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To cite this article: Kara Blohm, Joshua Beidler, Phil Rosen, Jochen Kressler & Mee Young Hong (2019): Effect of acute watermelon juice supplementation on post-submaximal exercise heart rate recovery, blood lactate, blood pressure, blood glucose and muscle soreness in healthy non-athletic men and women, International Journal of Food Sciences and Nutrition, DOI: [10.1080/09637486.2019.1675604](https://doi.org/10.1080/09637486.2019.1675604)

To link to this article: <https://doi.org/10.1080/09637486.2019.1675604>



Published online: 10 Oct 2019.



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RESEARCH ARTICLE



## Effect of acute watermelon juice supplementation on post-submaximal exercise heart rate recovery, blood lactate, blood pressure, blood glucose and muscle soreness in healthy non-athletic men and women

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### ABSTRACT

The objective of this study was to determine the effects of a single pre-exercise dose of watermelon juice on submaximal post-exercise heart rate (HR) recovery, blood lactate (BL), blood pressure (BP), blood glucose (BG), and muscle soreness in healthy adults. In a randomised crossover design, 27 healthy non-athletic participants (13 males/14 females) consumed 355 mL of watermelon juice, Gatorade, sugar water, or water. HR and BL were significantly higher post-exercise, and both watermelon juice and sugar water increased postprandial BG. However, there were no significant differences among the supplements in HR recovery, BL, or post-exercise muscle soreness. Watermelon juice prevented increased post-exercise systolic and diastolic BP in females, but not in males. More research is warranted to examine the effect of sex on the efficacy of watermelon consumption for controlling BP.

### ARTICLE HISTORY

Received 28 May 2019  
Revised 26 September 2019  
Accepted 30 September 2019

### KEYWORDS

Watermelon juice; L-citrulline; post-exercise heart rate recovery; lactate

### Introduction

Sports nutrition supplements that promote higher levels of nitric oxide (NO) have become increasingly popular due to their potential ergogenic effects (Jones 2014). NO is well known for lowering blood pressure by promoting vasodilation (Zhao et al. 2015). NO also downregulates cytochrome c oxidase in mitochondria, which may increase the availability of oxygen to skeletal muscle (Zhao et al. 2015). Other metabolic effects of NO include promoting the uptake and oxidation of glucose and fatty acids by skeletal muscle (Dai et al. 2013).

One method of increasing NO levels is ingestion of the amino acid L-arginine. NO is primarily generated endogenously by the nitric oxide synthase (NOS) family of enzymes, which utilise L-arginine as a substrate (Figueroa et al. 2017). L-arginine supplementation has been shown to increase serum NO<sub>x</sub> concentrations by 50% and liver NO<sub>x</sub> by up to 164% (Jobgen et al. 2009; Alam et al. 2013).

L-citrulline is a non-essential amino acid that is involved in NO production as a precursor of arginine (Allerton et al. 2018). Interestingly, oral L-citrulline supplementation may increase plasma levels of arginine more effectively than arginine itself (Bailey et al.

2015; Wijnands et al. 2015; Moinard et al. 2016). This is due to the fact that L-citrulline is not catabolized by arginase in the small intestine and liver (Suzuki et al. 2016). Another benefit of L-citrulline is that it may reduce endothelial dysfunction by inhibiting arginase activity (Morita et al. 2014; Kövamees et al. 2016). Besides increasing NO production, L-citrulline may reduce muscle fatigue and post-exertional muscle soreness by increasing the elimination of ammonia through the urea cycle (Breuillard et al. 2015).

Watermelon (*Citrullus lanatus*) is naturally rich in L-citrulline, containing between 0.9 and 4.3 mg per kg raw flesh (Perkins-Veazie et al. 2012). In addition, the watermelon matrix contributes to greater bioavailability of L-citrulline (Tarazona-Díaz et al. 2013). These attributes have caused watermelon to be described as a potential functional drink for athletic recovery (Tarazona-Díaz et al. 2013). Following 16 days of watermelon juice supplementation, plasma L-arginine, L-citrulline, and NO<sub>x</sub> levels increased and muscle oxygenation improved during moderate- to high-intensity exercise (Bailey et al. 2016). Martínez-Sánchez et al. reported that a single dose of watermelon juice (3.45 g L-citrulline) reduced systolic and diastolic blood pressure (BP), post-exercise muscle soreness, and blood concentrations of lactate and glucose in amateur male

runners (Martínez-Sánchez et al. 2017b). In a separate study, one dose of watermelon juice (3.3 g L-citrulline) increased peak force and reduced perceived exertion during lower-body resistance exercises in male athletes (Martínez-Sánchez et al. 2017a). Also, 14 days of watermelon puree (1.47 g/day L-citrulline) decreased perceived exertion during a 75-km cycling time trial in male cyclists, but without improving performance time (Shanely et al. 2016).

Most previous investigations of watermelon's potential ergogenic effects have been conducted in male athletes (Tarazona-Díaz et al. 2013; Bailey et al. 2016; Shanely et al. 2016; Martínez-Sánchez et al. 2017a, 2017b). Therefore, the current study included both male and female subjects in order to detect possible sex differences. The purpose of this study was to examine the effect of a practical dose (355 mL) of watermelon juice (providing 780 mg L-citrulline) on heart rate recovery, blood glucose, BP, blood lactate levels, and post-exercise muscle soreness in healthy non-athletic men and women. In order to distinguish the effects of L-citrulline versus carbohydrate, other trials were included: water, sugar water, and Gatorade, a popular sports drink. We hypothesised that watermelon juice supplementation would reduce heart rate recovery time, decrease blood lactate accumulation, and diminish post-exercise muscle soreness compared with other beverages.

## Methods

### Participants

Thirty-four untrained healthy men and women volunteered to take part in this study on heart rate response and post-exercise muscle soreness after submaximal exercise on a cycle ergometer under controlled laboratory conditions at San Diego State University (SDSU). Recruited participants were 21 to 35 years of age and able to exercise at up to 80% of their predicted heart rate max ( $HR_{max}$ ), which was calculated using the age predicted heart rate equation ( $80\% HR_{max} = [220 - \text{age}] \times 0.80$ ). Exclusion criteria included injury that could interfere with performance; allergy to watermelon; pregnancy; the presence of any known medical condition resulting in metabolic disorder or chronic inflammation; current smokers; and medications or supplements that were taken for chronic conditions or could affect BP, blood lipids, or blood glucose. The health status of participants was assessed using a screening questionnaire. Thirty-four total subjects were recruited, but two males and five females dropped out due to reasons unrelated to the study

**Table 1.** Nutritional information for beverages (355 mL).

	Water	Sugar Water	WJ	Gatorade
Calories (kcal)	0	90	90	90
Carbohydrate (g)	0	22.5	22.5	22.8
Sugar (g)	0	22.5	18	21
Potassium (mg)	0	0	1110	36
L-citrulline (mg)	0	0	780	0

(time conflict, pregnancy, and injury unrelated to the current study). We therefore analysed a final group of twenty-seven participants, 13 total males and 14 total females. Participant physical characteristics can be found in Table 1.

Participants were asked not to consume any watermelon, watermelon products, or dietary supplements except for the provided beverages for 1 week prior to the beginning of the study and for the duration of the study period. Participants were asked to refrain from caffeine, alcohol, and exercise during the 24 hours prior to each blood collection. Participants were asked to consume a typical breakfast, keep food intake consistent for each testing day, and refrain from eating within one hour of testing. No further dietary or physical activity restrictions were imposed for the duration of the study. The present study was approved by the San Diego State University Institutional Review Board. All details of the study were explained to the participants, who also gave their written informed consent (clinicaltrials.gov, NCT03380195).

### Study design

The study was conducted at San Diego State University (San Diego, CA, USA). Participation in this randomised crossover design required four laboratory visits and included a separate trial for each of the four conditions with at least a two-day washout period between trials. The beverages, which were consumed prior to submaximal exercise, were allocated in random order across the four trials: (1) 355 mL bottled water, (2) 355 mL sugar water, (3) 355 mL watermelon juice (WTRMLN WTR, World Waters, LLC, NY, USA), and (4) 355 mL Gatorade. Nutritional information for each beverage can be found in Table 1. The watermelon juice was fortified with additional L-citrulline to provide a total of 780 mg per dose. The sugar water beverage was produced by adding 22.5 g table sugar to 355 mL bottled water so that the placebo supplement had a carbohydrate and Kcal load equal to the watermelon juice.

On each visit, participants arrived at the laboratory and were fitted with a Polar chest strap heart rate monitor (Polar USA, Lake Success, NY, USA). Height, weight, percent body fat (bioelectrical impedance

analysis, Omron Healthcare Inc., Kyoto, Japan), baseline BP (mm Hg), heart rate (bpm), lactic acid (mmol/L) (Nova Biomedical, Waltham, MA, USA), and blood glucose (mg/dL) (Nova Biomedical) were measured after a 15-minute rest. Blood samples were measured by puncture on the fingers of the non-dominant hand using a sterile lancet and dispensed into testing strips for the immediate determination of lactate and glucose concentrations using an automated analyser. Thereafter, participants ingested 355 mL of the randomised beverage in a cup. Following beverage intake, the participants rested quietly for 45 min before additional BP, heart rate, lactic acid, and blood glucose measurements were taken. The participants were then fitted to cycling shoes, familiarised with the Lode cycle ergometer (Lode Excalibur Sport, Groningen, Netherlands), completed a warm-up, and were asked to perform a criterion work rate trial ending at 80% predicted  $HR_{max}$ . After the test, the same measurements as baseline were collected immediately and at 5 min and 20 min post-exercise. Heart rate was recorded every minute post-exercise for a maximum of 20 min.

### Stationary bike cycling testing

The exercise protocol was preceded by a 3-minute warm up at 20 watts (W), after which the work rate increased 20 W per minute until 80% of predicted  $HR_{max}$  was achieved. The target of 80%  $HR_{max}$  was selected for ecological validity, as it was assumed that participants would not normally reach peak capacity. In addition, the lower intensity was designed to reduce apprehension regarding a maximal test. Participants cycled at a self-selected pedal rate >70 rpm. During the cycling test, ratings of perceived exertion were assessed using the Borg Scale (Borg 1998) with a range of 6–20, and exercise was terminated if perceived exertion was over 17. Once 80% predicted  $HR_{max}$  was achieved, participants were asked to stop cycling, unclip from the cycle ergometer, and return to a chair close by. BP, lactic acid, and blood glucose were taken 5 min and 20 min post-exercise. Heart rate was recorded immediately and at one minute intervals until baseline heart rate was achieved or for a maximum 20 min post-exercise. Once HR reached baseline, final HR, BP, lactic acid, and blood glucose were taken.

### Post-exercise soreness scale

After each session (water, sugar water, watermelon juice, Gatorade), participants self-reported 24-hour

post-exercise muscle soreness using a scale of 1 (no soreness) to 5 (maximum soreness with physical disability for daily activities) (Tarazona-Díaz et al. 2013).

### Statistical analysis

Based on the study by Tarazona-Díaz et al. (2013), a power analysis using G\*Power showed that 12 male subjects would be needed to detect heart rate differences at 1-minute post-exercise with 90% power and an  $\alpha$  of  $p < .05$ . Our study included 13 males and a similar number of females in order to assess potential sex differences.

Data were analysed using repeated measures analysis of variance (ANOVA) with SPSS (IBM, Armonk, NY). Data for blood lactate, systolic blood pressure (SBP), and diastolic blood pressure (DBP) were analysed using a 4 (condition; water, sugar water, watermelon juice, Gatorade)  $\times$  3 (time; baseline, pre-exercise, 5 min post-exercise) repeated measures analysis of variance followed by Bonferroni adjustments to determine differences between groups. Data for heart rate were analysed using a 4 (condition; water, sugar water, watermelon juice, Gatorade)  $\times$  5 (time; baseline, immediately, 1-min, 3-min, and 5-min post-exercise) repeated measures analysis of variance followed by Bonferroni adjustments to determine differences between groups. Data for 24 hour post-exercise muscle soreness were analysed using paired *t*-tests. Statistically significant differences were established at  $p < .05$ .

## Results

### Demographic information

Among the 28 participants, the mean age of the 13 male participants was 24.8 years old, mean height was 177.1 cm, and mean weight was 75.1 kg (Table 2). The male participants had a mean BMI ( $\text{kg}/\text{m}^2$ ) of 23.8, mean body fat of 14.1%, and mean  $HR_{max}$  of 195 (80%  $HR_{max} = 156$ ). The mean age of the 14 female participants was 24.4 years old, mean height was 165.3 cm, and mean weight was 59.9 kg. Female

**Table 2.** Physical characteristics of participants.

	Male ( $n = 13$ )	Female ( $n = 14$ )
Age (year)	24.8 $\pm$ 0.52	24.4 $\pm$ 0.41
Height (cm)	177.1 $\pm$ 1.81	165.3 $\pm$ 1.52
Weight (kg)	75.1 $\pm$ 3.70	59.9 $\pm$ 1.86
BMI ( $\text{kg}/\text{m}^2$ )	23.8 $\pm$ 0.92	21.8 $\pm$ 0.44
$HR_{max}$ (bpm)	195.2 $\pm$ 1.07	195.8 $\pm$ 0.82
80% $HR_{max}$ (bpm)	156.2 $\pm$ 0.86	156.4 $\pm$ 0.65
Body fat (%)	14.1 $\pm$ 1.51	19.8 $\pm$ 0.88

BMI: body mass index;  $HR_{max}$ : predicted maximum heart rate = 220-age.

participants had a mean BMI of 21.8, mean body fat of 19.8%, and mean  $HR_{max}$  of 196 ( $80\% HR_{max} = 156$ ). BMI and body fat percentage were within normal ranges for both males and females.

### Heart rate

There was a significant time effect on heart rate ( $p < .001$ ). Baseline heart rate was 64 beats per minute (bpm) and increased to 156 bpm with exercise. However, there was no significant effect of beverage type on heart rate in either males (Figure 1(A)) or females (Figure 1(B)). The change in heart rate from the end of exercise to 1-minute post-exercise followed a similar pattern across trials, independent of beverage type in both males and females.

### Time, power output to 80% $HR_{max}$ minutes to recovery, and perceived muscle soreness

Time and power output to reach 80% predicted  $HR_{max}$  and heart rate recovery time showed no significant differences among the four beverages in either males or females (Table 3). Males took longer than females to reach 80% predicted  $HR_{max}$  and achieved higher wattage ( $p < .01$ ). Muscle soreness was reported using a scale from 1 to 5 in all treatments. Neither males nor females showed significant differences in post-exercise muscle soreness according to beverage type (Table 3). Recovery time and 24-hour post-exercise muscle soreness did not differ significantly according to sex.

### Blood pressure

Neither time nor beverage type significantly affected SBP or DBP in males (Table 4). Among females, SBP

and DBP were significantly elevated at 5 min post-exercise for the water, sugar water, and Gatorade beverages ( $p < .05$ ), but not for the watermelon juice beverage (Table 4).

### Blood lactate

There was a significant exercise effect for blood lactate concentration ( $p < .001$ ). Blood lactate increased after exercise compared to baseline and pre-exercise in both males and females (Table 4). There was no difference in lactate concentration between baseline and pre-exercise. No significant effect for type of beverage on lactate value was found.

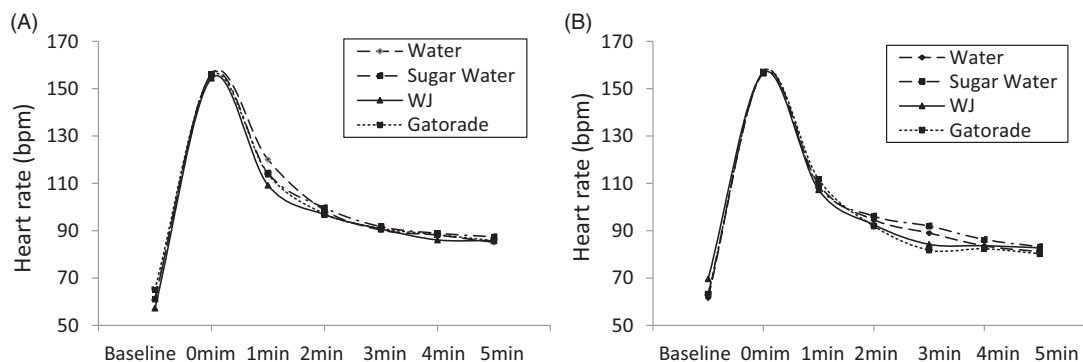
### Blood glucose

Blood glucose concentration showed a significant Beverage x Time interaction ( $p < .001$ ) (Table 4). In both males and females, consumption of sugar water, watermelon juice, and Gatorade resulted in higher blood glucose than water in the pre-exercise stage

**Table 3.** Minutes and watts and muscle soreness.

	Water	Sugar Water	WJ	Gatorade
<b>Males</b>				
Minutes*	9.3 ± 0.43	8.9 ± 0.59	9.1 ± 0.47	9.2 ± 0.47
Watts*	216.9 ± 10.39	220.8 ± 9.55	215.0 ± 9.54	221.2 ± 11.10
Recovery	16.6 ± 2.13	17.3 ± 1.92	17.3 ± 2.02	15.1 ± 2.16
Muscle soreness	1.1 ± 0.08	1.1 ± 0.09	1.2 ± 0.07	1.3 ± 0.12
<b>Females</b>				
Minutes	6.9 ± 0.44	6.4 ± 0.61	6.4 ± 0.49	6.7 ± 0.49
Watts	160.7 ± 10.0	151.8 ± 9.20	155.4 ± 9.19	155.4 ± 10.70
Recovery	13.0 ± 2.05	13.4 ± 1.85	15.2 ± 1.95	13.0 ± 2.08
Muscle soreness	1.1 ± 0.07	1.1 ± 0.09	1.0 ± 0.07	1.1 ± 0.11

Minutes: mean minutes until 80% heart rate max reached; Watts: watts until 80% heart rate max reached; Recovery: mean minutes until baseline heart rate reached; Muscle soreness: 24 hr post-exercise muscle soreness on scale 1 (no soreness) to 5 (maximum soreness with physical disability for daily activities);  $N = 27$ ; \*Gender effect  $p < .01$ .



**Figure 1.** Heart rate recovery. Heart rate in beats per minute (bpm), at initial measurement (prior to beverage consumption), end of exercise (0 min), and every minute until 5 min in males (A) and females (B). WJ, watermelon juice;  $N = 27$ . No significant differences were found between the beverages provided.



**Table 4.** Blood pressure, lactic acid and blood glucose.

	Water	Sugar Water	WJ	Gatorade
<b>Males</b>				
SBP (mmHg)				
Baseline	125.3 ± 2.47	130.4 ± 2.96	128.4 ± 4.16	132.8 ± 4.57
Pre-ex	129.4 ± 4.18	125.5 ± 3.47	127.8 ± 4.77	131.1 ± 3.70
Post-ex	131.6 ± 3.59	128.8 ± 4.32	131.0 ± 3.06	131.5 ± 4.73
DBP (mmHg)				
Baseline	73.1 ± 2.92	76.1 ± 3.82	77.6 ± 3.04	77.4 ± 3.01
Pre-ex	69.5 ± 2.44	67.8 ± 2.62	71.8 ± 2.82	76.6 ± 3.04
Post-ex	71.3 ± 2.64	72.6 ± 2.39	71.6 ± 3.06	74.8 ± 3.18
LA (mmol/L)				
Baseline	2.3 ± 1.70	7.1 ± 2.45	3.3 ± 0.82	4.3 ± 2.24
Pre-ex	3.9 ± 1.76	4.9 ± 1.95	3.5 ± 0.39	7.2 ± 1.74
Post-ex	6.8 ± 2.05 <sup>#</sup>	8.3 ± 1.79 <sup>#</sup>	7.9 ± 1.41 <sup>#</sup>	7.6 ± 1.49 <sup>#</sup>
Glucose (mg/dL)				
Baseline	114.5 ± 4.16	120.9 ± 6.71	109.9 ± 5.00	110.3 ± 6.15
Pre-ex	105.0 ± 6.75	124.4 ± 8.45 <sup>^</sup>	112.0 ± 6.20 <sup>^</sup>	120.3 ± 6.69 <sup>^</sup>
Post-ex	104.5 ± 6.98	109.5 ± 6.60	91.5 ± 5.89	98.4 ± 6.67
<b>Females</b>				
SBP (mmHg) <sup>+</sup>				
Baseline	105.4 ± 2.33	106.8 ± 2.79	109.4 ± 3.92	108.8 ± 4.30
Pre-ex	103.4 ± 3.94	111.7 ± 3.27	103.9 ± 4.50	109.4 ± 3.49
Post-ex	113.9 ± 3.39 <sup>#</sup>	116.1 ± 4.07 <sup>#</sup>	107.4 ± 2.88	117.9 ± 4.46 <sup>#</sup>
DBP (mmHg) <sup>+</sup>				
Baseline	63.4 ± 2.76	61.6 ± 3.60	61.9 ± 2.87	64.0 ± 2.84
Pre-ex	60.8 ± 2.30	61.4 ± 2.47	62.8 ± 2.65	63.8 ± 2.87
Post-ex	64.6 ± 2.49 <sup>#</sup>	65.1 ± 2.25 <sup>#</sup>	62.9 ± 2.89	68.7 ± 3.00 <sup>#</sup>
LA (mmol/L)				
Baseline	2.08 ± 0.57	3.30 ± 2.00	2.93 ± 0.67	4.42 ± 1.83
Pre-ex	6.20 ± 1.44	5.42 ± 1.59	4.18 ± 0.32	3.10 ± 1.42
Post-ex	8.12 ± 1.67 <sup>#</sup>	5.25 ± 1.46 <sup>#</sup>	6.42 ± 1.15 <sup>#</sup>	6.17 ± 1.22 <sup>#</sup>
Glucose (mg/dL)				
Baseline	93.7 ± 3.73	104.0 ± 6.00	99.0 ± 4.47	105.0 ± 5.50
Pre-ex	92.5 ± 6.04	120.3 ± 7.55 <sup>^</sup>	106.7 ± 5.55 <sup>^</sup>	114.0 ± 5.98 <sup>^</sup>
Post-ex	92.4 ± 6.24	95.7 ± 5.90	91.1 ± 5.27	90.7 ± 5.96

SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; LA Lactic Acid; <sup>#</sup>indicates different from baseline or Pre-ex at  $p < .05$ ; <sup>^</sup> indicates difference from water at  $p < .05$  among beverage groups; <sup>+</sup> indicates which variables show sex differences; Post-exercise measures were taken 5 min after the cessation of exercise;  $N = 27$ .

(45 min post-consumption) ( $p < .001$ ). However, there were no significant differences in post-exercise blood glucose among the beverage types.

## Discussion

In this study, females who consumed water, sugar water, or Gatorade had increased SBP and DBP after exercise, while watermelon juice prevented an increase in BP. In males, post-exercise BP did not differ from baseline, regardless of beverage type. Watermelon juice did not significantly affect heart rate, exercise performance, post-exercise muscle soreness, or blood lactate or glucose concentration in either males or females.

L-citrulline effectively raises circulating levels of L-arginine, the substrate for production of NO, which is well known for its vasodilatory effects (Bailey et al. 2015; Figueroa et al. 2017). Accordingly, BP has been a major focus of watermelon and L-citrulline research. In a pilot study by Figueroa et al., pre-hypertensive but otherwise healthy adults were given watermelon

powder providing 2.7 g L-citrulline and 1.3 g L-arginine for 6 weeks (Figueroa et al. 2011). Watermelon significantly reduced SBP without affecting DBP. In two subsequent studies, a higher dose of watermelon powder (providing 4 g L-citrulline and 2 g L-arginine) reduced SBP and DBP in obese adults with prehypertension or stage 1 hypertension and obese postmenopausal women with stage-1 hypertension (Figueroa et al. 2012, 2013). SBP was also significantly lower in healthy men treated with 100 mg L-citrulline per kg body weight (~8.5 g per day) for 14 days and heart failure patients given 3 g L-citrulline for 2 months (Orozco-Gutiérrez et al. 2010; Sanchez-Gonzalez et al. 2013). In the current study, females who consumed 355 mL watermelon juice providing a 780 mg dose of L-citrulline had significantly lower post-exercise SBP and DBP compared with females who consumed water, sugar water, or Gatorade. In contrast, males did not show a significant effect of beverage type on BP. This is a novel finding, as previous studies have not shown greater effects of watermelon or L-citrulline supplementation on BP in females. In one study involving older adults, L-citrulline reduced DBP in males but not in females, a difference that the authors attributed to higher baseline BP in the male subjects (Gonzales et al. 2017). Important sex differences in BP regulation are known to exist. Young women typically have lower BP than young men, likely due to greater  $\beta$ -adrenergic vasodilation, while hypertension is more common in older women than in their male counterparts (Joyner et al. 2016). Several animal studies have shown greater NOS activity in females compared with males (Chen et al. 2017; Oydanich et al. 2019). Therefore, the effect of watermelon on post-exercise BP in females could be due to enhanced NO production. This hypothesis is speculative, and further research is needed to elucidate the mechanisms responsible for the observed sex differences.

Although we hypothesised that watermelon would reduce heart rate recovery time, heart rate was not affected by beverage type. Tarazona-Díaz et al. reported that 500 mL of natural or citrulline-enriched watermelon juice (containing either 1.17 g or 6 g L-citrulline) lowered recovery heart rate following a max cycling test (Tarazona-Díaz et al. 2013). However, most studies have failed to show an effect of L-citrulline or watermelon on either resting or post-exercise heart rate (Figueroa et al. 2011, 2012, 2013; Bailey et al. 2016; Shanely et al. 2016; Martínez-Sánchez et al. 2017b).

Beverage type had no effect on performance-related measures, including time and power output to reach

80% predicted  $HR_{max}$ . L-citrulline has been hypothesised to decrease muscle fatigue by increasing conversion of ammonia to urea (Figueroa et al. 2017). In addition, increased NO levels may reduce mitochondrial oxygen consumption, thereby improving the availability of oxygen in skeletal muscles (Zhao et al. 2015). Previous studies have shown mixed results regarding the ergogenic effects of watermelon or L-citrulline supplementation. L-citrulline increased exercise duration and power output during moderate- to severe-intensity cycling and reduced time to completion during a cycling time trial (Bailey et al. 2015; Suzuki et al. 2016). However, watermelon supplementation failed to improve performance during a cycling time trial, a ramped cycle ergometer test, or a half-marathon (Bailey et al. 2016; Shanely et al. 2016; Martínez-Sánchez et al. 2017b). Bailey et al. found that L-citrulline improved  $VO_2$  mean response time during severe-intensity but not moderate-intensity exercise (Bailey et al. 2015). Therefore, the relatively low exercise intensity in the current study may have contributed to the lack of performance differences between groups.

Beverage type did not significantly affect blood lactate concentration. Lactate is produced during high-intensity anaerobic exercise through the activation of phosphofructokinase by ammonia (Takeda et al. 2011). Elevated blood lactate is therefore associated with muscle fatigue, although the actual cause of fatigue is not lactate but an increased concentration of hydrogen ions in the muscle tissue (Cairns 2006). A single 500 mL dose of citrulline-enriched watermelon juice (3.45 g L-citrulline) significantly reduced blood lactate after a half-marathon (Martínez-Sánchez et al. 2017b). However, blood lactate was not affected by 14 days of watermelon puree or 24 hours of L-citrulline supplementation after a 75 km cycling time trial and an incremental treadmill test, respectively (Hickner et al. 2006; Shanely et al. 2016). Most studies using citrulline malate similarly showed no effect on blood lactate concentration (Wax et al. 2015; Cunniffe et al. 2016; Wax et al. 2016; da Silva et al. 2017; Farney et al. 2017; Chappell et al. 2018). Based on the literature, practical doses of L-citrulline may not effectively reduce blood lactate concentrations, but it is also possible that the dose of L-citrulline in this study (780 mg) was too small to produce an effect.

L-citrulline may reduce post-exercise muscle soreness by buffering exercise-induced acid, lactate, and ammonium (Pérez-Guisado and Jakeman 2010). Watermelon juice has been found to significantly reduce muscle soreness following a max cycle

ergometer test, a half marathon, and a half-squat protocol (Tarazona-Díaz et al. 2013; Martínez-Sánchez et al. 2017a, 2017b). In this study, muscle soreness was not significantly different before and after exercise and was not affected by beverage type. The relatively short duration, low to moderate intensity, and concentric mode of exercise likely contributed to the low incidence of muscle soreness duration.

Watermelon juice, sugar water, and Gatorade significantly increased pre-exercise blood glucose. This was expected, as the three beverages contained similar amounts of carbohydrate. Post-exercise blood glucose did not differ significantly among the beverages. Watermelon has shown hypoglycaemic effects in some animal studies. For example, watermelon juice decreased blood glucose in male Zucker diabetic rats and female alloxan-induced diabetic rats (Wu et al. 2007; Abd El-Razek and Sadeek 2011). The effect could result from NO-induced vasodilation enhancing delivery of glucose to the muscles. NO also appears to promote insulin production and insulin sensitivity, increasing the transport of glucose into muscle cells, and to promote glycolysis by increasing cGMP production (Nakata and Yada 2003; Jobgen et al. 2006). Few studies have evaluated the effects of watermelon or L-citrulline on blood glucose concentration in humans. A single dose of watermelon juice (providing 3.45 g L-citrulline) significantly reduced blood glucose after a half marathon (Martínez-Sánchez et al. 2017b). However, 14 days of watermelon puree and 24 hours of L-citrulline did not affect blood glucose levels after a cycling time trial and an incremental treadmill test to exhaustion, respectively (Hickner et al. 2006; Shanely et al. 2016).

### Limitations

Although subjects were advised to maintain normal dietary intakes and physical activity levels, to avoid watermelon and dietary supplements throughout the study, and to abstain from caffeine and alcohol for 24 hours before blood collections, no further attempt was made to standardise diet or activity levels. Therefore, a future study could prioritise a uniform diet and physical activity protocol for all subjects in order to reduce within-group differences and provide a more stable baseline of measurement for the data. Asking subjects to maintain a food diary could also provide useful data about dietary patterns. The post-exercise increase in BP was ameliorated in watermelon-consuming females. Although we believe this effect is likely due to watermelon's L-citrulline

content, we cannot rule out a role for other bioactive substances in watermelon. Compared with the other beverages, the watermelon drink was much higher in potassium, which is known to have antihypertensive effects. A future study could include watermelon and L-citrulline treatments to isolate the effects of L-citrulline from other watermelon components. As previously mentioned, the lack of significant differences in blood lactate concentration may be explained by an insufficient dose of L-citrulline. Another limitation is that post-exercise muscle soreness was not effectively examined, as none of the groups experienced significant muscle soreness. With a longer or more intense exercise protocol, significant differences in post-exercise muscle soreness as well as exercise performance might be observed. In future studies, it could be beneficial to measure nitric oxide as a function of watermelon juice consumption. Longer-term watermelon supplementation may also yield greater differences between groups.

## Conclusion

The significant finding of this study is that an acute single dose of watermelon juice as a pre-exercise supplement prevented increased post-exercise BP in females without altering BP in males. In female subjects, post-exercise SBP and DBP increased significantly from baseline with water, sugar water, and Gatorade, but not with watermelon juice. Watermelon juice did not significantly affect exercise performance, blood lactate levels, or post-exercise muscle soreness in either males or females. These results support the ability of watermelon juice to prevent a post-exercise increase in BP in healthy non-athletic females. Additional research is needed to determine the mechanisms responsible for the influence of sex on the relationship between beverage type and BP.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## Funding

This study was funded by the National Watermelon Promotion Board (NWPB 19-20).

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