JOURNAL OF THE INTERNATIONAL SOCIETY OF SPORTS NUTRITION
2024, VOL. 21, NO. 1, 2393364
https://doi.org/10.1080/15502783.2024.2393364

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Rehydration effect of qingshu buye decoction on exercise and high temperature-induced dehydration

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ABSTRACT

Objective: The aim of this study was to conduct a comprehensive evaluation of the rehydration efficacy of QSBYD and elucidate its potential underlying mechanism.

Design: 38 participants were randomly assigned to receive either QSBYD or placebo before and after exercise and heat-induced dehydration. Hydration indicators were measured over time. Blood tests assessed cellular anaerobic respiration metabolites, serum inflammatory markers, and coagulation markers. Perceptual measures of thirst, fatigue, and muscular soreness were also taken.

Results: QSBYD consumption resulted in lower urine volume (Control vs. QSBYD: 260.83 ± 167.99 ml vs. 187.78 ± 141.34 ml) and smaller decrease in percentage of nude body weight change from baseline (Control vs. QSBYD: −0.52 ± 0.89% vs. −0.07 ± 0.52%). Although no significant differences in urine specific gravity, QSBYD resulted in reduced urine volume at 120 min, suggesting improved fluid retention. Furthermore, QSBYD resulted in lower levels of IL-1β (Control vs. QSBYD: 2.40 ± 0.68 vs. 1.33 ± 0.66 pg/mL), suggesting QSBYD may provide benefits beyond hydration.

Conclusion: Further investigation into the underlying mechanisms and long-term effects of QSBYD on hydration is warranted. QSBYD may be an effective alternative to commercial sports drinks in mitigating dehydration effects.

ARTICLE HISTORY
Received 24 July 2023
Accepted 9 August 2024

KEYWORDS
Qingshu buye decoction; hydration; dehydration; exercise; high temperature

1. Introduction

According to a recent report from the National Oceanic and Atmospheric Administration, the past eight years (2014–2022) are anticipated to constitute the warmest eight-year

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period on record, with signs and impacts of climate change becoming increasingly pronounced [1]. Additionally, the current global average surface temperature is 1.75°F (0.97°C) higher than the mean temperature of the 20th century. Mar 2023 average global surface temperature was the second highest for Mar since global records began in 1850 [2]. The health implications of rising environmental temperatures are garnering heightened attention.

Under physiological conditions, the human body employs various mechanisms for heat dissipation. Notably, fluid loss through perspiration constitutes a crucial cooling mechanism. Water loss via the skin amounts to 0.3 liters per hour under sedentary conditions and escalates to 2.0 liters per hour during strenuous activities in high-temperature environments [3,4]. Without adequate fluid intake compensation, especially during high temperatures or intense physical activities, significant loss of water and electrolytes, such as sodium, potassium, and calcium, can lead to various adverse effects on the human body, including dehydration and hyponatremia, among others [5–7].

In high-temperature environments, excessive heat transfer to the human body or increased metabolic heat production due to strenuous physical labor, along with dehydration, can hinder the body's ability to manage heat stress, reduce heat dissipation capacity, raise core body temperature, and consequently compromise the muscular, cardiovascular, central nervous, and renal systems [8–11]. Such conditions, resulting from inadequate physiological heat dissipation responses, are referred to as heat-related illnesses (HRI). Studies indicate that dehydration levels exceeding approximately 3–6% of body weight loss significantly augment the risk for HRI, including heatstroke, which is the most severe form of HRI [12,13]. Heatstroke is characterized by a high fever and coma, with early mortality rates ranging from 50 to 70% [14,15]. Furthermore, the escalating incidence of extreme temperatures and heatwaves due to global warming is likely to increase the occurrence and severity of HRI, highlighting the pressing need for effective heat stress management and hydration strategies [16–18].

The dehydration issues resulting from high temperatures and intense exercise pose significant risks, particularly to populations such as athletes [19], firefighters [20], agricultural workers [21], and the elderly [22]. In this context, it is essential to explore effective rehydration strategies to mitigate the adverse effects of dehydration. Commercial sports drinks are a common rehydration method, as they contain mixed carbohydrates and electrolytes, such as glucose, fructose, and/or maltodextrin. However, commercial sports drinks have certain drawbacks, including high caloric content (approximately 150–300 kilocalories per bottle), which may concern some individuals regarding body weight and composition, the use of food dyes, artificial additives, and sweeteners, as well as potential gastrointestinal discomfort. Although sugar-free or low-calorie commercial sports drinks can address some of the issues mentioned, natural alternatives may offer additional health benefits due to the presence of certain bioactive components, as well as a stronger appeal to specific groups such as individuals with diabetes or those seeking to reduce their intake of artificial additives. As a result, there is growing interest in natural alternatives [23–27].

Traditional Chinese medicine (TCM) associates the occurrence of HRI with the invasion of external "heat evils" into the human body and the subsequent depletion of vital energy and body fluids. As a result, the treatment principle for HRI focuses on replenishing energy and moisturizing. The 2020 edition of the Pharmacopoeia of the People's Republic of

China lists Ophiopogonis Radix root, Mume Fructus, Phragmitis Rhizoma, Crataegi Fructus, Perillae Folium, Menthae Haplocalycis Herba, Citri Reticulatae Pericarpium and Pogostemonis Herba as dual-purpose traditional Chinese herbal medicines, acknowledging their use as both medicinal and food substances. These herbal ingredients are known for their cooling, moisturizing, and energy-boosting properties, which are widely recognized in TCM. A TCM beverage consisting of these eight components is referred to as the Qingshu Buye Decoction (QSBYD). QSBYD contains various sugars, saponins, and flavonoid compounds, with numerous bioactive substances, such as ophiopogonin, β-sitosterol, iso-menthone, menthol, menthone, neomenthol and dihydrokaempferol A, exhibiting extensive anti-inflammatory and antioxidative effects [28–34]. Unlike conventional options, QSBYD is mainly composed of natural herbal ingredients known for their hydrating and health-promoting properties, without the reliance on high sugar content or artificial components. While QSBYD is widely applied in the daily lives of Chinese people and in various diseases, no studies have investigated its potential role in HRI. Consequently, this randomized, double-blind, placebo-controlled clinical study aimed to assess the effectiveness of QSBYD as a rehydration beverage for participants who reach a mildly dehydrated state following moderate-intensity exercise and high-temperature environment.

2. Methods

2.1. Ethical approval

The study protocol was approved by the human ethical committee of Hospital of Chengdu University of Traditional Chinese Medicine (approval number: 2022QKL–003) and was conducted in accordance with the Declaration of Helsinki and the principles of good clinical practice. Besides, this trial was registered in the Chinese Clinical Trial Registry (ChiCTR), with the registration ID ChiCTR2400082204.

2.2. Participants

Participants were healthy, physically active college students from Southwest University of Science and Technology, recruited through public advertisements and word of mouth. Eligible participants had no history of smoking, cardiovascular, renal, musculoskeletal, or endocrine diseases, and no prior medication history. They regularly engaged in a minimum of 30 minutes of moderate-intensity aerobic activity at least three days a week [35]. To ensure the health and safety of participants in the study, specific exclusion criteria were established, including: individuals who exhibited symptoms such as cold, diarrhea, or vomiting within 15 days prior to the test; those with a history of allergy to any components of the experimental beverage (QSBYD); participants with any form of liver and kidney function impairment, as determined by medical assessment; abnormalities detected in chest radiographs and electrocardiograms; and female participants with pregnancy-related needs. Previous studies indicated that sex had no impact on hydration responses, and menstrual cycle phases did not affect rehydration following exercise-induced dehydration; thus, we imposed no sex restrictions and did not account for female menstrual cycle information [36]. All participants provided written informed consent

before participation. We determined a minimal sample size based on a preliminary experiment involving eight participants (1:1) and observed a decrease in urine volume with the ingestion of QSBYD 120 minutes after exercise and high-temperature induction compared to a placebo control. Using an effect size of 86 ml and a standard deviation of 78 ml, we determined that a minimal sample size of 32 participants was required to detect a difference in urine volume with a power of 95% and an α-error probability of 0.05. Considering the trial's involvement of moderate-intensity exercise and high-temperature environmental interventions, and assuming a 10% dropout rate, we decided on a sample size of at least 36 participants.

2.3. Test beverage

The QSBYD is developed by Sichuan Depeiyuan Chinese Medicine Technology Co., Ltd. (Product standard code GB/T 31,326). The beverage is composed of 1000 ml of herbal extract purchased from Sichuan Xingshengyuan Pharmaceutical Co., Ltd., which includes Ophiopogon japonicus root (5 g, No.220601), Prunus mume fruit (6.67 g, No. 220501), Phragmites australis rhizome (5 g, No.220502), Crataegus pinnatifida fruit (6.67 g, No.21101), Perilla frutescens leaf (2.67 g, No.211101), Mentha haplocalyx herb (5 g, No.220302), Citrus reticulata peel (1.33 g, No.220401), and Pogostemon cablin herb (1.33 g, No.211001). Additionally, the beverage contains taurine (0.030 g), sodium chloride (0.650 g), sodium citrate (0.720 g), potassium chloride (0.380 g), glucose (3.380 g), erythritol (0.060 g), trichlorosucrose (0.060 g), citric acid (0.100 g), potassium sorbate (0.100 g), and disodium ethylenediaminetetraacetate (0.020 g).

The placebo was created by diluting QSBYD to 5% of its original concentration and adding extracts of the four components to simulate taste and appearance, but it provided no nutritional value. The nutrients contained in QSBYD were determined by the National Light Industry Food Quality Supervision and Inspection Center in Chengdu (Report No. 202206532), and the results are presented in Table 1.

2.4. Study design

This study was conducted using a double-blind, placebo-controlled design. All participants were randomly allocated to the QSBYD group and the control group in a 1:1 ratio. A random number table was generated using SPSS 26.0. An independent individual sent the random number table to Sichuan Deyuanpei Chinese Medicine Technology Development Co., Ltd., which packaged the trial beverages according to the numerical

Table 1. Nutritional content of QSBYD.

Ingredients	Content
Energy (kJ/100 ml)	0
Protein (g/100 ml)	0
Lipid (g/100 ml)	0
Carbohydrate (g/100 ml)	3
Total sugar (g/100 ml)	0
Sodium (g/100 ml)	12
Potassium (g/100 ml)	5
Chloride (mg/L)	215

codes. Participant numbers were labeled on the packaging to ensure a one-to-one correspondence between participants and beverages, thus maintaining the double-blind status. Clinical researchers assigned participant numbers in the order of enrollment and distributed the corresponding beverages. All participants remained blinded throughout the entire trial. The randomization list and blinding codes were sealed in opaque envelopes and stored in a double-locked cabinet at an independent data center. This study conducted two unblindings: the first unblinding revealed only the beverage categories, labeled as A and B; the second unblinding occurred after statistical analysis was completed, revealing the beverages corresponding to codes A and B.

As depicted in Figure 1a, for the three days before the experiment, participants began consuming the test beverages, with both groups receiving either 300 ml of QSBYD or placebo three times a day.

Participants were instructed to refrain from consuming alcohol and caffeine, and from engaging in strenuous physical activity at least 72 hours prior to the experimental trial. Additionally, the night before the experimental session, they were encouraged to consume a standard meal consisting of approximately 115 g of carbohydrate, 20 g of fats, and 27 g of protein with an energy equivalent of about 750 kcal [37]. To achieve adequate hydration, which was confirmed by USG < 1.020 at baseline, participants were asked to consume 30 ml/kg/day of water 24 hours prior to the experiment. Participants were prohibited from eating and drinking and reported to the laboratory between 7:30 and 8:00 am, where baseline data were collected. They were then given a standard light breakfast consisting of a cup of jelly and an energy bar (approximately 39 g of carbohydrate, 7.7 g of fat, 2 g of protein, and 0.3 g of salt; energy equivalent of 183 kcal) and 500 ml of water.

To induce mild dehydration, participants underwent two stages: running exercise and exposure to a simulated high-temperature environment. Before the exercise

	Screening	Baseline	Post	30min	120min	24h
Demographic charcateristics	●	○	○	○	○	○
Blood test	○	●	○	●	●	○
Urine volume	○	●	●	●	●	○
USG	○	●	●	●	●	○
Nude body weight	○	●	●	●	●	○
Thrist sensation	○	●	●	●	●	●
Muscular Soreness	○	●	●	●	●	●
Fatigue	○	●	●	●	●	●

● Check required ○ No Check required

Figure 1. The measured indicators and their time points in this experiment.

began, participants performed a 10-minute warm-up under the guidance of a professional fitness coach. Then, running exercises were conducted in an open-space laboratory under conditions of 28°C and approximately 50% relative humidity. Participants ran on a treadmill for 30 minutes, with the speed set to maintain their maximum heart rate (220 minus participant's age) at 60%-70%. Heart rate tested with a built-in pulse oximeter was displayed on the treadmill screen and five independent individuals monitored and adjusted the speed accordingly. Previous research has shown that a single exercise session can reduce body weight by 0.5%-2% [38]. Researchers supervised all participants during the trial to ensure any discomfort experienced during exercise was promptly addressed, and the exercise was terminated with appropriate medical treatment provided. After completing the running exercise, participants entered a sealed room simulating a high-temperature work environment at 45°C and 50% relative humidity. After sitting quietly in this environment for 15 minutes, the dehydration induction was terminated, and immediate post-exercise measures were taken. After obtaining immediate post-exercise measures, beverages were consumed in four 250 ml dosages, timed 4–7.5 minutes apart and served at room temperature to maximize gastric emptying and fluid uptake while minimizing diuresis. Thus, using this metered intake to control for intake pacing, ingestion was completed in no less than 15 minutes but no more than 30 minutes. To avoid the potential confound of food ingestion on fluid retention, food intake was prohibited during the rehydration period.

2.5. Measurements

The measured indicators and their time points in this experiment are shown in Figure 1. Entire urine voids were collected in 120 ml urine specimen cups and then measured using a graduated cylinder. Urine volume (UV) was also used to calculate cumulative urine output after fluid ingestion (30–120 min). Following the assessment of urine volume, urine specific gravity (USG) was determined. USG compares the density and whole body hydromineral balance of urine to the density of water and is an estimate of hydration. USG was assessed via a portable refractometer (LH-Y12, Luheng Environmental Technology), which was calibrated to manufacturer specifications. The average value was calculated through duplicate measures. If duplicates were not within 10%, a third measurement was obtained, and the three values were averaged.

At baseline, 30 minutes post- dehydration, and 120 minutes post- dehydration, venous blood samples were collected from participants. Part of blood samples was left to settle at 4°C and later centrifuged at 1500 r/min for 10 minutes, with the upper layer of the supernatant used for analysis. ELISA was employed to detect Thrombin/Antithrombin complex (TAT) (E-EL-H1788c, Elabscience), Thrombomodulin (TM) (E-EL-H0166c, Elabscience), and IL-1β (E-EL-H0149c, Elabscience). Biochemical assay kits were used to detect D-Lactic (E-BC-K002-M, Elabscience) and L-Lactic (E-BC-K044-M, Elabscience). Another part of blood samples was preserved in a 4°C transport box and sent to the Department of Clinical Laboratory, Fulin Hospital, Mianyang City, Sichuan Province for C-reactive protein and safety indicator tests (liver and kidney function, blood routine, etc.).

At baseline, immediate post-dehydration, 30 minutes, and 120 minutes post-dehydration, participants were instructed to weigh themselves nude in a private

examination room, ensuring they were thoroughly dried and free of any sweat. Percentage change of nude body weight (NBW) from baseline was utilized for calculating fluid loss, retention.

Previous studies have employed the Visual Analog Scale (VAS) for evaluating subjective sensations, such as thirst, demonstrating its validity and reliability in quantifying such sensations [38–41]. Therefore, thirst sensation, fatigue, and muscular soreness were assessed using a VAS at multiple time points: prior to dehydration, immediately post-dehydration, 30 minutes, 120 minutes, and 24 hours post-dehydration. The VAS comprised a 100 mm horizontal line with anchor points at either end, representing "no thirst," "no fatigue," or "no muscular soreness" on the far left, and "very thirsty," "severe fatigue," or "intense muscular soreness" on the far right. While seated in a resting position, participants marked a point on the VAS corresponding to their perception at each respective time point. These sensations were subsequently quantified by measuring the distance from the left endpoint of the continuum to the mark made by the participant.

2.6. Data analysis

Data are presented as means ± SD, and statistical significance is set at 0.05. All statistical analyses were performed using SPSS (version 26.0, IBM). For data measured repeatedly at different time points, the baseline values were used as covariates, with time, beverages (QSBYD, Placebo), and time × beverage as fixed effects, and participants as random effects included in the mixed effects model. Demographic characteristics and quantitative data were analyzed using independent samples t-test, while categorical data were analyzed using Pearson χ^2 test. If the theoretical frequency was too small, Fisher's exact probability method was applied. Covariance analysis was used to analyze cumulative urine volume, with baseline urine volume as a covariate.

3. Results

In this study, a total of 52 participants were initially screened, with 38 participants ultimately included (Figure 2). No significant differences were observed in the baseline demographic characteristics of the participants, and all participants successfully completed the exercise and high-temperature induction. A summary of the participant characteristics is presented in Table 2.

3.1. Assessment of hydration

Baseline hydration assessments did not significantly differ between groups (Control vs. QSBYD, $p > 0.05$). As shown in Figure 3, significant interactions between beverage condition and time were observed for urine volume ($p = 0.03$) and the percentage change of NBW from baseline ($p < 0.001$), indicating that the effects of QSBYD consumption on these hydration markers varied over time post-hydration. Follow-up analyses revealed that, compared to placebo, consumption of QSBYD resulted in significantly lower urine volume (Control vs. QSBYD, $p = 0.031$, 95% CI 8.17 to 167.95) and a smaller decrease in the percentage change of NBW from baseline (Control vs. QSBYD, $p < 0.001$, 95% CI −1.01 to −0.52) at 120 minutes post-hydration.

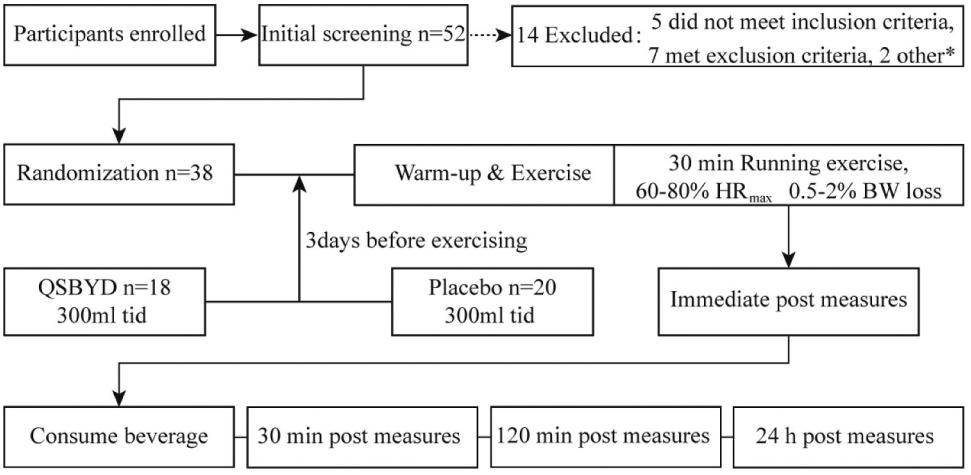


Figure 2. Enrollment and randomization in the overall population. *one participant was excluded due to a scheduling conflict, and another was excluded due to withdrawal of consent.

Table 2. Characteristics of the overall population at baseline.

	Control ($n = 20$)	QSBYD ($n = 18$)	*P*-value
Height, cm	167.81 ± 9.71	167.56 ± 9.06	0.94
Weight, kg	57.36 ± 10.14	60.71 ± 9.84	0.31
BMI, kg/m^2	19.84 ± 2.48	21.44 ± 2.74	0.07
Age, years	22.50 ± 3.10	22.00 ± 3.30	0.63
Male	12(60)	11(61)	0.94
Oxygen saturation	99.2 ± 0.70	98.28 ± 1.99	0.06
Systolic pressure, mmHg	120.70 ± 12.52	117.22 ± 15.47	0.45
Diastolic pressure, mmHg	80.25 ± 8.69	71.56 ± 21.71	0.11

Despite these significant interactions, the analysis of main effects showed that, overall, there was no significant effect of beverage condition alone on urine volume, USG, or the percentage change of NBW from baseline ($p > 0.05$ for all), underscoring the importance of considering the interaction between beverage consumption and time in understanding hydration outcomes. Both groups exhibited elevated USG after exercise, which significantly decreased following rehydration, and although the Control group had a higher cumulative urine output compared to the QSBYD group (Control vs. QSBYD: 321.49 vs. 236.81 ml), the difference was not statistically significant ($p = 0.16$).

3.2. Blood test

We investigated the effects of exercise, high temperature, and QSBYD on various cellular anaerobic respiration metabolites, serum inflammatory markers, and coagulation markers (Figure 4). Significant beverage by time interactions were observed in D-lactic ($p = 0.002$), IL-1β ($p = 0.002$) and TM ($p < 0.001$).

Although both groups experienced a decrease in D-lactic after dehydration, QSBYD exhibited significantly lower levels at 30 min post-exercise (Control vs. QSBYD, $p < 0.001$, 95% CI 0.11 to 0.24). At 120 minutes post-dehydration, IL-1β

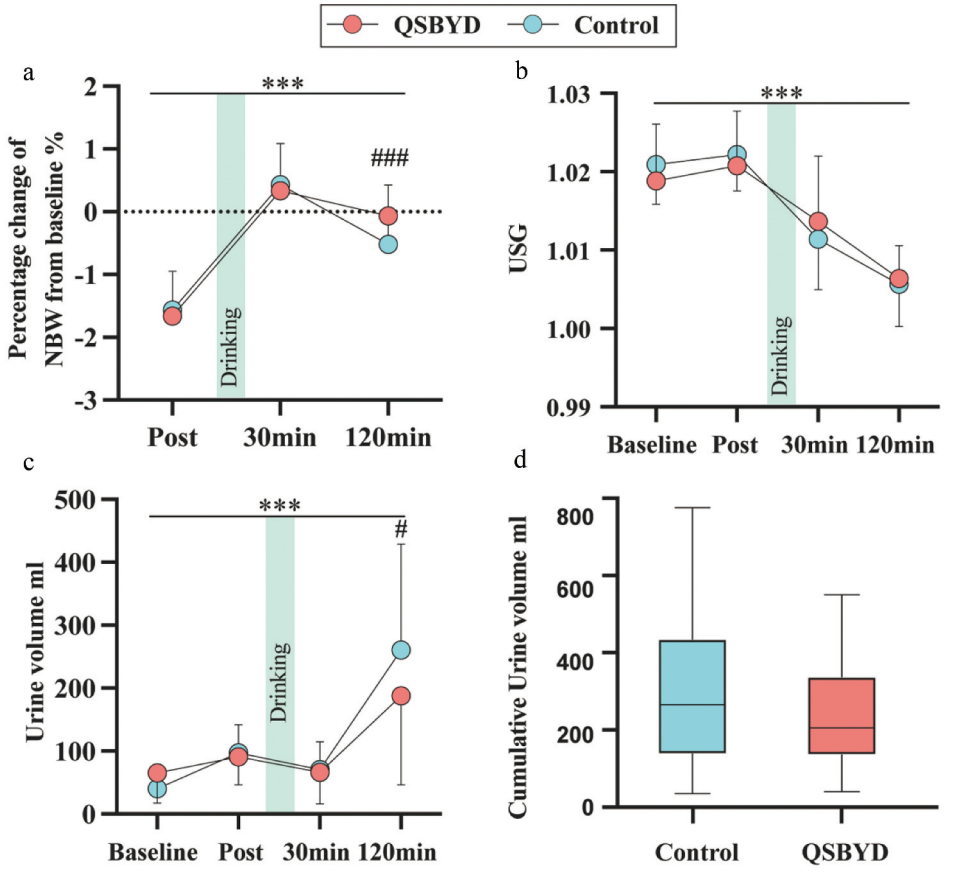


Figure 3. Measurements of dehydration status at baseline, immediate post dehydration, and after ingestion of control or QSBYD. (a) Percentage change of Nude body weight (NBW) from baseline. (b) Urine Specific Gravity (USG). (c) Urine volume. (d) Cumulative urine volume post exercise & high-temperature-induced dehydration. *P<0.05, ***P<0.001 main effect for time. #P<0.05, ###P<0.001 interaction effect for time and beverage.

levels in the QSBYD group were significantly lower compared to those in the control group (Control vs. QSBYD, $p < 0.001$, 95% CI 0.50 to 1.68). Similarly, TM levels were significantly higher in the QSBYD group at 30 minutes post-dehydration (Control vs. QSBYD, $p < 0.001$, 95% CI −233.53 to −121.51), though this difference was not maintained at the 120-minute.

Significant time effects were observed for all markers except TAT, IL-1β, and CRP, suggesting a general response to exercise and rehydration over time. L-lactic levels peaked in both groups at 30 min post-dehydration and subsequently returned to near baseline levels at 120 min, aligning with typical physiological responses to exercise, with no significant beverage effect or interaction observed. Notably, no significant main effects or interactions concerning beverage type and time were observed for TAT and CRP, indicating that while QSBYD influences specific metabolic and inflammatory pathways, its effects on certain coagulation and inflammation markers may be limited or variable.

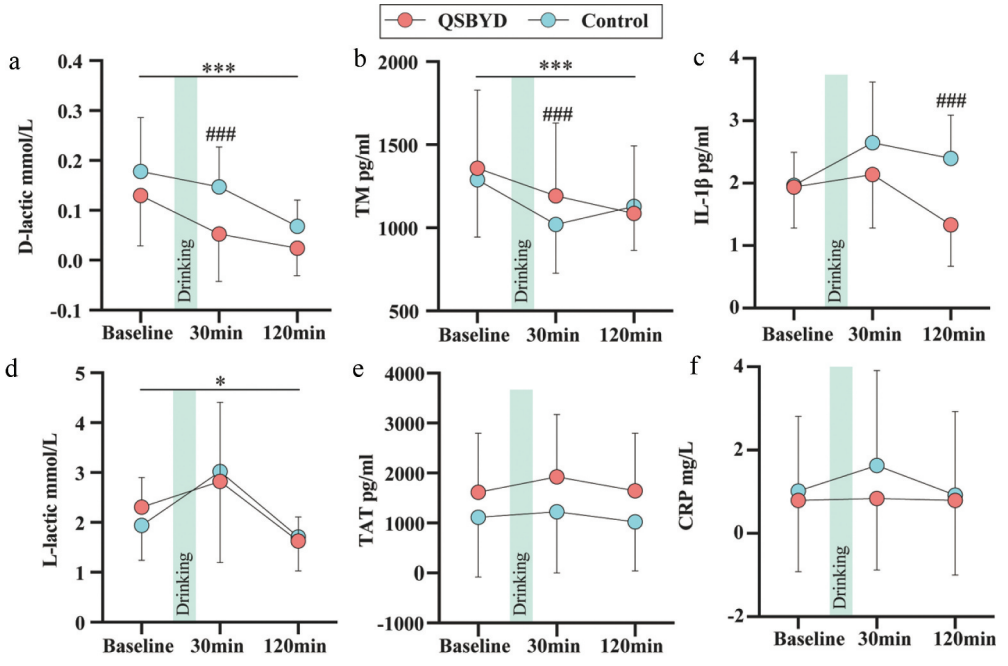


Figure 4. Measurements of dehydration related serum markers at baseline and after ingestion of control or QSBYD. (a) D-lactic. (b) Thrombomodulin (TM). (c) IL-1β. (d) L-lactic. (e) Thrombin/Antithrombin complex (TAT). (f) CRP. *P<0.05, ***P<0.001 main effect for time. ###P<0.001 interaction effect for time and beverage.

3.3. Perceptual measures of thirst, fatigue and muscular soreness

In our investigation of subjective perceptions following dehydrating exercise, we observed a significant interaction between beverage type and time specifically for thirst sensation at the 30-minute. Participants in the QSBYD group reported higher levels of thirst compared to those in the Control group (Control vs. QSBYD, $p = 0.02$, 95% CI −1.86 to 0.19), underscoring the differential impact of beverage consumption on the acute perception of thirst shortly after exercise (Figure 5). Following dehydrating exercise, significant time effects were noted across all perceptions, indicating a general increase in sensations of fatigue, thirst, and muscular soreness. At 30 min, thirst sensation decreased to levels near or below baseline, while fatigue and muscular soreness remained elevated above baseline levels at 120 min. Notably, for fatigue and muscular soreness, neither a significant interaction of beverage and time nor a main effect of beverage was detected ($p > 0.05$).

4. Discussion

Dehydration during exercise is a prevalent concern, as it can negatively impact physical performance and increase the risk of HRI. Ensuring adequate hydration is crucial for athletes and individuals participating in physical activities in hot environments. To address this challenge, various sports drinks, including QSBYD, have been developed.

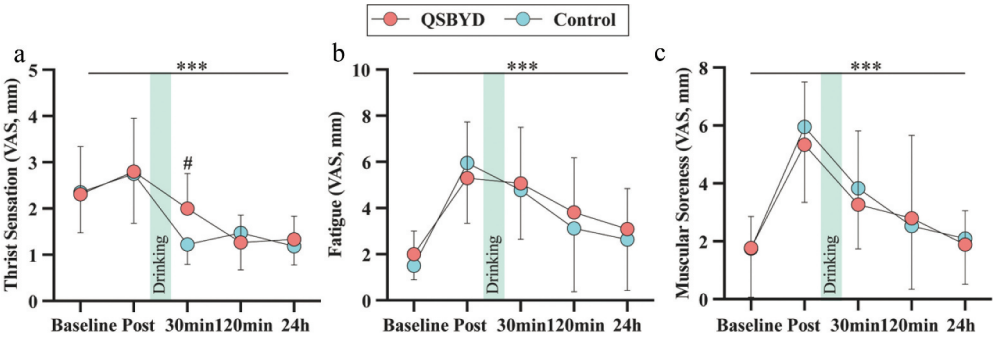


Figure 5. Measurements of thirst, fatigue, and muscular soreness at baseline, immediately post dehydration, 30 min, 120 min, and 24 h post dehydration. (a) Thirst sensation. (b) Fatigue. (c) Muscular soreness.*P<0.05, ***P<0.001 main effect for time. #P<0.05 interaction effect for time and beverage.

The objective of this study was to assess the efficacy of QSBYD as a rehydration beverage and its influence on exercise and high-temperature-induced dehydration. It's important to note that in this study, the efficacy of QSBYD as a rehydration beverage was assessed in comparison to a placebo beverage, specifically designed for this research. The placebo utilized was a 5% dilution of QSBYD, with lower osmolality and electrolyte content, serving as a control to isolate the effects of QSBYD's unique composition. This approach allowed us to specifically evaluate the rehydration potential and physiological benefits of QSBYD without comparing it to other commercially available hydration drinks. Our findings, therefore, provide insights into the effectiveness of QSBYD in the context of exercise and high-temperature-induced dehydration, rather than its comparative advantages over other hydration solutions available on the market.

In previous research, the potential active ingredients may not have had sufficient time to exert their effects due to the brief duration between beverage intake and examination [38,42–45]. Consequently, we administered QSBYD to participants three days prior to the exercise trial commencement, and baseline data indicated that continuous intake for three days did not affect dehydration-related markers in participants.

We hypothesized that QSBYD is an effective rehydration beverage capable of maintaining adequate hydration levels in individuals experiencing exercise and high-temperature-induced dehydration. The trial data supported our hypothesis, as urine volume significantly increased and NBW correspondingly decreased at 120 minutes post-dehydration in both groups. However, QSBYD resulted in reduced urine volume compared to the control group, suggesting improved fluid retention. Although no between-group differences were observed in USG, previous research has indicated that there is no gold standard measure of hydration, and sensitivity varies between methods. Comprehensive assessment of dehydration and rehydration magnitude, such as urine osmolality and salivary osmolality, is necessary [46].

Interventional studies on rehydration are relatively abundant in the literature, with the majority focusing on carbohydrate-electrolyte-rich sports beverages. The consensus is that sports beverages are likely more effective in restoring sweat-induced hydromineral loss than water alone [47,48]. High concentrations of electrolytes play a crucial role in aiding body hydration, which partly explains QSBYD's supportive hydration capability. Its

sodium concentration of 12 g/100 ml meets the Chinese standard Q/YQSL.0006S-2020 for electrolyte beverages. However, our study found that QSBYD's rehydration effect may also be related to its impact on serum levels of IL-1β and CRP, two markers closely associated with inflammation. Some studies have shown that elevated levels of CRP and IL-6 are predictors of dehydration and acute kidney injury caused by dehydration [49,50]. The exact nature of inflammatory responses to dehydration, their duration, and their effects remain largely unknown. However, some researchers believe that under normal circumstances, the intestinal epithelial barrier maintains relative impermeability to gut microbiota and their byproducts. Conditions including thermal stress, intense exercise, dehydration, and gastrointestinal inflammation may weaken the intestinal barrier, allowing inflammatory microbial antigens, such as lipopolysaccharides, to escape the gut and circulate within the body. These antigens can trigger potent inflammatory responses, involving the release of cytokines such as IL-6 and CRP [51,52]. Our research also discovered that participants experienced transient elevations in inflammatory factors following exercise and high-temperature-induced dehydration, which rapidly subsided after adequate rehydration. QSBYD significantly reduced IL-1β compared to the placebo, which may be related to certain active compounds in its herbal ingredients. The exact mechanism of this effect requires further investigation, but the results suggest that QSBYD may have additional benefits beyond hydration.

Findings from uromodulin knockout experiments in mice demonstrated a significant inverse correlation between levels of uromodulin in urine and inflammatory factors in serum [53]. Agricultural workers exposed to high-temperature environments are prone to low levels of uromodulin and high levels of inflammatory factors [21]. Therefore, it is necessary to further explore the levels of uromodulin and inflammatory factors in urine and blood during dehydration to assess the degree of dehydration and more comprehensively investigate its underlying mechanisms.

The effects of exercise on coagulation are well documented, although differing conclusions have arisen due to variations in exercise environments, workloads, and hydration statuses. For instance, some studies have shown that high-intensity exercise increases the levels of physiological activators of fibrinolysis, such as tPA [54–56]. However, exercise, dehydration, and hemoconcentration leading to increased viscosity and hypercoagulability are often acknowledged [55,57]. Increased platelet and procoagulant activity have also been observed, even though the underlying mechanisms remain under investigation [55]. Another study disclosed the activation of clotting and increased clot strength, as measured by viscoelastic testing and standard coagulation assays, following a marathon run [58]. Thus, in our investigation, we meticulously regulated the overall physical activity levels and hydration statuses of the participants, uncovering a decline in the levels of TM, a cofactor for thrombin, following exercise. Functionally, this aligns with the characteristics of post-exercise hypercoagulability. The attenuation of TM reduction by QSBYD may suggest its potential role in enhancing the fibrinolytic system subsequent to physical exertion.

We assessed three subjective perceptions of the participants using the VAS, with no distinctions between groups except for thirst sensation at 30 minutes post-exercise and heat exposure intervention. The placebo utilized by the control group was a 5% dilution of QSBYD, with lower osmolality and electrolyte content, which may have contributed to the sustained elevation of thirst sensation after QSBYD consumption, suggesting a potential for enhanced rehydration under ad libitum conditions.

5. Conclusion

This study demonstrates that QSBYD is an efficacious rehydration beverage, capable of ameliorating dehydration induced by exercise and high temperature. Its capacity to improve fluid retention and reduce urine output, as well as its potential impact on serum biomarkers, is noteworthy. However, one limitation of this research is the absence of a comparison with commercial hydration beverages, which are widely recognized and used for their hydrating effects. This decision was primarily due to the focus on assessing the unique benefits of QSBYD. Acknowledging this, further investigation into the underlying mechanisms and long-term effects of QSBYD on hydration is warranted. Future research should aim to evaluate the efficacy of QSBYD in diverse populations and environments, and importantly, include comparisons with established commercial hydration beverages to ascertain its relative effectiveness. Such comparisons would be invaluable in assessing QSBYD's potential benefits for specific types of athletic activities or sporting events, providing a clearer understanding of its place within the broader context of sports nutrition and hydration strategies.

Authors' contributions

Huanyu Jiang and Quanyu Du devised the experimental framework; Huanyu Jiang and Huan Wang scrutinized the data and composed the principal manuscript; Lin Zhao, Jiankun Gao, Yingduo Yang, Yingduo Yang, Jiahua Ma, Shan Gu, and Fenglin Hu executed the experimental procedures; Fei Wang oversaw the study and appraised the manuscript. All contributors have perused and consented to the published rendition of the manuscript.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This study was supported by the Sichuan Provincial Administration of Traditional Chinese Medicine under the 2022 Special Project for Innovation Teams in Science and Technology in Traditional Chinese Medicine [No. 2022C002].

Availability of data and materials

The data sets used and/or analyzed during the current study available from the corresponding author on reasonable request.

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