

Citrulline Malate fails to improve German volume training performance in healthy young men and women

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Title: Citrulline Malate fails to improve German Volume Training performance in healthy young men and women.

Short Running Head: Citrulline fails to improve exercise performance

1 **Abstract**

2 **Background:** Citrulline malate (CM) is purported to buffer lactic acid, enhance
3 oxygen delivery, and attenuate muscle soreness. Anaerobic exercise trials with CM
4 have produced conflicting results. **Objective:** The aim of the current investigation
5 was to test the efficacy of CM on resistance training (RT) with the hypothesis that CM
6 would improve performance. **Design:** A double-blind, counter-balanced, randomised
7 control trial was utilised to assess the effects of CM on RT. 19 subjects (8 female)
8 (25.7 ± 7.7 years), regularly engaged in RT consumed either 8 g of CM (1.1 : 1 ratio)
9 or a placebo (6 g citric acid). Subjects attempted to perform a German Volume
10 Training (GVT) protocol comprising 10 sets of 10 repetitions of barbell curls at 80 %
11 of their one repetition maximum. **Results:** Repeated ANOVA suggested no effect of
12 CM on RT performance (treatment \times time \times order $p = 0.217$). There was no
13 difference ($p = 0.320$) in the total number of reps over the ten sets (CM median = 57,
14 IQR 45 to 73; placebo median = 61, IQR 51 to 69). Blood lactate and creatine kinase
15 did not differ between CM and placebo ($p > 0.05$). Finally, total muscle soreness was
16 reduced significantly in CM compared to placebo (treatment \times time \times order $p = 0.004$).
17 **Conclusions:** These results require corroboration; an ergogenic benefit is yet to be
18 established and weight trainers should exercise caution when assessing the efficacy
19 of CM. Future research should focus on the potential effects of loading doses of CM.

20 **Keywords:** Resistance Training, Supplementation, Muscle Soreness, Arginine,
21 Creatine Kinase, NOS

22

23 **Introduction**

24 Citrulline (CIT) is a non-essential amino acid, which acts as a nitrogen ion acceptor
25 from carbamoyl-phosphate within the urea cycle. The dietary supplement citrulline
26 malate (CM) has been purported to improve aerobic and anaerobic exercise
27 performance via a variety of mechanisms including improved ammonia, arginine and
28 lactic acid metabolism, alongside an increase in ATP production (da Silva et al.,
29 2018). Increasing muscle CIT may attenuate ammonia accumulation resulting in a
30 lactic acid buffer effect, which might enhance subsequent recovery, attenuate fatigue
31 and reduce post exercise muscle soreness (Ochia et al., 2012; Cutufrello et al.,
32 2015). Ammonia influences fatigue by stimulating phosphofructokinase, leading to
33 an increased rate of glycolysis (Takeda et al., 2011). This may increase blood lactic
34 acid during exercise inhibiting pyruvate oxidation leading to hydrogen ion
35 accumulation, and a reduction in muscle pH, and contractile potential (Cutufrello et
36 al., 2015).

37 Citrulline is also adjacent to arginine succinate in the urea cycle, and can be directly
38 synthesised to arginine. Studies have demonstrated that supplementation with CIT
39 increases circulating levels of arginine, which may simultaneously acting as a lactic
40 acid buffer, and vasodilator via nitric oxide synthase (Takeda et al., 2011; Cutufrello
41 et al., 2015; Martinez-Sanchez et al., 2017). Trials have demonstrated that blood
42 arginine increases to a greater extent with oral CIT than arginine due to splanchnic
43 extraction (Moinard et al., 2008; Sureda et al., 2010; Takeda et al., 2011; Wijnands et
44 al., 2015). By way of comparison, a 0.75 g twice daily oral dose of CIT resulted in
45 similar increase in blood arginine compared to a 1.6 g twice daily dose of arginine
46 (Schwedhelm et al., 2007). Finally, malate acid is combined with CIT to form the salt
47 CM. Malate is an intermediate in the TCA cycle, and increasing the pool size of

48 intermediates may theoretically increase oxidative ATP (Thomas et al., 2004),
49 although to date, no trials have investigated the performance enhancing effects of
50 malate.

51 Citrulline malate as an ergogenic aid and has become of interest to exercise
52 scientists in recent years, with studies suggesting conflicting effects on exercise
53 performance (Bendahan et al., 2002; Perez-Guisda and Jakeman 2010; Wax et al.,
54 2015; Wax et al., 2016; Farney et al., 2017; Glenn et al., 2017; da Silva et al., 2018).
55 However, some evidence suggests an acute dose of 6-8 g of CM improves
56 resistance training (RT) performance (Perez-Guisda and Jakeman 2010; Wax et al.,
57 2015; Wax et al., 2016; Glenn et al., 2017) and aerobic energy production (Bendahan
58 et al., 2002). More recently however, studies using similar dosages and comparable
59 RT protocols have found no effect (Farney et al., 2017; da Silva et al., 2018). The
60 aim of the current investigation was to assess the effects of CM on German Volume
61 Training (GVT) performance to elucidate its efficacy of this potential ergogenic aid.
62 We hypothesised that supplementation with CM would increase the total amount of
63 work performed during repeated bouts of exercise.

64

65 **Subjects and Methods**

66 **Subjects**

67 Twenty one subjects volunteered to participate in this study. Two females dropped
68 out, without citing a reason for doing so, leaving 12 males and 7 females who
69 completed the study. Table 1 displays the subject characteristics. Subjects were
70 recruited from Sheffield Hallam University campus via posters, and word of mouth.
71 All subjects were healthy, non-smokers, free from injury and any underlying health

72 conditions, and not currently using medication or taking supplements containing CM.
73 Subjects were advised to follow their normal diet and supplement regime for the
74 duration of their involvement in the trial, to avoid strenuous exercise 48 h pre and
75 post laboratory visits and to maintain their regular exercise schedule post 48 h. All
76 subjects were at least "moderately resistance trained" defined as following a
77 structured RT programme at least twice per week, for the last 6 months. Written
78 consent was obtained from all subjects prior to taking part in the trial. The Sheffield
79 Hallam University Business School Food Research Ethics Committee approved the
80 trial.

81 *(Table one approx. here)*

82

83 **Experimental Design**

84 A randomised double-blind placebo cross-over design was implemented. Each
85 subject reported to the laboratory on three separate occasions 7 days apart. Subjects
86 were randomised to either CM or placebo using a random number generator and an
87 independent researcher (JG) performed concealment. The treatments were
88 counterbalanced and blinding was revealed on completion of the trial. On the first
89 visit subjects had, the GVT protocol and the muscle soreness visual analogue scale
90 (VAS) explained to them. Subjects then performed a bicep barbell curl one rep
91 maximum (1RM) test, used to calculate 80% 1RM used for the GVT.

92 On the second and third visits, subjects arrived fasted to the laboratory, provided a
93 blood sample and then consumed either 8 g of CM or a placebo which were both
94 provided as sports drinks. Subjects then completed a 24 h dietary recall and baseline
95 muscle soreness VAS was recorded. One hour after consuming the sports drink,

96 subjects performed the GVT barbell curl protocol (10 sets to failure with a maximum
97 of 10 repetitions per set, one-minute rest between sets). The total number of
98 repetitions was counted across each set, and failure was determined when a full
99 range of motion could no longer be completed. Following the GVT a second blood
100 sample was taken, subjects then completed the muscle soreness VAS and then
101 again at 24, 48 and 72 h. The following week subjects completed the trial under the
102 opposite treatment condition.

103

104 **Anthropometrics and Muscle Soreness Scale**

105 Height and weight were assessed using a stadiometer (Holtain, Crymych, United
106 Kingdom) and column scale (Seca, Birmingham, United Kingdom), body composition
107 via bioelectrical impedance (Bodystat 1500, Douglas, Isle of Man) and body mass
108 index (BMI) was calculated kg/m^2 . Muscle soreness was scored using a 100 mm
109 VAS at four sites on the upper and lower arm (Biceps brachii: long and short head
110 and Brachioradialis and Flexor carpi radialis). On the VAS 0 indicated no pain, and
111 100 indicated the worst pain imaginable. The sum of the four sites was combined and
112 used to represent total soreness at each time point. Muscle soreness was recorded
113 immediately pre and post exercise under supervision and self-assessed at 24, 48
114 and 72 h following GVT. A demonstration of how to self-palpate and score the
115 muscle soreness was provided by the researchers along with an instruction sheet
116 with diagrams detailing the points of palpation. The research team reminded the
117 subjects to complete muscle soreness VAS at the same time of day using both text
118 message and email prompts.

119

120 **Supplementation Protocol**

121 Subjects were provided with either 8 g of CM (1.1:1 ratio, 4.2 g citrulline, 3.8 g malate,
122 Bulk Powders, United Kingdom), or a placebo 6 g of citric acid (Sigma-Aldrich, Dorset,
123 United Kingdom). Both placebo and supplement drinks were mixed in 70 ml of fruit
124 cordial and 150 ml of water and consumed within 5 minutes. The dosages and timing
125 of the CM were based on research showing that peak CIT levels occur 1 h after
126 administration (Moinard et al., 2008). The CM and placebo drinks were both well
127 tolerated, and subjects reported no side effects.

128

129 **Assessment of Supplement Quality**

130 Determination of the supplement quality was assessed using nuclear magnetic
131 resonance (NMR) spectroscopy. The CM utilised in the present investigation had a
132 purported ratio of 2:1 citrulline to malate (Bulk Powders, United Kingdom). Briefly, a
133 standard NMR tube containing 100 mg of the CM supplement powder was added to
134 1 mL of D₂O (Fisher Scientific, UK). The sample was then warmed to 40 °C and
135 agitated to ensure complete dissolution of the solid for analysis of the total organic
136 fraction. Once the solid was dissolved, the solution was cooled to room temperature
137 and analysed on a Bruker Avance DPX-400 NMR spectrometer operating at
138 resonance frequencies of 400 MHz (¹H) and 100 MHz (¹³C). All ¹H and ¹³C NMR
139 chemical environments in both CIT and malic acid were unambiguously assigned
140 using ¹H, ¹H-COSY, ¹³C, DEPT-135, HSQC and HMBC experiments. The ¹H NMR
141 signals were then integrated, with the signal resulting from H9 on malic acid (at δ =
142 4.37 ppm) being calibrated as 1. The integration values for the triplicate runs were
143 then calculated. All possible comparisons of integral values between chemical

144 environments in CIT and those in malate were then performed and the mean nuclear
145 ratios for each individual replicate were then compiled into overall mean and
146 standard deviation values, which represent the citrulline:malate molar ratio calculated
147 from 8 individual data comparisons and three total experimental repeats.

148

149 **German Volume Training and One Rep Max Testing**

150 The 1RM testing protocol was carried out in accordance with the recommendations
151 of the National Strength and Conditioning Association (2015). 48 hours prior to and
152 48 h after each visit to the laboratory subjects were asked to refrain from all
153 strenuous exercise. Subjects fasted and avoided caffeine intake on the morning of
154 testing. Both GVT sessions were performed at the same time of day (± 1 h), 7 days
155 apart, and under the same laboratory environmental conditions (21°C, 45 - 55%
156 Relative Humidity). One hour after consuming the sports drink subjects completed a
157 warm-up (5 min brisk walk followed by 3 sets of barbell curls with no weight on the
158 bar) before proceeding with the GVT consisting of 10 sets, of 10 repetitions of barbell
159 curls at 80 % of the subjects 1RM, with 60 s rest between sets. The numbers of
160 complete repetitions performed for each set were recorded with the set terminating
161 when the subject could no longer complete a full repetition, full repetitions were
162 determined by one of the investigators (TS).

163

164 **Blood Sampling, Lactate and Creatine Kinase Analysis**

165 Prior to the GVT exercise protocol, subjects reported to the laboratory and rested for
166 10 minutes in a seated position. Immediately after the GVT a second blood sample

167 was obtained. Blood samples were obtained via finger prick using a lancet (Accu-
168 chek, Safe-T-Pro). A 20 μ l blood sample was taken with a capillary tube and added to
169 an Eppendorf containing heparin and saline lactate was then read immediately using
170 a Biosen C-line (EKF Diagnostics, Ebendorfer, Germany). Creatine kinase (CK) was
171 measured via a 30 μ L capillary sample collected pre and post-exercise in Microsafe
172 Collection and dispensing tube (Inverness Medical, Cheshire, UK) and applied
173 immediately to a Reflotron Creatine kinase strip (Refletron Plus clinical chemistry
174 analyser; Woodley Laboratory Diagnostics, Bolton, United Kingdom).

175

176 **Dietary Intake and Analysis**

177 Subjects were instructed to consume similar foods the day before testing and refrain
178 from starting/stopping any new dietary/supplement regimes for the duration of their
179 involvement in the trial. Prior to taking part in the GVT subjects completed a 24 h
180 dietary recall. Nutritics (version 2017, Dublin, Ireland) dietary analysis software was
181 used to analyse the data (see Table 2). Nutrition data was adjusted for bodyweight
182 and expressed as grams and calories per kg of bodyweight.

183

184 **Statistics**

185 All data were analyzed using SPSS (IBM, version 24). The main outcome measure,
186 RT performance during GVT, was analysed using a 2 condition (CM and placebo)
187 repeated measures analysis of variance to determine any differences in performance
188 over the ten sets (treatment \times time). Treatment order was added to the model as a
189 covariant (treatment \times time \times order). Muscle soreness was analysed in the same way,

190 using the sum of the 4-site muscle soreness VAS for each time point. Mauchly's test
191 of sphericity was applied to determine sphericity, where this was violated; the
192 Greenhouse-Geisser estimate was used. Data for blood lactate, CK, total reps (the
193 sum of all repetitions across all 10 GVT sets), and dietary intake were assessed for
194 normality using the Kolmogorov-Smirnov test. A paired sample t-test or Wilcoxon
195 Signed Rank test was used as appropriate, when data met the requirements for
196 parametric or non-parametric testing. Statistical significance was established at $p <$
197 0.05. Where data was normally distributed it is presented as means, standard
198 deviation and 95 % confidence interval (CI). For non-normally distributed data the
199 median and the inter-quartile range were presented.

200

201 **Results**

202 Analysis of dietary recall indicated no difference ($p > 0.05$) in macronutrient or energy
203 intake, between CM and placebo conditions (Table 2). Subjects confirmed that they
204 did not stop or start any new supplements over the duration of the trial. Determination
205 of the citrulline to malate ratio revealed the supplement contained a 1.1:1 ratio
206 citrulline to malate rather than the purported 2:1 ratio advertised on the back of the
207 packaging. Resistance training performance during the GVT is presented in Figure 1.
208 There was no significant difference, between the CM and placebo condition, on GVT
209 performance, measured by repetitions performed per set (treatment \times time $p = 0.174$).
210 Treatment order had no effect on GVT performance (treatment \times time \times order $p =$
211 0.217). There was a significant effect of time ($p < 0.001$) on GVT performance, *e.g.*
212 the number of repetitions performed declined as sets progressed (mean repetitions
213 set 1, placebo 9.8 ± 0.7 vs CM 9.5 ± 1.1 ; set 10, placebo 4.4 ± 2.9 vs CM 4.6 ± 2.4).

214 There was no statistically significant difference ($Z = 0.995$, $p = 0.320$) in the total
215 number of repetitions achieved over the ten sets of GVT between the CM (median =
216 57, IQR 45 - 73) and placebo conditions (median = 61, IQR 51 - 69).

217 *(Table 2, and Figure 1 approx. here)*

218 Blood lactate data is presented in Figure 2. Lactate increased significantly ($p < 0.001$)
219 post GVT in both the CM (mean lactate pre, 1.9 ± 0.6 , post 4.7 ± 2.0 mM) and
220 placebo conditions (mean lactate pre, 1.8 ± 0.6 , post 4.9 ± 1.7 mM). There was
221 however, no difference ($t = 0.434$ $p = 0.670$) in the magnitude of change in lactate
222 post GVT between CM and placebo with a mean increase of 3.01 mM (95 % CI 2.41
223 - 3.62). There was no difference in CK levels post GVT under the CM treatment (pre,
224 172 I/U IQR 48.5 - 222.9; post, 179.00 IQR 149.5 - 370.4, $Z = 1.552$, $p = 0.121$),
225 however there was a difference under the placebo condition (pre, 145 I/U IQR 52.9 -
226 333.0; post, 219 IQR 91.1 - 423.2, $Z = 1.991$, $p = 0.046$). The median difference of
227 the differences the subjects for CK pre to post exercise did not differ ($Z = 0.052$, $p =$
228 0.959) between CM (median = 66.1 I/U IQR 34.3 - 152.6) or the placebo condition
229 (median = 60.4 I/U IQR 19.3 - 150.0).

230 *(Figure two approx. here)*

231 The effect of CM on 72 h muscle soreness is detailed in Figure 3. Muscle soreness
232 was significantly higher in the placebo compared to the CM treatment over 72 h
233 (treatment \times time $p = 0.004$). The statistical difference was maintained when
234 treatment order was included in the model (treatment \times time \times order $p = 0.008$).

235 *(Figure three and table two approx. here)*

236 **Discussion**

237 In the current investigation, we hypothesised that an acute dose of CM prior to an
238 exercise session would increase the total amount of work performed during GVT.
239 Citrulline malate had no effect on GVT performance, blood lactate or CK compared to
240 a placebo, although subjects did report an overall reduction in muscle soreness. The
241 results of the present investigation accept the null hypothesis and are in agreement
242 with recent findings showing no effect of CM on RT performance (Farney et al., 2017;
243 Chappell et al. 2018; da Silva et al., 2018,). Moreover, these findings are in contrast
244 to others who have identified an effect of CM with RT (Wax et al., 2015; Wax et al.,
245 2016; Glenn et al., 2017). Specifically, Perez-Guisda and Jakeman (2010) and Wax
246 et al., (2016) reported a 13 and 12.5 % respectively, increase in the number of
247 repetitions achieved after consecutive bouts of RT following CM supplementation.
248 By way of comparison, a similar increase would have amounted to an 8-repetition
249 difference in the total repetitions between the CM and placebo condition in the
250 present investigation.

251 The reduction in soreness identified with CM was accompanied by a lack of
252 difference in the total amount of work performed between treatment groups. This
253 could lead to the conclusion that less soreness was elicited from the same workload
254 when the subjects consumed CM. Although we note that subjects did not report high
255 values for muscle soreness pre or post exercise, which may reflect the nature of the
256 exercise i.e only small muscle groups were involved in our protocol. da Silva et al.
257 2017 and Chappell et al. 2018, both found a greater degree of soreness, this seems
258 to be commensurate with protocols involving larger muscle groups. We also note a
259 lack of any immediate difference in CK or lactate levels between conditions, which
260 might be expected to accompany any difference in soreness. The lack of change, in
261 these markers or muscle damage and exercise intensity is in agreement with recent

262 trials utilising CM during RT protocols (Wax et al., 2015; Wax et al., 2016; da Silva et
263 al., 2017; Farney et al., 2017). Effects of CM on muscle soreness and RT have so far
264 produced mixed results, with both reductions in soreness (Perez-Guisado & Jakeman
265 2010) and no difference when compared to placebo (da Silva et al., 2017; Chappell
266 et al., 2018). Curiously, trials of aerobic exercise have so far indicated a reduction in
267 soreness utilising CM (Tarozona-Diaz et al., 2013, Martinez-Sanchez et al., 2017).
268 Potential explanations for a reduction in soreness therefore may be attributed to
269 CIT's role in the urea cycle and the augmented clearance of ammonia (Callis et al.,
270 1991).

271 Finally, we sought to corroborate the level of the active ingredient used in the present
272 investigation with the manufacturer's labelling. The data suggests that the amounts of
273 active ingredient in the supplement varied, by almost half, from the manufacturers
274 labelling. The dosage consumed by subjects was 4.2 g CIT and 3.8 g malate (1.1:1
275 ratio) instead of the intended 6 g CIT and 2 g malate (2:1 ratio). A previous
276 investigation reported similar findings from five "over the counter" CM supplements
277 (Chappell et al., 2018).The disparity between the actual and intended dosage may
278 account for a lack of significant findings. Moinard et al., (2008) however, reported a
279 significant increase in plasma CIT using a similar dosage to the one used in the
280 present investigation. Moreover, the data highlights the need for researchers to
281 conduct analyses of supplement quality prior to publishing trials. Caution therefore
282 needs to be taken when assessing any dose-response study using commercial CM
283 supplements. Commercial supplements, however, are the products recreationally
284 active individuals and athletes alike use in an attempt to aid recovery and improve
285 performance.

286

287 **Strengths and Limitations**

288 A counterbalanced design was employed to account for a potential training effect,
289 and statistical analysis identified that subjects did not perform better on their second
290 GVT session compared to the first. There was also no difference in dietary intake for
291 the 24 hours preceding testing, between the CM and placebo conditions, Therefore
292 any lack of statistical finding may not be attributed to a disparity in diet (e.g. an
293 increased carbohydrate or energy intake between conditions).

294 The investigation did not include a measure of ammonia to accompany the data
295 gathered on lactate and CK to corroborate the difference in muscle soreness.
296 Furthermore, although we advised subjects to rest 48 h prior to commencing the trial,
297 several subjects had elevated CK suggesting engagement in prior exercise.
298 Increases in CK levels in response to exercise are known to be highly variable and
299 increase significantly in days following exercise (Ehlers et al. 2002). Creatine kinase
300 was only measured immediately post exercise and a measurement taken alongside
301 muscle soreness over 72 h would have elucidated the recovery process more clearly.
302 Moreover, measurements of muscle soreness were self-reported between the 24-72
303 h measures potentially and supervised measures would have been preferable. The
304 subjects involved in the present investigation were not a homogenous group.
305 Training experience varied and no controls were put in place to account for the
306 impact of menstrual cycling. Finally, we utilised citric acid as a placebo condition. We
307 only found a single study focused on the effect of citric acid on exercise. Sugino et al.
308 (2007) utilised an 8 day loading protocol combined with aerobic exercise, the authors
309 found no effect on performance, blood citric acid or lactate levels. The placebo was
310 effective at replicate the taste of CM and was well tolerated.

311 Subjects completed the trial fasted to eliminate the influence of feeding on
312 performance. We could alternatively have included a standardised breakfast in the
313 protocol to reflect the probability that exercise is often not carried out in a fasted state.
314 Finally, we asked the participants not to stop or start any other supplement intake for
315 the duration of the trial and a condition of participation was that they weren't taking
316 any supplements containing CM. Although we acknowledge the potential effects of
317 other supplements on performance the crossover design of this study to some extent
318 mitigates against this. Secondly we are reminded of the real-world nature of
319 supplement intake whereby in reality people will not postpone ongoing
320 supplementation regimes when they begin new ones.

321

322 **Conclusion**

323 An acute dose of 8 g CM (1.1:1 ratio) did not confer any benefits to the main outcome
324 measure of RT performance, in a moderately trained group. Total muscle soreness
325 was reduced over the 72 h following CM treatment however; both CK and lactate
326 were unaffected immediately following exercise. This is the first study to date to test
327 the effectiveness of CM using a GVT free weight exercise protocol. Further trials on
328 acute and chronic use of CM are warranted to confirm or deny its effectiveness as an
329 ergogenic aid. Athletes and coaches should proceed with caution when deciding
330 whether to utilise CM as part of a supplementation protocol; the present study and
331 current literature is mixed and recommendation of CM as an anaerobic ergogenic aid
332 is not warranted based on the present results, although we note with caution there
333 may be a positive effect on muscle soreness. Finally, in light of our findings, future

334 researchers should endeavour to carry out chemical analysis to ensure the validity of
335 treatment dose.

336

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348 252.

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Tables**Table 1 Participant Characteristics (n - 19, 12 male, 7 female)**

Age (years)	Height (m)	Weight (kg)	BMI (kg/m²)	Bodyfat (%)
25.7 ± 7.7	1.7 ± 0.1	75.3 ± 13.7	24.8 ± 2.9	18.3 ± 5.8

Abbreviations: m, metres; kg, kilogram; BMI, body mass index.

All values are mean ± SD

Table 2. 24 Hour Dietary Intakes Preceding the German Volume Training

	Placebo	Citrulline Malate	P value
Carbohydrate (g / kg BW)	3.8 ± 1.8	3.2 ± 1.7	0.285
Protein (g / kg BW)	2.2 ± 1.5	1.8 ± 0.9	0.575
Fat (g / kg BW)	1.0 ± 0.4	0.9 ± 0.4	0.223
Energy (Kcal / kg BW)	34.6 ± 10.7	28.8 ± 10.7	0.730

Abbreviations: g, grams; kg, kilograms, BW, bodyweight; Kcal, calories.

(Paired t-test: Fat; Wilcoxon Signed Rank Carbohydrate, Protein and Energy). All values are means ± SD,

Legends for Figures

Figure 1 - The effect of citrulline malate on resistance training performance. Exercise performance with the placebo is represented by the solid black line ($n = 19$); citrulline malate is represented by the dashed line ($n = 19$). (repeated measures ANOVA time $p < 0.05$; treatment \times time \times order $p > 0.05$)
The data presented is the mean \pm SD.

Figure 2 - The effect of citrulline malate on blood lactate following resistance training. Pre-exercise lactate values are represented by the grey bars ($n = 18$); post-exercise values are represented by the black bars ($n = 18$); the white bars represent the magnitude of change between placebo and supplement ($n = 18$). Results analysed using a paired t-test, * indicates significant difference pre to post exercise. The data presented is the mean \pm SD.

Figure 3 - The effect of citrulline malate on muscle soreness following resistance training. Muscle soreness with the placebo is represented by the solid black line ($n = 19$); citrulline malate is represented by the dashed line ($n = 19$). Over time muscle soreness was significantly higher in the placebo compared to citrulline malate treatment (repeated measures ANOVA: treatment \times time \times order $p = 0.008$). The data presented is the mean \pm SD.