Significance of the research

The research investigated the impact of two polyphenol supplements on high intensity cycling performance. To date, little research has been undertaken with antioxidant polyphenol supplements regarding exercise performance, particularly CherryActive and Pycnogenol®. This is the first study to investigate the supplementation of either CherryActive or Pycnogenol® on gross efficiency and 20 km cycling time trial performance. Findings suggest that the Pycnogenol® supplement may have a small effect on performance during the final stages of a 20 km TT, however further research with greater dosages are needed to clarify the ergogenic potential of the supplements.

Agreement of authors for publication

The authors agree to the publication of this research.

Figures and tables

This manuscript contains 2 tables and 2 figures.

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The influence of different sources of polyphenols on sub-maximal cycling and time trial performance

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Abstract

The primary purpose of the study was to establish the effects of commercially available polyphenol-rich antioxidant supplements, Pycnogenol® with added bioflavonoids (PYC-B) and CherryActive (CHA), on 20 km cycling performance. Using a double-blind counterbalanced, repeated-measures design, nine male cyclists or triathletes (32.1 ± 11.2 years; maximal aerobic capacity 4.2 ± 0.7 $L \cdot min^{-1}$; maximal power output 391.7 ± 39.5 watts) consumed 200 mg of CHA, 120 mg of PYC-B, or 200 mg of placebo (PLA) capsules, 2 days before and on the day of each experimental trial. The experimental trials consisted of four 5 minute stages at 40%, 50%, 60%, and 70% maximal power output (W_{max}), followed by a 20 km time trial (TT). Statistical analyses revealed no significant differences between trials for heart rate, respiratory exchange ratio, gross mechanical efficiency, oxygen consumption, or blood lactate, at any of the intensities completed during the initial 20 minute phase of the trial ($p > .05$). Final 20 km TT times were not significantly different between trials ($p = .115$), but, compared to PLA, PYC-B did significantly increase power output by 6.2% over the final 5 km of the TT ($p = .022$). The study suggests that PYC-B could be beneficial towards the end of an intense bout of cycling exercise. However, as total 20 km time was not significantly different between trials the doses used are unlikely to benefit 20 km cycling time trial performance.

Key words

Pycnogenol®, free radicals, antioxidants, vasodilation, cherries.

Abbreviations

PYC = Pycnogenol®

CH = Cherries

PYC-B = Pycnogenol with added bioflavonoids.

CHA = CherryActive

FR = Free radicals

AO = Antioxidants

VO_2 = Oxygen uptake

HI = High intensity

O_2 = Oxygen

NO = Nitric oxide

TT = Time trial

MAP = Maximal aerobic power test

PLA = Placebo

Cm = Centimetres

Kg = Kilograms

RER = Respiratory exchange ratio

B_{lac} = Blood lactate

W_{max} = Maximal power output

GME = Gross mechanical efficiency

ES = Effect size

Introduction

When undertaking endurance exercise at a high intensity (HI), the exercising muscles produce free radicals (FR) causing cellular damage [1, 2]. Free radicals accumulate due to the greater oxygen uptake (VO_2) associated with HI exercise, and appear to impair skeletal muscle contraction, accelerating fatigue and diminishing performance [1, 3, 4]. Fatigue in HI exercise may also arise from circulatory limitations as the exercising muscles fail to receive a sufficient oxygen (O_2) supply in order for HI performance to be sustained [5, 6]. To offset fatigue during HI exercise, recent research has suggested that performance could be improved through nutritional interventions which simultaneously combat FR damage and promote blood flow [4]. Various polyphenols appear to stimulate these antioxidant (AO) and vasodilatory effects [7, 4].

Adding AO-rich polyphenols to the diet may assist the body's own AO system to counteract FR damage and the associated muscular fatigue [8-10]. Furthermore, polyphenols stimulate nitric oxide (NO) production within the cell walls, encouraging blood vessels to dilate [7, 12]. This could be beneficial during HI performance as NO enhanced vasodilation has been shown to enhance blood flow to the working muscles, which is essential if a high level of exercise performance is to be maintained [13, 6]. The combination of AO activity and enhanced vasodilation may be particularly beneficial in situations where a high level of FR damage is possible, such as when undertaking HI exercise [8, 11].

126 It has been suggested that consuming nutrients that exert containing
127 a variety of AOs are more beneficial in an attempt to counteract the
128 FR damage caused by exercise-induced oxidative stress compared
129 to singular AO nutrients (*e.g.* Vitamin C), potentially aiding HI
130 exercise performance [9, 11]. Two such mixtures are Pycnogenol®
131 (PYC) and Cherries (CH). There are numerous polyphenols in PYC,
132 including several proanthocyanidins, which produce a powerful
133 mixture displaying AO and vasodilatory effects [12, 14, 15]. It has
134 been shown that even a single dose of PYC (≥100 mg) has
135 significant effects on blood flow [16]. Three studies have reported
136 that PYC supplementation can offset muscular fatigue and prolong
137 time to exhaustion in exercise trials involving HI running [17] and
138 cycling [18, 19]. However, whether or not PYC supplementation can
139 lead to improvements in time trial (TT) tests, which are similar to race
140 performance and are therefore considered superior tests, has not
141 been investigated [20]. Similarly, the numerous polyphenols present
142 in CH including anthocyanins, catechin and kaempferol have AO
143 effects [21]. Anthocyanins in particular are found in large quantities in
144 CH and have been shown to have powerful vasodilatory effects [22].

145 Due to cherries' AO capabilities, two recent studies found that
146 supplementing with CH juice for 5 days can alleviate muscle damage
147 following intense running exercise and boosts total antioxidant
148 capacity [23, 24]. However, neither study measured the effect of CH
149 juice on race time, therefore whether CH can directly enhance HI
150 exercise performance remains unclear.

The majority of similar studies have employed longer protocols ranging from 5-30 days [2, 9, 17, 23, 24] whereas elite cyclists seem to prefer shorter protocols. Therefore the purpose of this study is to determine whether the acute ingestion of two polyphenol mixtures, Pycnogenol® (with added bioflavonoids; PYC-B) and/or CherryActive (CHA) for 3 days will significantly improve physiological measures during sub-maximal cycling and enhance subsequent 20 km TT performance in moderately trained cyclists and triathletes. The effects on power output during the final 5 of the TT are of particular interest as skeletal muscle fatigue will likely be more evident at this point, partly due to increased FR production, acidosis and increased demand on the circulatory system [3, 6 11]. It is hypothesized that both PYC-B and CHA will improve gross mechanical efficiency, enhance lactate efflux during sub-maximal cycling and improve 20 km TT performance.

Method

Participant characteristics

Nine moderately trained cyclists and triathletes completed the study (Age: 32.1 ± 11.2 years, Height; 179.7 ± 5.9 cm, weight: 80.2 ± 8.6 kg, VO_{2max}: 4.2 ± 0.7 $L \cdot min^{-1}$, maximal power output: 391.7 ± 39.5 watts). All participants were male, >3 years competitive cycling experience and were familiar with time trials and cycling distances of ≥20 km. The study was reviewed by the University of Portsmouth's BioSciences Research Ethics Committee.

176

177 *Study design*

178 A double blind repeated measures crossover design was employed
179 with the participants ingesting one of three supplements, CHA, PYC-
180 B or a placebo (PLA) in three separate trials. CHA contained dried
181 montmorency cherries which provided 216 mg of polyphenols
182 (CherryActive, Twickenham, UK), PYC-B contained 120 mg of
183 Pycnogenol® and 600 mg of citrus bioflavonoids (Horphag Research
184 Ltd, NBTY, Warks, UK) and the placebo contained 1g of maltodextrin
185 (PSP22 orange, Science in Sport Ltd. Lancashire, UK). The trial
186 orders were allocated using a partial counter-balance with 6
187 participants fully counterbalanced and the remaining 3 partially
188 counter-balanced. The participants visited the University on 4
189 occasions, firstly, to record their physical characteristics and to
190 complete a maximal aerobic power test (MAP). The participants
191 completed three experimental trials at a similar time of day, each
192 separated by ≥5 days at the University of Portsmouth's exercise
193 laboratory. Each trial consisted of 20 minutes of progressive intensity
194 cycling and a 20 km TT on an electronically braked cycle ergometer
195 (Velotron, Racermate Inc. Seattle).

196

197 Procedures

198 *Preliminary measures*

199 The participants' first trial at the laboratory was a MAP test. Initially,
200 participants' height (cm) (Harpenden portable stadiometer, Holtain,
201 UK) and body mass (kg) (770, Seca, Germany) were recorded.

Participants were fitted with a heart rate monitor (T31, Polar, UK) and a face mask (7400 Series, Hans Rudolph, USA) attached to an breath-by-breath expired gas analyser (Cosmed, Italy). This same procedure and equipment was used in all MAP tests and experimental trials.

An initial workload of 50 watts was set on the ergometer using their preferred cadence. The workload was increased by 25 watts every 60 seconds until the participant voluntarily stopped or was unable to continue cycling at >70 rev·min^{-1} [25]. Participants were deemed to have reached VO_{2max} when they could not maintain cycling at >70 rev·min^{-1} for 15 seconds and HR was ≥90% of age-predicted maximum. The mean VO_2 attained over the final 60 seconds of the trial was considered as VO_{2max} and the highest power output attained for a given 60 second increment was considered the participants' W_{max} [26].

Experimental trials and supplements

Three experimental trials were completed with a different supplement consumed prior to each. For three days (two days before and on the day of the trial) participants consumed one of three supplements; PYC-B, CHA or a PLA, consuming the other two supplements in the subsequent two trials. The supplements were provided in capsule form of the same size and the contents were of similar colour to maintain the blinding of the study. The participants were instructed to consume two capsules together with a meal. Timing of intake was

standardized across trials by instructing participants to consume the supplements at the same time of day equivalent to two to three hours prior to each trial.

Prior to testing, participants were provided with food diaries and instructed to detail their food and fluid intake on the two days before and on the day of their first experimental trial. They were then told to repeat this diet over the same time period prior to the subsequent trials. A list detailing foods with a high quantity of polyphenols were provided to participants so that these were not consumed in the 24 hours leading up to the experimental trials. Participants were instructed to avoid undertaking strenuous exercise and consuming caffeine, alcohol or any vitamin supplement in the 48 hours prior to each experimental trial. Participants were asked to arrive at the laboratory in a fed state having eaten a meal of similar macronutrient content two to three hours prior to each trial.

The initial phase of the experimental trial involved cycling at four 5-minute incremental stages, each corresponding to 40, 50, 60 and 70% of the participants' W_{max}. The Cosmed system recorded heart rate (HR), expired gas concentrations (oxygen uptake [VO_2] and carbon dioxide production [VCO_2]) continuously. A 20 µl blood sample was obtained via a finger-prick sample before the end of each stage to determine blood lactate (B_{lac}) concentrations (Biosen C_line Sport, EFK-Diagnostics GmbH, UK). Gross mechanical efficiency (GME) was calculated for each stage to determine if the

supplements affected the energy cost of sub-maximal cycling using the following equation:

Mechanical power (kcal·min^{-1}) / metabolic power (kcal·min^{-1}) X 100 = GME %. Efficiency was measured.

Once the 20 minutes was completed the participants had a 10 minute break before starting the 20 km TT. The TT was self-paced and participants were instructed to complete the course as quickly as possible. The only feedback the participants received was distance, which was projected onto a screen in front of them. Expired gases and HR were recorded continuously throughout the TT, along with power output (Watts), speed (km·h^{-1}), cadence (rev·min^{-1}) and time (milliseconds) using the Velotron computer software. A final B_{lac} measure was taken in the last 0.5 km of the TTs.

Data analysis

Statistical analyses were performed using PASW statistics version 18 for Microsoft Windows, and results are presented as mean ± SD. Coefficient of variation (CV) was established for time to complete 20 km. All data were checked for normality and one and two way analyses of variance (ANOVA) with repeated measures were applied. If the ANOVA found significant differences, paired samples t-tests with bonferroni correction were applied to determine which conditions were significantly different. Statistical power was calculated and effect sizes were calculated using partial eta and Cohens *d* [27]. The alpha was set at $p < .05$.

Results

Sub-maximal data

Due to equipment failure, data for the sub-maximal portion of the trial was only collected for 6 participants. Table 1 displays the descriptive data for the 5 parameters assessed. There were no significant differences in GME at any of the intensities (40, 50, 60, 70% W_{max}) during between trials (p = .952, eta-squared = .05, power = .11). Mean VO_2 for the 5 minute stages was also not significantly different between trials (p = .966, eta-squared = .04, power = .10). There were no differences in RER (average value over the 5 minute stage) at any of the intensities completed during the trials (p = .562, eta-squared = .14, power = .27), or for HR at the end of each stage (p = .064, eta squared = .21, power = .71). The B_{lac} data was collected from eight participants and there were no differences in B_{lac} at any of the intensities between trials (p = .742, eta-squared = .08, power = .21).

291 Table 1. HR, B_{lac}, GME, $\dot{V}O_2$ and RER data collected for each 5 minute stage (mean ± SD).

Measure	% of W_{max}											
	40			50			60			70		
	PLA	CHA	PYC-B	PLA	CHA	PYC-B	PLA	CHA	PYC-B	PLA	CHA	PYC-B
HR ($b \cdot min^{-1}$)	119.4 ± 14.1	117.6 ± 11.9	120.9 ± 12.9	134.2 ± 16.6	132.6 ± 13.7	134.2 ± 15.4	151.1 ± 17.2	148.2 ± 14.9	157.8 ± 16.4	164.9 ± 17.7	161.9 ± 16.2	162.4 ± 15.3
B_{lac} ($mmol \cdot l^{-1}$)	2.1 ± 0.8	1.8 ± 0.3	2.2 ± 0.7	2.6 ± 1.2	2.2 ± 0.9	3.1 ± 1.4	3.7 ± 1.7	2.9 ± 0.8	3.4 ± 1.4	5.6 ± 2.3	4.8 ± 1.0	5.6 ± 1.7
GME (%)	21.1 ± 1.9	20.9 ±1.6	21 ± 1.1	21.6 ± 1.8	21.4 ± 1.0	21.3 ± 1.1	22 ± 1.3	22.9 ± 0.9	22 ± 1.2	22.4 ± 1.5	22.3 ± 1.0	22.3 ± 1.2
$\dot{V}O_2$ ($L \cdot min^{-1}$)	2.18 ± 0.29	2.19 ± 0.17	2.19 ± 0.15	2.65 ± 0.38	2.64 ± 0.20	2.67 ± 0.24	3.10 ± 0.39	3.14 ± 0.28	3.08 ± 0.29	3.54 ± 0.41	3.54 ± 0.33	3.53 ± 0.31
RER	0.92 ± 0.03	0.93 ± 0.03	0.91 ± 0.03	0.97 ± 0.06	0.97 ± 0.02	0.97 ± 0.03	0.99 ± 0.06	0.99 ± 0.04	0.99 ± 0.03	1.00 ± 0.04	1.02 ± 0.01	1.02 ± 0.03

Time trial data

Time

The average CV across the 20 km time trials was 1.68%. Mean ± SD time for the 20 km was PYC-B: 1990.07 ± 93.18 s, PLA: 2030.30 ± 124.73 s and CHA: 2008.56 ± 97.50 s (Figure 1). Time taken to complete the 20 km TT was not significantly different between trials (p = .115, eta-squared = .24, power = .43). Effect size for the mean difference between the PYC-B and PLA trials was calculated at 0.46 and 0.37 for the CHA and PLA trials.

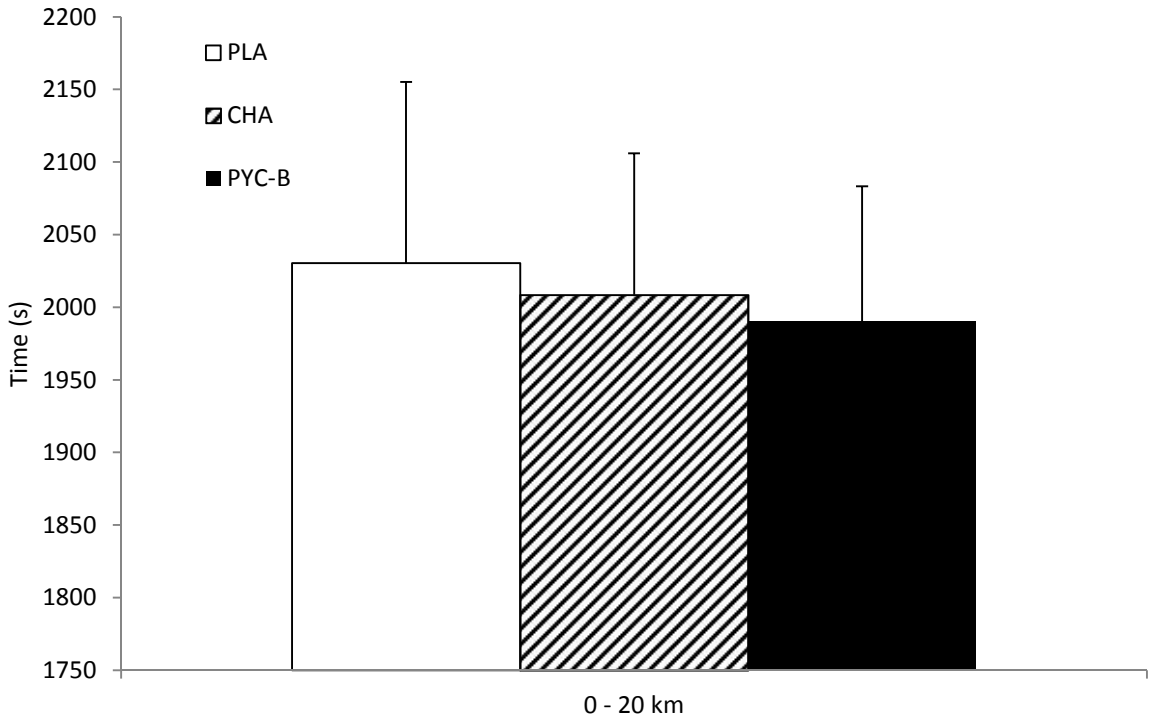

Figure 1 Time taken (s) to complete 20 km for the 3 trials.

Power output

Mean ± SD power output over the 20 km was PYC-B: 250.58 ± 27.89 W, CHA: 244.98 ± 29.29 W and PLA: 240.69 ± 35.31 W. There was no significant difference in 20 km power output between the trials (p = .171, eta-squared = .20, power = .35). However, there was a significant difference between trials in the final 5 km of the TT (p = .038, eta-squared = .34, power = .63) with a paired samples t-test revealing that power output was significantly greater during PYC-B compared to PLA (p = .022, ES = .45) (Figure 2). Mean ± SD in the final 5 km was PLA: 247.29 ± 36.98 W and PYC-B: 263.77 ± 25.1 W.

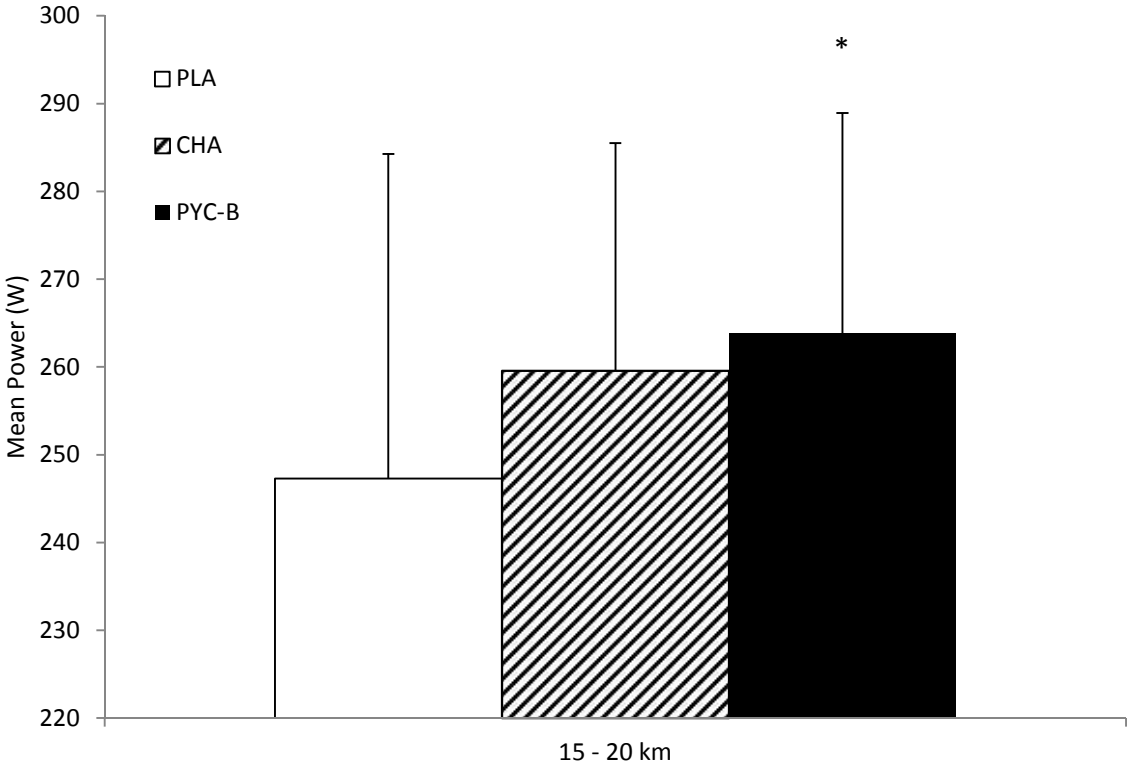

Figure 2 Mean power output (W) for the final 5 km of the 3 trials.* significantly greater power output compared to PLA.

Blood lactate and Heart rate

No significant differences were observed between trials for HR at 10, 15, 18 and 20 km (p = .160, eta-squared = .16, power = .64). B_{lac}, collected at 19.5 km, were not significantly different between trials (p = .859, eta-squared = .19, power = .07) (Table 2).

Table 2. B_{lac} ($mmol \cdot l^{-1}$) at 19.5 km into the 3 trials and average HR ($b \cdot min^{-1}$) at 10, 15, 18 and 20 km of the TT (mean ± SD).

	PLA	CHA	PYC-B
B_{lac}	6.66 ± 2.58	6.77 ± 2.03	6.41 ± 2.23
HR_{10}	163 ± 13.64	158.8 ± 11.42	161.77 ± 8.96
HR_{15}	167 ± 14.86	161.44 ± 10.10	165.33 ± 8.39
HR_{18}	167.44 ± 10.19	166.66 ± 10.23	168.44 ± 8.45
HR_{20}	176.66 ± 12.19	175.22 ± 10.4	178.11 ± 10.82

Discussion

The primary aim of the study was to determine if supplementing with 2 different polyphenol mixtures (PYC-B and CHA) for only 3 days could improve cycling TT performance. It was found that after PYC-B supplementation, participants were able to generate a significantly greater power output over the final 5 km by 6.2% (Figure 2). However, overall 20 km TT performance was not significantly different between trials. No performance benefits were observed at any time point following CHA supplementation. Furthermore, neither PYC-B nor CHA had any effect on GME, HR, RER, VO_2 or B_{lac} at 40, 50, 60 and 70% of W_{max} when compared to the PLA. The only

346 physiological measures taken during the TT was HR and B_{lac} at 19.5
347 km, which were both not significantly different between the 3 trials.

348 In previous similar studies, acute PYC consumption extended time to
349 fatigue in cycling trials [17, 18] and enabled participants to run for
350 29.6% longer following 30 days of PYC (200 mg/day)
351 supplementation [16]. This however is the first study to assess the
352 effects of a PYC based supplement during a performance test and
353 supplementing for as little as 3 days. Although there was no
354 statistical difference between trials, a small effect size of .46 was
355 observed for 20 km time in favour of PYC-B. Participants completed
356 the 20 km 1.98% faster during the PYC-B trial compared to the PLA.
357 It is possible that any small effects resulting from the supplements
358 could have been better detected amongst a group of elite cyclists
359 since elite cyclists have demonstrated a CV of 1.1% for the 20 km TT
360 [28] compared to the 1.68% demonstrated in this study.

361 The significant improvement in the last 5 km of the TT in PYC-B
362 could be related to the greater intensity of exercise being performed.
363 This is demonstrated by the increase in HR over this time (see table
364 2). The increase in intensity would have decreased muscle pH and
365 increased VO_2, causing the exercising muscles to produce more free
366 radicals [3, 11]. This is likely to result in more cell damage and
367 disruption to skeletal muscle contraction and an increased need for
368 exogenous AOs [3, 11]. It is therefore possible that the AO effects of
369 PYC-B were only significant at this time when skeletal muscle

370 contractions were most likely to be compromised by increased
371 oxidative stress [1, 3, 15].

372 Performance may also have been enhanced by PYC-B through
373 increased blood flow, since the release of the vasodilator NO and
374 reductions in endothelial damage and platelet formation are some of
375 the proposed benefits of PYC [4, 15, 29]. This increased blood flow
376 may help to overcome any potential circulatory limitations towards
377 the end of the TT, attenuating the diminishing O_2 supply to the
378 exercising muscles and maintaining force production during the final
379 5 km [6, 30]. Support for these mechanisms is provided by various
380 studies of the physiological effects of PYC and bioflavonoids [29, 31].

381 Both supplements had no effect on B_{lac} levels at 40, 50, 60 and 70%
382 of W_{max} and 19.5 km into the TT. These results are comparable to
383 previous studies that found consuming polyphenol supplements had
384 no effect on B_{lac} levels throughout and after HI cycling exercise [2,
385 17]. One study however, found that B_{lac} levels were reduced by
386 ingesting a pre-trial AO and PYC beverage when cycling at a fixed
387 output of 70% of W_{max} [18]. It was proposed that the polyphenols
388 within PYC encourage lactate removal, possibly via the vasodilatory-
389 induced increases in blood flow [18, 29]. Whether this effect occurs
390 has not been investigated and requires more research.

391 The supplements had no effect on RER when cycling at 40, 50, 60
392 and 70% of W_{max}. Another study also found that substrate use was
393 unaffected by AO-rich quercetin consumption during a 30 km cycling
394 TT [9]. In two other studies, no significant differences were found, but

395 there was a slight reduction in RER throughout running exercise after
396 ingesting a pre-trial dose of *Ecklonia cava* [4] and a cocoa
397 polyphenol supplement prior to cycling exercise [2]. Only studies
398 using polyphenol mixtures such as green tea, which contains
399 epigallocatechin gallate, have found significant increases in fat
400 oxidation during exercise [32, 33].

401 The CHA and PYC-B supplements also had no effect on GME and
402 VO_2 ($L \cdot min^{-1}$) (Table 2). Few studies investigating polyphenols and
403 exercise performance have measured efficiency. Although one study
404 found that VO_2 was lower throughout a 30 km TT following ingestion
405 of an AO and quercetin supplement GME was not calculated [9].
406 How polyphenols contribute to superior efficiency remains unclear,
407 other studies investigating nitrate consumption have implied that
408 boosting NO production could lower VO_2, leading to improved
409 exercise efficiency [34, 35]. Based on this, it is possible that in this
410 study the polyphenol supplements effects on NO were insufficient to
411 make any major difference to efficiency, however NO was not
412 measured.

413 Further research to help explain the results should be undertaken as
414 no measures of FR damage or muscle blood flow were taken
415 throughout the TT and therefore it can only be speculated that this
416 was the case during the final 5 km. Furthermore, an optimal dosage
417 of PYC-B and CHA has not yet been determined and it is
418 conceivable that for an exercise protocol of this volume and intensity
419 a greater daily dose and/or longer supplementation period is required

for both supplements to have a significant impact on performance, particularly during the CHA trial and should be the focus of future research. It should also be considered that the low sample size may have confounded the results, as VO_2, RER and GME data was only available for 6 participants, a recognized limitation of this study. Future research should build upon these findings and employ designs with greater participant numbers.

Conclusion

To conclude, neither the PYC-B nor CHA polyphenol supplement significantly enhanced 20 km TT performance or had any physiological effect during sub-maximal cycling. PYC-B enhanced final 5 km power output suggesting that the supplement may provide some benefit towards the end of an intense bout of exercise. However as total 20 km time was not significantly different between trials the dosing protocol employed does not appear to benefit 20 km cycling time trial performance. Future studies should focus on using a greater dosage of the supplements and also the use of longer performance tests to see if further beneficial effects can be revealed under these conditions.

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