calibre. Changes over time (baseline $\times$ intervention) for the same parameters were evaluated using mixed-model ANOVAs. Linear mixed models (LMMs) were used to assess the effects of time (baseline $\times$ intervention), chocolate group (dark $\times$ milk), outcome type and their interactions on the outcome variables. Participant ID was modelled as a random intercept to account for individual-level variability across repeated measures. Fisher-Freeman-Halton exact test was used to compare the distribution of low, moderate, and high MCS severity categories between chocolate groups at baseline and intervention. Dietary data and training load were considered as potential covariates. However, these variables were retained in the final model only if they differed between chocolate groups and subgroups at baseline or changed significantly over time. Normality of residuals was checked via histogram inspection. All analyses were performed in MATLAB 2023b (Mathworks, Natick, MA, USA) and RStudio (version 2024.12.0 + 467).

Athlete experiences and perceptions were explored through semi-structured interviews using the virtual communication platform Microsoft Teams (version 1.6.00.4472) and analysed using reflexive thematic analysis [7].

Results

Participants

Twenty-five participants randomly allocated to a dark ($n=13$; mean age = $30.0 \pm \text{SD } 4.7$) or milk ($n=12$; mean age = $27.2 \pm \text{SD } 6.5$) chocolate completed the study. Characteristics of participants are summarised in Table 1.

Body composition, dietary intake and training loads

Independent sample *t*-tests at baseline revealed no significant differences between chocolate groups for

body composition, dietary patterns, or training load. In terms of dietary analysis, based on the Goldberg cut-off method, ten dietary records were identified as under-reporting and excluded from analysis. Similarly to chocolate groups, no significant differences in these parameters were found between, NCathletes ($n=3$), EUathletes ($n=14$), or HCathletes ($n=8$; one-way ANOVA), between athlete tiers (independent samples *t*-test), or between sport modalities (one-way ANOVA). Two exceptions were noted. First, body mass index (BMI) was significantly higher in strength/power athletes (mean = $27.6 \text{ kg/m}^2 \pm 4.7$; $F(2, 22) = 5.08$; $p = 0.02$; $\eta^2 = 0.32$) compared to endurance (mean = $23.2 \text{ kg/m}^2 \pm 2.4$) and hybrid/team-sport athletes (mean = $21.1 \text{ kg/m}^2 \pm 3.9$). Second, Tier 3 athletes showed higher energy intake (mean = $2,476 \text{ kcal} \pm 371$; $p = 0.03$, Cohen's $d = 1.43$), dietary fibre (mean = $34 \text{ g} \pm 11$; $p = 0.02$, Cohen's $d = 1.61$), iron (mean = $13 \text{ mg} \pm 4$; $p = 0.03$, Cohen's $d = 1.45$), and calcium (mean = $1,617 \text{ mg} \pm 1,002$; $p = 0.02$, Cohen's $d = 1.52$) compared to Tier 2 athletes ($1,843 \text{ kcal} \pm 450$, $21 \text{ g} \pm 8$, $9 \text{ mg} \pm 3$, and $764 \text{ mg} \pm 498$ for mean energy intake, dietary fibre, iron and calcium respectively), with large effect sizes. However, given the small Tier 3 subgroup ($n=3$), these *p*-values and effect sizes are calculated from minimal degrees of freedom and have high uncertainty. These dietary differences are reported for completeness and should be interpreted cautiously. Mixed-model ANOVAs revealed no significant time effect of chocolate group on changes in body composition, dietary intake, or training load, nor were there significant time $\times$ group interactions, indicating these parameters remained stable throughout the study. Hence, these parameters were excluded from the final model due to non-significance and concerns about overfitting given the small sample size.

Menstrual cycle-related symptoms, brain fog and high sensitivity C-reactive protein

At baseline, differences between NCathletes, EUathletes and HCathletes, and between athlete tiers or sport modalities in MCS severity ($p = 0.76$ and $p = 0.99$), frequency ($p = 0.89$ and $p = 0.85$), brain fog scores ($p = 0.38$ and $p = 0.32$), or hsCRP levels ($p = 0.50$ and $p = 0.78$), were not significant. Across chocolate groups, most participants experienced moderate MCS severity at baseline (76% dark chocolate, 75% milk chocolate) and intervention (61.5% dark chocolate, 66.7% milk chocolate) (Table 2).

Given the limited sample size, participants were pooled for the primary analysis after exploratory analysis showed no significant differences in baseline MCS scores or intervention responses by MC status. This was for the HCathletes versus non-HC athletes (NCathletes + EUathletes)

Table 1 Baseline stage subject characteristics of 25 female athletes

Continuous variables	Dark Chocolate Group (n = 13)		Milk Chocolate Group (n = 12)		p-value
	Mean (SD)	Range	Mean (SD)	Range	
Age, years	30.0 (4.7)	23.0/40.0	27.2 (6.5)	20.0/40.0	0.23
Body mass index (kg/m ²)	23.0 (2.5)	18.8/27.1	23.5 (4.8)	17.0/33.0	0.63
Fat free mass (kg)	45.9 (4.4)	40.2/54.5	46.5 (6.7)	37.7/56.8	0.70
Percentage body fat (%)	27.9 (8.5)	14.1/42.4	29.2 (5.5)	20.9/42.4	0.62
Energy intake (kcal)	1942 (472)	1185/2857	1895 (514)	1149/2858	0.81
Protein (g)	87 (21)	48/125	98 (39)	49/160	0.35
Carbohydrate (g)	212 (72)	127/410	207 (76)	126/411	0.87
Total fat (g)	75 (20)	47/110	74 (24)	37/111	0.87
Sugar (g)	78 (42)	36/177	74 (41)	33/178	0.82
Fibre (g)	23 (10)	12/41	21 (8)	10/42	0.56
Iron (mg)	9 (3)	6/17	10 (4)	5/18	0.78
Calcium (mg)	905 (614)	400/2760	825 (645)	319/2761	0.75
Training load (units)	183.0 (106.0)	46.6/404.5	225.0 (125.4)	64.6/486.7	0.37
Nominal variables	Frequency (%)		Frequency (%)		Total
Menstrual cycle characteristics	Naturally cycling	3 (12)			3
	Confirmed Eumenorrhoeic at Baseline	6 (24)	8 (32)		14
	Hormonal contraceptive users	4 (16)	4 (16)		8
Sport modalities	Endurance-based	11 (44)	3 (12)		14
	Strength and Power-based	1 (4)	3 (12)		4
	Hybrid/team sport	1 (4)	6 (24)		7
Athlete calibre	Tier 2	10 (40)	12 (48)		22
	Tier 3	3 (12)			3

Participants allocated to either a dark chocolate group (70% cocoa) or a milk chocolate group (25% cocoa). Continuous variables results are shown as mean (standard deviation, SD), and minimum/maximum values. Nominal variables results are shown as frequency (percentage, %). Naturally cycling participants did not use hormonal contraception. Confirmed eumenorrhoeic at baseline participants were the subgroup of naturally cycling participants with confirmed ovulation (by urinary LH surge) and mid-luteal progesterone ≥ 16 nmol/L during the baseline cycle

Table 2 Percentage (frequency) distribution of low (scores < 40), moderate (scores < = 60) and high (scores > 60) severity of menstrual cycle-related symptoms (MCS) in the dark chocolate and milk chocolate groups at the baseline and intervention stages. Percentages and frequencies are based on standardised MCS severity scores (Z-scores). Fisher-Freeman-Halton exact t-test p-values for between-group differences in MCS severity category distributions are displayed

MCSs severity	Dark choco- late group (n = 13)	Milk choco- late group (n = 12)	Total	p- val- ue
Baseline				
Low (< 40)	1 (7.7%)	1 (8.3%)	2 (8.0%)	1.00
Moderate (< = 60)	10 (76.9%)	9 (75.0%)	19 (76.0%)	
High (> 60)	2 (15.4%)	2 (16.7%)	4 (16.0%)	
Intervention				
Low (< 40)	2 (15.4%)	3 (25.0%)	5 (20.0%)	0.72
Moderate (< = 60)	8 (61.5%)	8 (66.7%)	16 (64.0%)	
High (> 60)	3 (23.1%)	1 (8.3%)	4 (16.0%)	

comparison and for the HCathletes, NCathletes and EUathletes subgroup comparisons.

Across the nine MCS clusters, no baseline-to-intervention change (Δ) reached statistical significance in either chocolate group based on paired *t*-tests. Nevertheless, several descriptive patterns emerged (Fig. 4). In the

dark chocolate group, the largest numeric improvements (decrease Δ) were observed for “negative affect” (C6; 1.21 decline, 95% CI – 2.51 to 0.09, $p=0.06$), and “pain” (C1; 0.65 decline; 95% CI – 1.37 to 0.07, $p=0.07$). In the milk chocolate group, all changes were small ($|\Delta| \leq 0.64$). In contrast, “arousal” (C7), the only positive-valence symptom cluster, showed the largest numerical increase in both chocolate groups; however, estimates were imprecise and non-significant (dark chocolate: 95% CI – 1.01 to 2.77, $p=0.30$; milk chocolate: 95% CI – 0.69 to 1.97, $p=0.31$). Baseline variability was large across clusters (SD range 0.47–4.27 across clusters), and intervention variability was similar (SD range 0.36–4.33 across clusters), yielding wide 95% CIs (half-widths dark chocolate ± 0.45 –1.89 points and milk chocolate ± 0.52 –2.14 points) and limiting power to detect modest effects.

Linear mixed models showed no statistically significant main effects of time (estimate ≈ 0 , 95% CI: –5.77 to 5.76, $p=1.00$), chocolate group (milk x dark; estimate = 0.04, 95% CI: –8.19 to 8.27, $p=0.99$), or their interaction (estimate = –0.11, 95% CI: –8.44 to 8.20, $p=0.98$) on any of the primary outcomes (MCS severity, MCS frequency, hsCRP, or brain fog). Likewise, no significant effects were observed in the time x outcome, group x outcome, or time x group x outcome interactions ($p > 0.19$), indicating

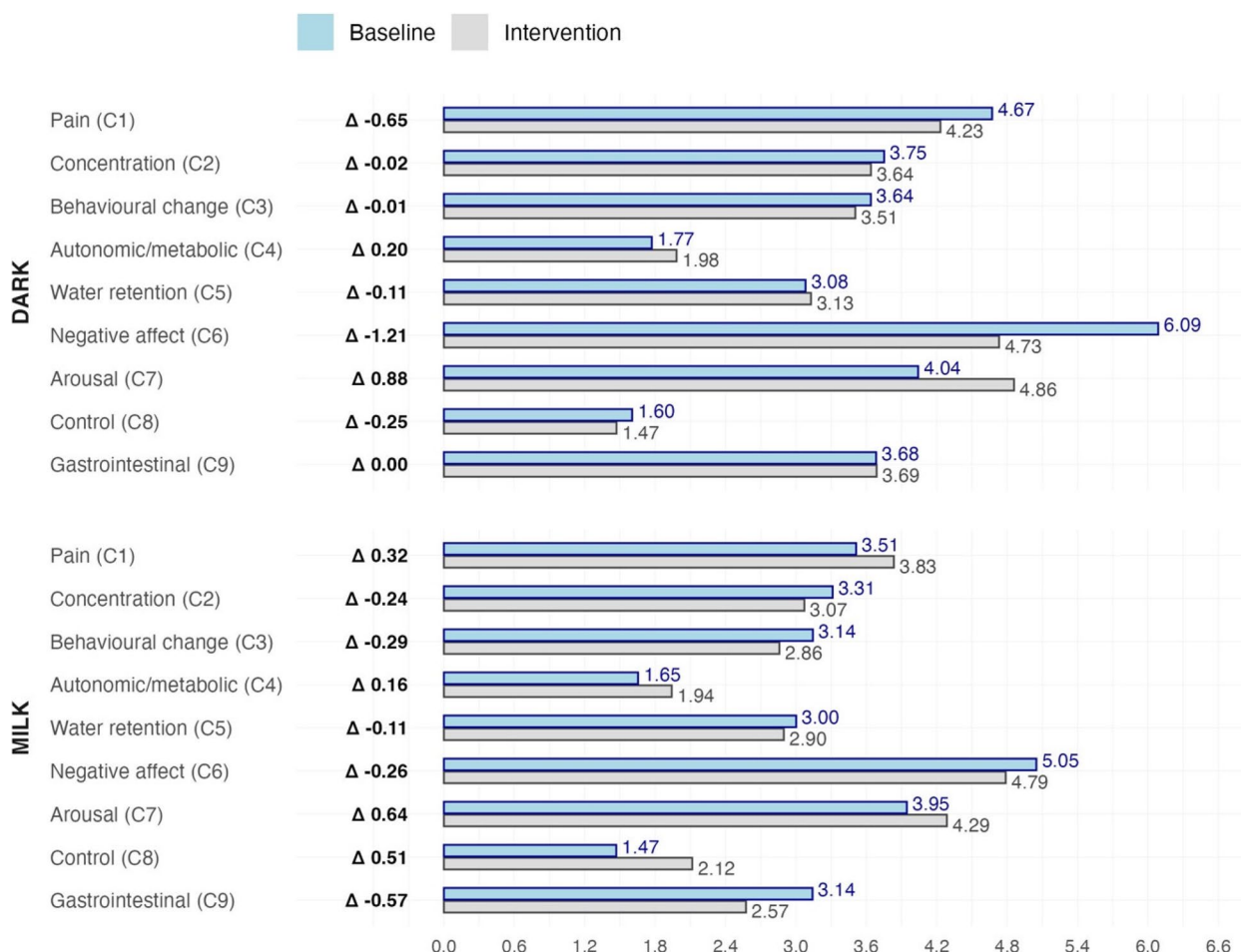


Fig. 4 Mean menstrual cycle-related symptom (MCS) severity by symptom cluster before and after the chocolate intervention. *Note.* Horizontal bars depict the mean participant-level severity score for each MCS cluster (C1–C9) at baseline (cycles one and two, light blue) and intervention (cycles three and four, light grey). Data are presented separately for the dark chocolate group ($n = 13$, upper panel) and the milk chocolate group ($n = 12$, lower panel). For every diary day recorded, non-zero symptom scores were summed within each cluster, and these daily totals were averaged across the eight day studied window to yield one score per participant per stage. Bold Δ values to the left of each cluster show the mean paired change (Intervention – Baseline) with negative values indicating symptom improvement and positive values intensification. For each cluster, individual symptoms are listed: Pain (C1): Muscle stiffness, headaches, cramps, backache, fatigue, general aches and pains; Concentration (C2): Insomnia, forgetfulness, confusion, lowered judgment, difficulty concentrating, distractible, accidents (blood leaks), lowered motor coordination; Behavioural change (C3): Lowered school or work performance, take naps/stay in bed, stay at home, avoid social activities, decreased efficiency; Autonomic/metabolic (C4): Dizziness/faintness, cold sweats, nausea/vomiting, hot flashes; Water retention (C5): Weight gain, skin disorders, painful breast, swelling; Negative affect (C6): Crying, loneliness, anxiety, restlessness, irritability, mood swings, depression, tension; Arousal (C7): Affectionate, orderliness, excitement, feelings of well-being, burst of energy/activity; Control (C8): Feeling of suffocation, chest pains, ringing in the ears, heart pounding, numbness/tingling, blind spots/fuzzy vision; Gastrointestinal (C9): Appetite changes, food craving, changes in taste preferences, constipation, diarrhoea or stomach upset

that temporal change and chocolate group differences did not depend on the primary outcomes measured. Descriptive patterns in Fig. 5 corroborate these results, showing that mean values (solid circles) remained relatively stable overtime in both chocolate groups, with SD overlapping extensively. However, Fig. 5 densities reveal marked inter-individual variability, especially for hsCRP, where a few isolated values (e.g., > 6 mg/L) produced long upper tails. MCS severity, frequency, and brain fog distributions were broad yet symmetric, showing no compression or shift over time.

Athlete perceptions

Post-intervention interviews revealed four themes: (1) expectations before commencing, (2) perceived effects on MCS, (3) acceptability and enjoyment of study tasks and (4) additional benefits from study participation.

Most participants began the study with a degree of scepticism over the benefits of chocolate intake for MCS management. For instance, “I’ve never really known if chocolate sort of helps with the menstrual cycle or not. I’ve sort of heard things here and there, but yeah, being able to sort of bust the myth is motivating” (P6). Fears about unwanted side effects, like “gaining some weight” (P5)

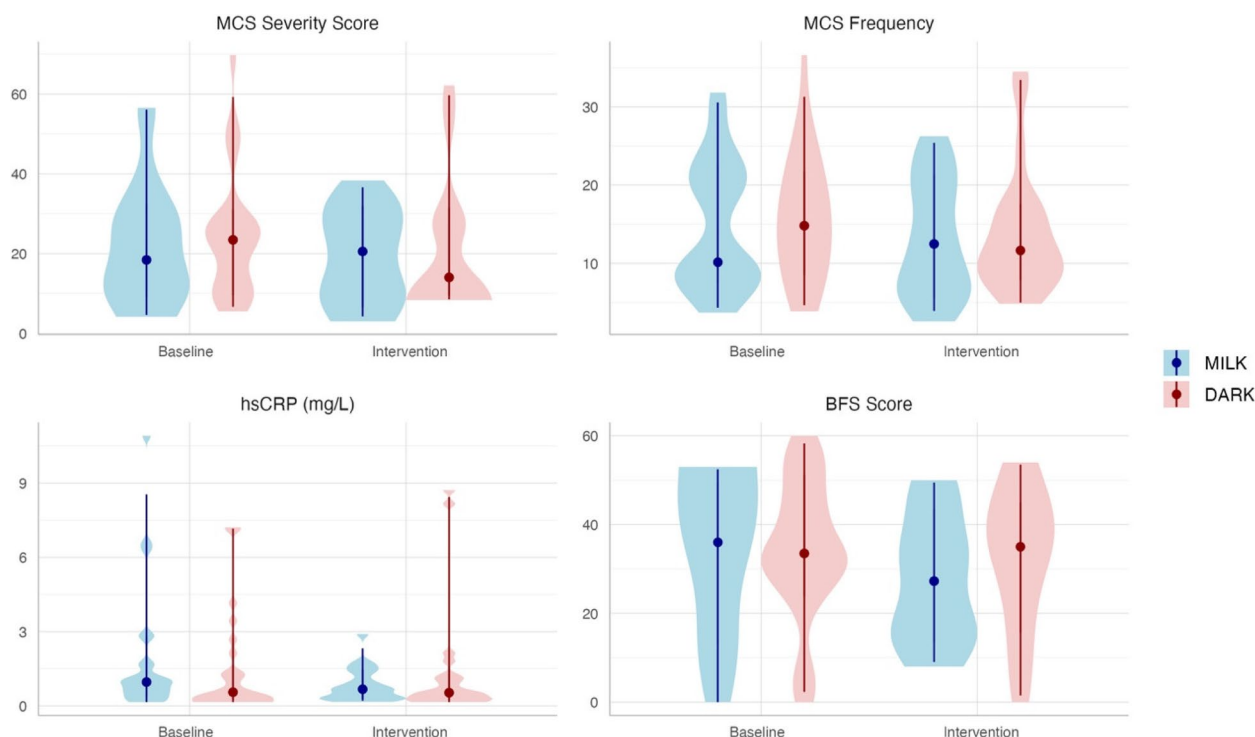


Fig. 5 Distributions of menstrual cycle-related symptom (MCS) severity score, MCS frequency, high sensitivity C-reactive protein (hsCRP; mg/L), and brain fog scale (BFS) score outcomes. Note. Rain plots show each outcome density distribution of participant-level cycle means per stage (baseline = cycles one and two; intervention = cycles three and four), distinguishing between the MILK (light blue) and DARK (red) chocolate groups. Within each rain plot the solid circle marks the sample mean, and the vertical bar represents $\pm$ standard deviation (SD) of the mean. Wider sections of the rain plot denote a higher concentration of participants at that value; narrow sections denote fewer participants. Vertical shifts of the two-coloured rain plots (i.e., MILK and DARK) within a panel indicates change between chocolate types, while vertical shifts between baseline and intervention reflect temporal (stage-related) change. Panels are plotted on independent y-axes to preserve the natural scale of each outcome: MCS severity score was calculated as the average of the daily sum of the total scores for each symptom (0–208) across an eight day window. MCS frequency was calculated as the average number of symptoms (0–52) rated one or higher across an eight day window. hsCRP values corresponded to a single measurement collected once per cycle at the onset of menstrual or hormonal bleeding. BFS corresponded to the average BFS score (0–92) obtained every two weeks (twice per cycle)

were prevalent. Unsurprisingly, most athletes expressed feeling “pleasantly surprised” (P11) that DXA scans showed no “negative” changes (i.e., unintentional weight gain) after consuming chocolate. This outcome positively shaped the perspectives of participants on chocolate allowance versus restriction, “I guess it sort of reassures that it’s OK to have a little bit of chocolate and a little bit of sugar, like it’s not gonna negatively affect my performance either” (P25).

Isolating the effect of chocolate on MCS was acknowledged by most as difficult. Some participants felt neutral and “pretty similar” (P4) across the study in terms of their symptoms. Nevertheless, some participants reported chocolate intake to be “comforting” (P2) and perceived improvements around fatigue, muscle stiffness, moodiness, bloating and cramping severity, “I started to feel a little bit better, and I think it was just because it was an emotional comfort for me having that chocolate... you know, I wasn’t crying as much towards the end of the study, but in the beginning it just felt a lot more up and down” (P1). Additionally, some participants expressed

feeling more energetic when eating the chocolate, which made their “cycles much more manageable” (P25) and made them feel they “wanted to exercise more” (P23). Reduced sugar cravings were also reported, with chocolate helping participants to feel “satisfied” (P8), and with some participants describing not experiencing their usual cravings towards the end of the study. Conversely, one participant reported “wanting to eat more chocolate [than the provided] and less healthy food” (P6) as a negative side effect, while few participants reported a sense of guilt.

Overall, the intervention was well received, with participants describing chocolate intake as both enjoyable and easy to “create a routine around it” (P19). Nevertheless, some described eight days of chocolate intake to be unexpectedly challenging, as they could “get sick of it” (P4) after a couple of days and acknowledged that 40 g of chocolate, regardless of the type, was “probably a bit too much chocolate to eat at once” (P12). Food diaries were described as “hard to do and remember” (P3) by most participants.

Lastly, some participants expressed that MCS questionnaires were “*really thought provoking*” (P11) and helped them be “*more conscious of my [their] body*” (P9) and to “*become more reflective*” (P23) of their MCS. One participant highlighted that participating in this study “*gave me a better understanding of learning to adapt my routine in my training to match that [symptoms]*” (P25). Some participants also appreciated the support given across the study and the opportunity of being open about their MCS, which were seen as helpful “*I think what helped was being able to talk about my symptoms openly*” (P5).

Discussion

This RCT is the first to evaluate athlete-generated concerns around the effectiveness of chocolate for the management of MCS in a diverse group of athletes across two menstrual or HC cycles. Daily intake of 40 g of dark (70% cocoa) or milk (25% cocoa) chocolate across symptomatic days did not result in statistically significant improvements in the primary outcomes: MCS, brain fog, or systemic inflammation, and revealed a high inter-individual variability within each chocolate group. Given this variability and the study’s small sample size, results should be interpreted cautiously and may reflect random rather than true effects. Nevertheless, exit interviews revealed perceived benefits from chocolate intake, such as improved energy, mood and motivation to train, and reduced chocolate cravings, irrespective of chocolate type. Such heterogeneity underscores the need for study designs that capture natural variability and single-athlete trajectories instead of relying solely on aggregate group means.

In contrast to our trial, previous studies in non-athletes using comparable dark chocolate doses (i.e., 35–40 g, 60–70% dark chocolate) reported significant reductions in menstrual-related pain and anxiety [39, 49]. Similarly, a double-blind, placebo-controlled crossover trial of naturally cycling CrossFit® athletes ($n=15$) showed that 30 g of 85% dark chocolate, administered during three consecutive days, improved physical and cognitive performance, particularly in the late luteal phase ($p=0.01$ and $p=0.002$ control and placebo comparisons) [55]. These earlier studies relied on a single chocolate dose [39] or short-term protocols [49, 55], were limited to one MC, and excluded HC users. Our RCT extends this work by testing chocolate intake along eight consecutive symptomatic days across two MC or HC cycles, offering a broader real-world perspective in athletic populations while explicitly accounting for between-cycle variability. This longer window and the inclusion of NC athletes and HC users, however, may also have increased within-group variability, potentially masking small but meaningful group effects.

The underlying mechanisms in the observed changes in MCS or brain fog were not directly investigated. Nevertheless, several possible pathways may explain modest improvements observed at the individual level. For instance, dark chocolate is a rich source of cocoa, which contains bioactive compounds like polyphenols (i.e., epicatechin: 0.31–1.25 mg/g, catechin: 0.11–0.40 mg/g, total procyanidins: 2.79–19.85 mg/g) that improve peripheral vascular function, cognitive function, oxidative stress and inflammation [53]. Additionally, cocoa-derived methylxanthines (i.e., theobromine: 2.20–16.40 mg/g, and caffeine: 1.00–2.40 mg/g) can stimulate the central nervous system, enhancing cognition, alertness, and mood [53]. Furthermore, chocolate’s orosensory properties might contribute to symptom relief via dopaminergic reward pathways [53]. Another potential contributor is chocolate’s mineral content, particularly magnesium in dark chocolate and calcium in milk chocolate, along with trace amounts of zinc (Supplementary Material 1). A 2023 review highlighted the positive role of magnesium, calcium and zinc, as well as vitamin D and curcumin, in MCS management [8]. While the quantities of these minerals in 40 g of 70% cocoa chocolate, are considerably lower (48.0 mg magnesium, 20.8 mg calcium, 0.8 mg zinc) than proposed therapeutic doses, including 600 mg calcium plus 300 mg magnesium daily, and 30 mg zinc gluconate daily [8], they may still contribute to overall daily intake.

A potential negative association between hsCRP levels and MCS severity has been identified in non-athlete populations [30, 52]. Our participants were primarily Tier 2 (trained/developmental) athletes who entered the study with moderate baseline MCS severity and showed no measurable group-level changes in hsCRP from baseline to intervention, despite individual perceived modest improvements in MCS. CRP is sensitive to numerous factors including training, stress, diet, and environmental pathogens (i.e., onset of illness), naturally exhibiting some degree of intra-individual variability [31]. This makes it difficult to attribute observed fluctuations solely to the MC or HC effects, limiting the clinical usefulness of this biomarker in this context. Athletes exhibit a complex and dynamic inflammatory profile, with regular physical activity and higher fitness levels generally supporting lower systemic inflammation and improved immune function [21]. Baseline hsCRP values in our participants were comparable (dark chocolate group = $1.53 \pm \text{SD } 2.04$ mg/L (0.66–2.39), milk chocolate group = $1.89 \pm \text{SD } 2.62$ mg/L (0.76–3.02)) to ranges previously reported in healthy, non-athlete, NC individuals during menstruation (0.74 to 2.30 mg/L) [6, 28, 33, 52, 58, 60]. Given that our participants regularly engaged in moderate-to-intense physical activity, yet still experienced moderate symptom severity, it is possible that habitual exercise might add

complexity to the interaction between MCS and inflammation, perhaps localising inflammation to reproductive tissues, thereby masking any anti-inflammatory effect of dark chocolate at the systemic level. Consequently, similar athlete cohorts might show symptom relief without detectable changes in hsCRP. Whether this dissociation persists in higher Tier athletes (i.e., elite athletes) experiencing more severe symptoms, remains to be tested.

Many athletes, both naturally cycling and using HCs, report cravings for sweet or salty, calorie dense foods like chocolate, particularly around bleeding [12, 40]. However, no consistent link has been found between MC hormonal fluctuations and cravings, suggesting that other factors may be at play [37]. Research points to dietary restraint as a major contributor, with cravings often emerging during emotional changes [37, 54]. Negative perceptions on body image, reduced motivation to exercise and increased fatigue during symptomatic phases, and sociocultural pressure to maintain an “ideal” physique can reinforce guilt around food [54]. This negative attitude towards cravings, in turn, may fuel restrictive behaviours and perpetuate cravings. Non-surprisingly, several athletes in this study expressed fears around weight gain and guilt tied to chocolate, which may have intensified craving patterns. Framing moderate (40 g per day) chocolate consumption as part of the study protocol, helped participants experience it as a “guilt-free” allowance, normalising moderate chocolate consumption, reducing cravings by the end of the intervention.

This RCT had several limitations. First, blinding was not possible due to differences in organoleptic properties between chocolate types. Second, MCS were assessed using a subjective self-report tool (MDQ), which despite its widespread use, has been criticised for its complexity [35]. Moreover, while modifications to the MDQ (i.e., addition of appetite and bowel-related symptoms) were made to capture symptom domains commonly reported by athletes [10], this modified version lacks formal validation and should be interpreted with caution. Third, relying solely on hsCRP is a limitation, as its sensitivity may be affected by athletes’ habitual exercise [26], and factors like diet and training load, which were monitored but not controlled, may have confounded results. Hence, energy availability was not formally assessed and the potential influence of under-fuelling on MCS or intervention responsiveness cannot be excluded. Moreover, hsCRP single timepoint measurements during bleeding, likely missed dynamic inflammatory changes across the cycle. Fourth, although participants’ dietary intake was not significantly different between baseline and intervention, polyphenol content from sources other than the provided chocolate was not quantified.

Importantly, several interpretive factors also warrant attention. Missing data prompted the aggregation

of cycles, yielding a two-group x two-time-point design. A subsequent sample size recalculation for this structure indicated a sample size of 34 athletes was needed. Therefore, the present sample is under-powered, and findings should be viewed conservatively. A non-significant baseline imbalance in MCS outcomes and brain fog between chocolate groups, with athletes in the dark chocolate group reporting slightly higher outcomes at baseline compared to the milk chocolate group, may have contributed to the appearance of greater symptom reduction, by symptom clusters, in the dark chocolate group through natural variability rather than an intervention effect. Most participants also reported moderate symptom severity at baseline, potentially limiting the opportunity for measurable improvements. While small symptom improvements at the participant-level aligned with qualitative feedback, these patterns did not reach statistical significance and may reflect individual variability rather than group-level effects. The absence of clear distributional shifts, as shown by the density plots in Fig. 5, together with marked inter-individual variability, suggests that any chocolate-related effects were likely smaller than the natural between-participant variability in this athlete cohort. This heterogeneity in MCS presentation and responsiveness underlines the need for personalised or stratified approaches (e.g., based on baseline MCS severity) in future research. Lastly, the intervention duration (eight days per cycle), chocolate composition (70% or 25% cocoa) and dose (40 g) may have been insufficient to produce measurable effects. Future studies should consider larger samples, stratification by baseline MCS severity, and alternative intervention designs including higher cocoa/polyphenol content, different doses, and longer intervention windows. Furthermore, this study intentionally adopted a more inclusive, ecologically valid approach, and future research should build on this by retaining menstrual and hormonal diversity while using larger samples that allow proper stratified analysis.

Implications for practice and research

This RCT provides evidence for a practical, athlete-informed, food-based strategy for the management of MCS in athletes with the following implications:

1. Exploration of MCS management strategies should be guided by the lived experiences and concerns of athletes. This ensures the development of relevant, sustainable strategies that resonate with real-world needs.
2. Athletes should be supported in understanding their individual MC experiences and encouraged to view their concerns as valid and worthy of discussion. Empowering athletes to track and speak about their

MCS fosters autonomy and opens the door for more athlete-centred support.

3. Purposeful, flexible adjustments to nutrition, such as consuming chocolate when craved, may help improve MCS on an individual level, while promoting overall psychological wellbeing and reducing guilt associated with cravings.

Conclusion

This study offers novel insights into the role of chocolate as an acceptable and practical dietary strategy for managing MCS in athletes, while also highlighting the complexity of evaluating food-based interventions in this context. While statistically significant changes were not detected at the group-level, high variability in MCS and brain fog at the participant-level, along with athlete narratives, suggest that psychological comfort and moderate allowance for cravings may meaningfully support some aspects of MCS management on an individual basis. Grounded in athlete voices and real-world concerns, this RCT moved beyond theoretical outcomes to address the realities of MC experiences in sport. This intervention was well received, showed no adverse effects on body composition or perceived performance, and helped normalise a commonly stigmatised and restricted food, reducing guilt and cravings. Future research should build on these findings to test underlying mechanisms and long-term feasibility in diverse athlete cohorts.

Abbreviations

MCS	Menstrual cycle-related symptoms
MC	Menstrual cycle
HC	Hormonal contraceptive
NC	Naturally cycling
CRP	C-reactive protein levels
hsCRP	High sensitivity C-reactive protein levels
NF-κB	Nuclear factor-kappa B
IL-6	Interleukin-6
TNF-α	Tumour necrosis factor-α
ROS	Oxygen species
IL-1β	Interleukin-1 β
RCT	Randomised Controlled Trial
CONSORT	Consolidated Standards for Reporting Trials
PMOS	Polyendocrine Metabolic Ovarian Syndrome
NCathletes	Naturally cycling athletes
HCathletes	Hormonal contraceptive user athletes
EUathletes	Eumenorrhoeic athletes
MDQ	Menstrual Distress Questionnaire
BFS	Brain Fog Scale
PETIA	Particle-enhanced immunoturbidimetric assay
LH	Luteinising hormone
DXA	Dual-energy X-ray Absorptiometry
kcal	Kilocalories
CI	Confidence intervals
PAL	Physical Activity Level
RPE	Rating of Perceived Exertion
sRPE	Session-RPE
CV	Coefficient of variation
LSC	Least significant change
SD	Standard deviation
ANOVA	Analysis of Variance
LMMs	Linear Mixed Models

BMI

Body mass index

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s44410-026-00032-y>.

Supplementary Material 1. Chocolate composition nutrition information for 40 g of commercially available 70% cocoa dark chocolate and 25% cocoa milk chocolate. The Australian Food Composition Database (AFCD) through the Foodworks.online V2.0, 2024 Brisbane Xyris Pty Ltd, provided detailed nutrient information for both chocolates used in this study; however, it did not provide polyphenol information. Estimations of mean polyphenol content (per 100 g) were sourced through the Phenol-Explorer database (<http://phenol-explorer.eu/classifications/foods/62/63>).

Acknowledgements

We would like to thank the University of Canberra Research Institute for Sport and Exercise for supporting this project and facilitating data collection. Above all, we would like to thank the athletes involved in this study whose time, commitment and honesty made this study possible.

Authors' contributions

SCL, MM and AJM conceived and designed the study. SCL and MM were responsible for data acquisition. SCL and TMG performed the data analysis and interpretation with input from MM. SCL drafted the manuscript. SCL, MM, AJM, MRL and TMG reviewed the manuscript, provided critical insight based on expertise, and read and approved the final manuscript. MM and AJM supervised the study.

Funding

This work was supported by the University of Canberra Research Institute for Sport and Exercise (UCRISE), and by an Australian Government Research Training Program (RTP) Scholarship <https://doi.org/10.82133/C42F-K220>.

Data availability

The data associated to this manuscript will be made available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Ethics approval for this study was obtained from the Human Research Ethics Committee of the University of Canberra (HREC – 13591). All participants provided written informed consent prior to participation.

Competing interest

The authors declare no competing interests.

Received: 8 March 2026 / Accepted: 10 August 2026

Published online: 24 August 2026

References

1. Agarwal K, Franks AT, Zhang X, Schisterman E, Mumford SL, Joseph PV. Association of inflammation biomarkers with food cravings and appetite changes across the menstrual cycle. *Clin Nutr ESPEN*. 2023;56:193–9. <https://doi.org/10.1016/j.clnesp.2023.06.004>.
2. Al-Khayri JM, Sahana GR, Nagella P, Joseph BV, Alessa FM, Al-Mssallem MQ. Flavonoids as potential anti-inflammatory molecules: a review. *Molecules*. 2022;27(9):2901. <https://doi.org/10.3390/molecules27092901>.
3. Armour M, Parry KA, Steel K, Smith CA. Australian female athlete perceptions of the challenges associated with training and competing when menstrual symptoms are present. *Int J Sports Sci Coach*. 2020;15(3):316–23. <https://doi.org/10.1111/1747954120916073>.
4. Bertone-Johnson ER, Ronnenberg AG, Houghton SC, Nobles C, Zagarins SE, Takashima-Uebelhoeer BB, et al. Association of inflammation markers with

- menstrual symptom severity and premenstrual syndrome in young women. *Hum Reprod.* 2014;29(9):1987–94. <https://doi.org/10.1093/humrep/deu170>.
5. Black A. Critical evaluation of energy intake using the Goldberg cut-off for energy intake: basal metabolic rate. A practical guide to its calculation, use and limitations. *Int J Obesity.* 2000;24(9):1119–30. <https://doi.org/10.1038/sj.ijo.0801376>.
 6. Blum CA, Müller B, Huber P, Kraenzlin M, Schindler C, De Geyter C, et al. Low-Grade Inflammation and Estimates of Insulin Resistance during the Menstrual Cycle in Lean and Overweight Women. *J Clin Endocrinol Metab.* 2005;90(6):3230–5. <https://doi.org/10.1210/jc.2005-0231>.
 7. Braun V, Clarke V. Thematic analysis: A practical guide. SAGE. 2022.
 8. Brown N, Martin D, Waldron M, Bruinvels G, Farrant L, Fairchild R. Nutritional practices to manage menstrual cycle related symptoms: A systematic review. *Nutr Res Rev.* 2023;1–24. <https://doi.org/10.1017/S0954422423000227>.
 9. Bruinvels G, Burden RJ, McGregor AJ, Ackerman KE, Dooley M, Richards T, et al. Sport, exercise and the menstrual cycle: where is the research? *Br J Sports Med.* 2017;51(6):487–8. <https://doi.org/10.1136/bjsports-2016-096279>.
 10. Bruinvels G, Goldsmith E, Blagrove R, Simpkin A, Lewis N, Morton K, et al. Prevalence and frequency of menstrual cycle symptoms are associated with availability to train and compete: a study of 6812 exercising women recruited using the Strava exercise app. *Br J Sports Med.* 2021;55(8):438–43. <https://doi.org/10.1136/bjsports-2020-102792>.
 11. Chica-Latorre S, Knight-Agarwal C, McKune A, Minehan M. A systematic review and meta-aggregation of the experiences and perceptions of menstrual and hormonal contraceptive cycle-related symptoms in female athletes. *J Sci Med Sport.* 2025a;1440244025001835. <https://doi.org/10.1016/j.jsams.2025.06.005>.
 12. Chica-Latorre S, Knight-Agarwal C, McKune A, Minehan M. Sport can do better: female athletes' perspectives on managing menstrual and hormonal contraceptive cycle-related symptoms. *Front Sports Act Living.* 2025;7:1597469. <https://doi.org/10.3389/fspor.2025.1597469>.
 13. Christ A, Lauterbach M, Latz E. Western Diet and the Immune System: An Inflammatory Connection. *Immunity.* 2019;51(5):794–811. <https://doi.org/10.1016/j.immuni.2019.09.020>.
 14. Cohen J. Statistical power analysis for the behavioural sciences (2nd ed.). Lawrence Erlbaum Associates. 1988.
 15. Condo D, Lastella M, Aisbett B, Stevens A, Roberts S. Sleep duration and quality are associated with nutrient intake in elite female athletes. *J Sci Med Sport.* 2022;25(4):345–50. <https://doi.org/10.1016/j.jsams.2021.11.045>.
 16. Cowley ES, Moore SR, Olenick AA, McNulty KL. "Invisible Sportswomen 2.0"—Digging Deeper Into Gender Bias in Sport and Exercise Science Research: Author Gender, Editorial Board Gender, and Research Quality. *Women Sport Phys Act J.* 2024;32(1):2023–0039. <https://doi.org/10.1123/wspaj.2023-0039>.
 17. Debowska A, Boduszewski D, Ochman M, Hrapkowicz T, Gaweda M, Pondel A, et al. Brain Fog Scale (BFS): Scale development and validation. *Personality Individ Differ.* 2024;216:112427. <https://doi.org/10.1016/j.paid.2023.112427>.
 18. Del Giudice M, Gangestad SW. Rethinking IL-6 and CRP: Why they are more than inflammatory biomarkers, and why it matters. *Brain Behav Immun.* 2018;70:61–75. <https://doi.org/10.1016/j.bbi.2018.02.013>.
 19. Di Lorenzo C, Colombo F, Biella S, Stockley C, Restani P. Polyphenols and Human Health: The Role of Bioavailability. *Nutrients.* 2021;13(1):273. <https://doi.org/10.3390/nu13010273>.
 20. Divani AA, Luo X, Datta YH, Flaherty JD, Panoskaltis-Mortari A. Effect of Oral and Vaginal Hormonal Contraceptives on Inflammatory Blood Biomarkers. *Mediators Inflamm.* 2015;2015(1):379501. <https://doi.org/10.1155/2015/379501>.
 21. Edwards MK, Loprinzi PD. Systemic inflammation as a function of the individual and combined associations of sedentary behaviour, physical activity and cardiorespiratory fitness. *Clin Physiol Funct Imaging.* 2018;38(1):93–9. <https://doi.org/10.1111/cpf.12388>.
 22. Elliott-Sale KJ, McNulty KL, Ansdell P, Goodall S, Hicks KM, Thomas K, et al. The Effects of Oral Contraceptives on Exercise Performance in Women: A Systematic Review and Meta-analysis. *Sports Med.* 2020;50(10):1785–812. <https://doi.org/10.1007/s40279-020-01317-5>.
 23. Elliott-Sale KJ, Minahan CL, De Jonge XAKJ, Ackerman KE, Sipilä S, Constantini NW, et al. Methodological Considerations for Studies in Sport and Exercise Science with Women as Participants: A Working Guide for Standards of Practice for Research on Women. *Sports Med.* 2021;51(5):843–61. <https://doi.org/10.1007/s40279-021-01435-8>.
 24. Evans J, Salamonsen LA. Inflammation, leukocytes and menstruation. *Rev Endocr Metab Disord.* 2012;13(4):277–88. <https://doi.org/10.1007/s11554-012-9223-7>.
 25. Faul F, Erdfelder E, Lang A-G, Buchner A. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods.* 2007;39(2):175–91. <https://doi.org/10.3758/BF03193146>.
 26. Fedewa MV, Hathaway ED, Ward-Ritacco CL. Effect of exercise training on C reactive protein: A systematic review and meta-analysis of randomised and non-randomised controlled trials. *Br J Sports Med.* 2017;51(8):670–6. <https://doi.org/10.1136/bjsports-2016-095999>.
 27. Foster C, Florhaug JA, Franklin J, Gottschall L, Hrovatin LA, Parker S, et al. A New Approach to Monitoring Exercise Training. *J Strength Cond Res.* 2001;15(1):109–15. <https://doi.org/10.1519/00124278-200102000-00019>.
 28. Gaskins AJ, Wilchesky M, Mumford SL, Whitcomb BW, Browne RW, Wactawski-Wende J, et al. Endogenous Reproductive Hormones and C-reactive Protein Across the Menstrual Cycle: The BioCycle Study. *Am J Epidemiol.* 2012;175(5):423–31. <https://doi.org/10.1093/aje/kwr343>.
 29. Gleeson M, Bishop NC, Stensel DJ, Lindley MR, Mastana SS, Nimmo MA. The anti-inflammatory effects of exercise: Mechanisms and implications for the prevention and treatment of disease. *Nat Rev Immunol.* 2011;11(9):607–15. <https://doi.org/10.1038/nri3041>.
 30. Gold EB, Wells C, Rasor MO. The Association of Inflammation with Premenstrual Symptoms. *J Women Health.* 2016;25(9):865–74. <https://doi.org/10.1089/jwh.2015.5529>.
 31. Gough A, Sitch A, Ferris E, Marshall T. Within-subject variation of C-reactive protein and high-sensitivity C-reactive protein: A systematic review and meta-analysis. *PLoS ONE.* 2024;19(11):e0304961. <https://doi.org/10.1371/journal.pone.0304961>.
 32. Granda D, Szmidi MK, Kaluza J. Is Premenstrual Syndrome Associated with Inflammation, Oxidative Stress and Antioxidant Status? A Systematic Review of Case-Control and Cross-Sectional Studies. *Antioxidants.* 2021;10(4):604. <https://doi.org/10.3390/antiox10040604>.
 33. Gursoy AY, Caglar GS, Kiseli M, Pabuccu E, Candar T, Demirtas S. CRP at early follicular phase of menstrual cycle can cause misinterpretation for cardiovascular risk assessment. *Interv Med Appl Sci.* 2015;7(4):143–6. <https://doi.org/10.1556/1646.7.2015.4.2>.
 34. Harris BS, Steiner AZ, Faurot KR, Long A, Jukic AM. Systemic inflammation and menstrual cycle length in a prospective cohort study. *Am J Obstet Gynecol.* 2023;228(2):215.e1–215.e17. <https://doi.org/10.1016/j.ajog.2022.10.008>.
 35. Haywood A, Slade P, King H. Assessing the assessment measures for menstrual cycle symptoms. *J Psychosom Res.* 2002;52(4):223–37. [https://doi.org/10.1016/S0022-3999\(02\)00297-0](https://doi.org/10.1016/S0022-3999(02)00297-0).
 36. Hopewell S, Chan A-W, Collins GS, Hróbjartsson A, Moher D, Schulz KF, et al. CONSORT 2025 statement: Updated guideline for reporting randomised trials. *Lancet.* 2025;405(10489):1633–40. [https://doi.org/10.1016/S0140-6736\(25\)00672-5](https://doi.org/10.1016/S0140-6736(25)00672-5).
 37. Hormes JM, Timko CA. All cravings are not created equal. Correlates of menstrual versus non-cyclic chocolate craving. *Appetite.* 2011;57(1):1–5. <https://doi.org/10.1016/j.appet.2011.03.008>.
 38. Kangasniemi MH, Haverinen A, Luiro K, Hiltunen JK, Komi EK, Arffman RK, et al. Estradiol valerate in COC has more favorable inflammatory profile than synthetic ethinyl estradiol: a randomized trial. *J Clin Endocrinol Metab.* 2020;105(7):e2483–90. <https://doi.org/10.1210/clinem/dgaa186>.
 39. Karakuş Selçuk A, Baysal E. The effect of dark chocolate and music on pain and anxiety in young women with primary dysmenorrhea: randomized controlled trial. *Eur J Integr Med.* 2022;56:102192. <https://doi.org/10.1016/j.eujim.2022.102192>.
 40. Langan-Evans C, Hearn MA, McQuilliam S, Burke LM, Stellingwerff T, Elliott-Sale KJ, et al. Hormonal contraceptive use, menstrual cycle characteristics and training/nutrition related profiles of elite, sub-elite and amateur athletes and exercisers: one size is unlikely to fit all. *Int J Sports Sci Coach.* 2024;19(1):113–28. <https://doi.org/10.1177/17479541231163088>.
 41. Maharani SI, Pramono N, Wahyuni S. Dark chocolate's effect on menstrual pain in late adolescents. *Belitung Nurs J.* 2017;3(6):686–92. <https://doi.org/10.33546/bnj.292>.
 42. Martin D, Sale C, Cooper SB, Elliott-Sale KJ. Period prevalence and perceived side effects of hormonal contraceptive use and the menstrual cycle in elite athletes. *Int J Sports Physiol Perform.* 2018;13(7):926–32. <https://doi.org/10.1123/ijssp.2017-0330>.
 43. McKay AKA, Stellingwerff T, Smith ES, Martin DT, Mujika I, Goosey-Tolfrey VL, et al. Defining training and performance caliber: a participant classification framework. *Int J Sports Physiol Perform.* 2022;17(2):317–31. <https://doi.org/10.1123/ijssp.2021-0451>.
 44. McNamara A, Harris R, Minahan C. 'That time of the month' ... for the biggest event of your career! Perception of menstrual cycle on performance of

- Australian athletes training for the 2020 Olympic and Paralympic Games. *BMJ Open Sport Exerc Med*. 2022;8(2):e001300. <https://doi.org/10.1136/bmjsem-2021-001300>.
45. McNulty KL, Elliott-Sale KJ, Dolan E, Swinton PA, Ansdell P, Goodall S, et al. The effects of menstrual cycle phase on exercise performance in eumenorrheic women: a systematic review and meta-analysis. *Sports Med*. 2020;50(10):1813–27. <https://doi.org/10.1007/s40279-020-01319-3>.
46. Meyerding SGH, Trinh BH. A cross-cultural study: how product attributes and cultural values influence chocolate preferences. *J Agricult Food Res*. 2025;19:101579. <https://doi.org/10.1016/j.jafr.2024.101579>.
47. Moos RH. The development of a menstrual distress questionnaire. *Psychosom Med*. 1968;30(6):853–67. <https://doi.org/10.1097/00006842-19681000-00006>.
48. Nana A, Slater GJ, Hopkins WG, Burke LM. Effects of Daily Activities on Dual-Energy X-ray Absorptiometry Measurements of Body Composition in Active People. *Med Sci Sports Exerc*. 2012;44(1):180–9. <https://doi.org/10.1249/mss.0b013e318228b60e>.
49. Nuha K, Rusmil K, Ganiem AR, Permadi W, Diah Herawati DM. Single-Blind Randomized Controlled Trial: Comparative Efficacy of Dark Chocolate, Coconut Water, and Ibuprofen in Managing Primary Dysmenorrhea. *Int J Environ Res Public Health*. 2023;20(16):6619. <https://doi.org/10.3390/ijerph20166619>.
50. Núñez-Troconis J, Carvallo D, Martínez-Núñez E. Primary Dysmenorrhea: Pathophysiology. *Investigación Clí*. 2021;62(4):378–406. <https://doi.org/10.2209/IC.v62n4a08>.
51. Oertelt-Prigione S. Immunology and the menstrual cycle. *Autoimmun Rev*. 2012;11(6–7):A486–92. <https://doi.org/10.1016/j.autrev.2011.11.023>.
52. Puder JJ, Blum CA, Mueller B, De Geyter C, Dye L, Keller U. Menstrual cycle symptoms are associated with changes in low-grade inflammation. *Eur J Clin Invest*. 2006;36(1):58–64. <https://doi.org/10.1111/j.1365-2362.2006.01591.x>.
53. Rojas R, Cabanillas B, Portales R, Candy R. Bioactive Compounds in Native Cocoa (Theobroma cacao L.). In: Repo-Carrasco-Valencia R, Tomás MC, Native Crops in Latin America (1st ed). CRC Press; 2022. pp. 91–114. <https://doi.org/10.1201/9781003087618-4>.
54. Ryan S, Ussher JM, Hawkey A. Managing the premenstrual body: A body mapping study of women's negotiation of premenstrual food cravings and exercise. *J Eat Disord*. 2021;9(1):125. <https://doi.org/10.1186/s40337-021-00478-6>.
55. Safari K, Hemmatinafar M, Suzuki K, Koushkie Jahromi M, Imanian B. Dark Chocolate Mitigates Premenstrual Performance Impairments and Muscle Soreness in Female CrossFit® Athletes: Evidence from a Menstrual-Phase-Specific Trial. *Nutrients*. 2025;17(8):1374. <https://doi.org/10.3390/nu17081374>.
56. Schoep ME, Adang EMM, Maas JWM, De Bie B, Aarts JWM, Nieboer TE. Productivity loss due to menstruation-related symptoms: A nationwide cross-sectional survey among 32 748 women. *BMJ Open*. 2019;9(6):e026186. <https://doi.org/10.1136/bmjopen-2018-026186>.
57. Taim BC, Ó Catháin C, Renard M, Elliott-Sale KJ, Madigan S, Ní Chéilleachair N. The Prevalence of Menstrual Cycle Disorders and Menstrual Cycle-Related Symptoms in Female Athletes: A Systematic Literature Review. *Sports Med*. 2023;53(10):1963–84. <https://doi.org/10.1007/s40279-023-01871-8>.
58. Vashishta S, Gahlot S, Singh A, Goyal R. Impact of menstrual cycle phases on C-reactive protein concentrations. *Int J Res Med Sci*. 2017;5(3):1090. <https://doi.org/10.18203/2320-6012.ijrms20170667>.
59. Wander K, Brindle E, O'Connor KA. C-reactive protein across the menstrual cycle. *Am J Phys Anthropol*. 2008;136(2):138–46. <https://doi.org/10.1002/ajpa.20785>.
60. Wunder DM, Yared M, Bersinger NA, Widmer D, Kretschmer R, Birkhäuser MH. Serum leptin and C-reactive protein levels in the physiological spontaneous menstrual cycle in reproductive age women. *Eur J Endocrinol*. 2006;155(1):137–42. <https://doi.org/10.1530/eje.1.02178>.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.