



Spirulina platensis Provides a Small Advantage in Vertical Jump and Sprint Performance But Does Not Improve Elite Rugby Players' Body Composition

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Spirulina platensis provides a small advantage in vertical jump and sprint performance but does not improve elite rugby players' body composition

RUNNING TITLE: Spirulina as an ergogenic nutrient in athletes?

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ABSTRACT

The present study aimed to examine the effects of Spirulina supplementation on anthropometrical measurements and physical performance in elite rugby players.

Twenty-two elite male Rugby Union players (21-36 years old) volunteered to participate in this study. They were randomly assigned to a Spirulina group (SPI: n = 11), or a placebo group (PLA: n = 11) in a double-blind design. Subjects were supplemented with Spirulina *platensis* (5.7g/d) or Placebo (iso-proteic and caloric) for seven weeks. At baseline (W₀) and after 7 weeks of supplementation (W₇), the same anthropometric measurements and physical performance test battery were performed. These tests included isokinetic leg strength and power, vertical jump, speed, and aerobic fitness assessment.

For anthropometric data, the fat mass (FM) percentage was significantly reduced in both groups without significant difference between groups. While both groups exhibited significant improvements for SJ, CMJ, 10 and 30-m sprints between W₀ and W₇, higher percentage improvements with the SPI group did not reach significance. Neither training alone (PLA) nor training associated with spirulina supplementation affected leg maximal strength and power or aerobic fitness.

Seven weeks of spirulina supplementation in elite rugby players did not improve body composition nor substantially increase physical performance. We only observed a non-significant small advantage in vertical jump and sprint performance in the SPI group. Based on the data from this study, spirulina supplementation has modest effects in elite rugby players during the competitive phase. Further studies are required to verify spirulina supplementation effects among athletes of different sports, age, gender and athletic level with longer durations and higher dosages.

KEY WORDS: Arthrospira, body composition, elite athletes, performance, supplementation.

49 Introduction

50 Spirulina (*Arthrospira*) is a blue-green microalga belonging to the Cyanobacteria class with
 51 prokaryotic photosynthetic characteristics [1-4]. The most well-known species of spirulina safe
 52 for consumption are *Spirulina maxima*, *Arthrospira fusiformis*, and *platensis*, this last one being
 53 the most commonly used species and largely studied in the scientific literature [4, 5]. It's known
 54 for its complex chemical makeup including high protein content (50 to 70% of its dry weight),
 55 all the essential amino and fatty- acids, and most of the vitamins and minerals [6-8], which
 56 confers to spirulina numerous health benefits such as antioxidant, immunomodulatory, anti-
 57 inflammatory, anti-cancer and anti-viral activities [1, 8-10].

58 In recent years, spirulina has been widely used by athletes for these health benefit effects and
 59 most of them consume it in the belief it will improve body composition, physical performance
 60 and recovery. It was speculated that Chinese and Cuban Olympic teams have consumed
 61 spirulina daily for many years to improve performance [2]. Data in the literature is still rare and
 62 controversial about spirulina effects on anthropometric parameters and performances in
 63 athletes. Indeed, only a few authors investigated the effects of spirulina supplementation on
 64 these data in athletes. Concerning anthropometric parameters, in untrained subjects, Miczke et
 65 al. [11] and Zeinalian et al. [12] indicated a loss of body mass (BM: -6%) without changes in
 66 fat mass (FM). However, Lee et al. [13] and Mazokopakis et al. [14] reported no significant
 67 effects on these parameters. In athletes, Milasius et al. [15] reported no significant decrease in
 68 BM and FM after supplementation (2.25 g/d) which may suggest no change in lean body mass
 69 (LBM) or muscle mass contrary to spirulina assertions. Concerning spirulina effects on
 70 performance, Lu et al. [16] studied the effects of three weeks of *Arthrospira platensis*
 71 supplementation (7.5 g/d) in students and reported a significantly increased time to exhaustion
 72 during the Bruce protocol test only in the spirulina group. In moderately trained men, Kalafati
 73 et al. [17] showed that time to fatigue after a submaximal run was significantly higher after

74 spirulina supplementation (6 g/d). Concerning the effects of spirulina consumption on muscular
75 strength, Sandhu et al. [18] examined the effects of eight weeks of spirulina supplementation
76 (2 g/d) in trained and untrained subjects. They reported significant improvements in isometric
77 peak force, average force, and fatigue index due to the use of spirulina for both groups.
78 Therefore, they recommend the use of spirulina as a nutritional supplement by athletes and non-
79 athletes for improving isometric strength and muscle endurance. Recently and contrary to these
80 conclusions, Juszkievicz et al. [19] showed that spirulina supplementation (1.5 g/d) was not
81 able to enhance the mean power output nor total run time during a 2000-m test on a rowing
82 ergometer with a Polish rowing team. Among the four studies which evaluated the effects of
83 spirulina on physical performance, only one examined elite athletes [19] and they only tested
84 the effect of spirulina on muscle power and not on various physical qualities. In addition to the
85 low level of evidence and the heterogeneity of previous studies concerning the types of the sport
86 involved, the duration and dose of supplementation, to our knowledge, no studies have
87 examined the effects of spirulina supplementation in team-sport athletes although they are
88 known for their widespread use of ergogenic aids [20, 21].
89 Thus, the aim of the present study was to examine the effects of spirulina supplementation on
90 anthropometric measurements and physical performance in elite rugby players. Physical
91 performance evaluation included a complete set of measurements such as leg strength and
92 power, vertical jump, speed, and aerobic fitness. We hypothesized that its high nutritional
93 quality protein content could reduce FM and possibly increase lean body mass (LBM), leading
94 to a greater improvement in performance.

95 **Materials and methods**

96 The experimental protocol was approved by a local ethics committee (NOD0172, Tours, France
97 - protocol number 2016-A00233-48). The protocol was conducted in compliance with both
98 Good Clinical Practices and the Declaration of Helsinki. Tests were realized at M2S lab (FINES

of 31/05/17; EJ: 350051454; ET: 350051462). After being informed of the objectives, the possible risks, discomforts and benefits, written and informed consent was obtained from all participants prior to inclusion.

Participants

Thirty elite male rugby union players belonging to the same French first federal division rugby club (Rennes Étudiants Club « REC ») volunteered to participate in this study. After having completed a clinical examination and medical interview to determine eligibility, only twenty-two participants (21-36 years old) satisfied the following inclusion criteria (being considered healthy in clinical examination, not having any history of surgery and not taking any kind of dietary supplement for the past 3 months). Exclusion criteria included tobacco use, current intake of spirulina, supplements or anti-inflammatory drugs, known chronic diseases and allergy to spirulina or any of its components.

Study design

A randomized, double-blind, placebo-controlled design was used. Sealed opaque envelopes numbered in the order of inclusions, with the allocated treatment listed in the envelope, were constructed from the established randomization list. The draw was conducted by a third party who held the codes assigned to the subjects and used for data collection. Participants were assigned to a spirulina group (SPI: n = 11), or a placebo group PLA: n = 11). Participant characteristics are reported in **Table 1**.

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The study consisted of a daily supplementation period during 7 weeks in which the SPI group received capsules with *Arthrospira platensis*, manufactured by Algae Green Value (AGV, Vannes, France). This spirulina is certified as safe and its composition is reported in **Table 2**.

<< Please insert table 2 here >>

Each subject was asked to take three capsules before the three daily meals. Based on the doses used in the previous human studies and taking into account the comfort of participants, the daily dosage was 5.7g, below the 10g safety dosage recommended by Fox [22]. The placebo group was given visually identical capsules with isocaloric and isoproteic content composed of 70.3 % egg proteins and 29.7 % carbohydrates.

Rugby players visited the laboratory five times during the study. The same anthropometric measurements and physical performance test battery were performed at baseline (W0) and after seven weeks of supplementation (W7). These tests included leg strength and power, vertical jump, speed, and aerobic intermittent fitness test (yo-yo IRT-1). At W0 and W7, all subjects were asked to record dietary intake for three days including one weekend day. Diet records were analyzed using the Nutrilog software (Nutrilog® SAS, France). Players were invited to make no modifications to their diet and to not use any other dietary supplements during the study or risk being excluded.

Supplementation compliance was assessed by counting the remaining capsules in the provided bottles at the end of the study. Gastrointestinal symptoms were monitored using a questionnaire as described by Bovenschen et al. [23]. The study design is illustrated in **Figure 1**.

<< Please insert Figure 1 here >>

148 ***Procedures***

149 All procedures were conducted during the competitive phase of the season (October-December
150 2018). All participants actively participated daily in the rugby-specific training sessions. They
151 were fully accustomed to the testing procedures used in this research as they routinely
152 performed these tests in the club as part of their medical/training follow-up.

154 ***Anthropometric data and body composition***

155 Each participant's height, BM and FM were collected. Height and BM were collected using a
156 wall-mounted stadiometer (Seca 206, Hamburg, Germany) and electronic scale (Terrillon,
157 Paris, France), respectively. FM percentage was estimated from the sum of skinfolds (biceps
158 brachii, triceps brachii, subscapular, and supra-iliac) monitored with Harpenden skinfold
159 calipers (Baty International, West Sussex, England) according to Siri [24]. All anthropometric
160 measurements were taken at W0 and W7 by the same experienced sports scientist.

162 ***Training load***

163 Throughout the experiment, the internal training load of all players was monitored using the
164 session Rate of Perceived Exertion (Session-RPE) method as described by Comyns and
165 Flanagan [25] expressed in arbitrary units (AU). About 30-minutes (min) after training sessions,
166 participants were asked to rate the global intensity of the entire workout session using the
167 French version CR-10 RPE scale [26]. The daily training load was evaluated by multiplying the
168 training duration (min) by the session RPE score and the weekly training load was determined
169 by summing the daily training loads each week for each rugby player.

171 ***Physical fitness tests***

172 Prior to each testing session, participants completed a 15-min standardized warm-up that
 173 included riding a cycle ergometer (Excalibur, Lode, Groningen, Netherlands) and dynamic
 174 stretching. All testing sessions were completed at the same moment of the day for both W0
 175 and W7, at the same turf pitch, with the same sports clothes, in the same order (**Fig. 1**) and by
 176 the same investigators.

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178 *Isokinetic leg strength and power*

179 Subjects were comfortably seated on the dynamometer chair, with the hip joint at a standardized
 180 position of 85° hip flexion from the anatomical position. Straps were applied across the chest,
 181 pelvis, and mid-thigh to minimize extraneous body movements. The distal shin pad of the
 182 dynamometer was attached 2–3 cm proximal to the lateral malleolus by using a strap. The axis
 183 of rotation of the dynamometer was aligned with the lateral femoral epicondyle of the knee.
 184 Gravity torque effects were recorded on each subject throughout the range of motion to correct
 185 torque measurements during testing. The participants were given standardized verbal
 186 encouragement and were asked to position their arms across the chest with each hand clasping
 187 the opposite shoulder during the testing procedure. The thigh muscles of the dominant limb
 188 were tested by using an isokinetic dynamometer (CON-TREX® MJ; CMV AG, Dübendorf,
 189 Switzerland) as described by Maffiuletti et al. [27]. Subjects were asked to complete three
 190 submaximal practice repetitions prior to each test series. Concentric measurements involved
 191 three continuous, maximal knee extensions and flexions, which were performed at two pre-set
 192 constant angular velocities, 60 and 240 °s⁻¹. Eccentric measurements consisted of three maximal
 193 contractions at a single velocity of 30° s⁻¹. Knee flexor and extensor trials were performed as
 194 movements in a single direction (i.e. non-reciprocal). Subjects recovered passively for 120s
 195 between series of measurements. The Con-Trex software calculated the peak torque and power
 196 for concentric and eccentric trials in knee extensors and flexors.

197 *Vertical jump*

198 Players performed the vertical jumps: squat jump (SJ) and countermovement jump (CMJ),
 199 using an Optojump next photocell system (Microgate, Bolzano, Italy), which are valid and
 200 reliable tools for the assessment of vertical jump height [28, 29]. Participants were instructed
 201 to place their hands on the hips to minimize lateral and horizontal displacement during the
 202 performance and to prevent any influence of arm movements on the vertical jumps. Participants
 203 also had to leave the ground with the knees and ankles extended and land in the same position
 204 and location to minimize horizontal displacement and influence on flight time. For SJ, the
 205 participant started from a stationary semi-squat position (knee angle $\sim 90^\circ$), held a three-second
 206 count and jumped vertically as high as possible. For CMJ, the participant started from an upright
 207 standing position, performed a very fast preliminary downward movement, flexing and then
 208 extended his knees and hip to jump vertically as high as possible off the ground. Three trials
 209 per test were performed with approximately 2-min recovery and the best result was used for
 210 analysis.

212 *Speed*

213 Running speed was evaluated using a stationary 10-m and 30-m sprint test as described by
 214 Chaouachi et al. [30]. Players were located 20-cm behind the start line position and were
 215 instructed to run as quickly as possible along the 30-m distance. Time was automatically
 216 recorded using photocell gates (Witty system, Microgate, Italy, accuracy of 0.01 s) placed 0.4-m
 217 above the ground. Participants performed two trials with at least 2-min rest between trials. The
 218 run with the lowest 30-m time was selected for analysis.

220 *Aerobic fitness*

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3 221 Players performed the Yoyo Intermittent Recovery Test Level 1 (Yoyo IRT-1) as described by
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5 222 Krstrup et al. [31]. This test focuses on the capacity to carry out intermittent exercise leading
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7 223 to maximal activation of the aerobic system [32]. It consists of 2 x 20-m runs back and forth
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9 224 between starting, turning, and finishing at the start line at a progressively increased speed
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11 225 controlled by audio bleeps on a tape recorder. Between each shuttle, the subjects had 10-s
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13 226 recovery time, consisting of 2 x 5-m of slowly jogging, but had to be stationary on the start line
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15 227 ready for the next shuttle. The test protocol started with four running bouts at 10–13 km/h and
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17 228 another seven runs at 13.5–14 km/h, thereafter it continues with stepwise 0.5 km/h speed
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19 229 increments after every eight running bouts until exhaustion. When the subjects failed twice to
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21 230 reach the finishing line in time, the distance covered was recorded and represents the test result.
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28 232 ***Statistical analyses***

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30 233 Data are presented as group mean values and standard deviations (mean \pm SD). After normal
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32 234 distribution was examined using the Shapiro-Wilk-Test, an independent samples t-test was
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34 235 calculated to determine significant differences between-group baseline values (W0).
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36 236 All parameters were compared using 2 repeated measures analysis of variance (2-RM-
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38 237 ANOVA), Group (SPI or PLA) \times Time (W0 or W7), respectively. The significance level was
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40 238 set at $p < 0.05$. Relative reliability was assessed using the intraclass correlation coefficient (ICC)
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42 239 between the test and retest (2 trials performed for vertical jump and sprint measures at W0)
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44 240 [33]. An ICC < 0.40 was considered low; between 0.40 and 0.70 acceptable; between 0.70 and
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46 241 0.90 good and > 0.90 excellent [34]. All analyses were performed using Statistical Package for
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48 242 Social Sciences (SPSS) version 20.
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Results

Compliance, diet, internal training load and test-retest reliability

SPI and PLA supplementation compliance was 98.3% and 92.3%, respectively. No adverse effects were reported during or after spirulina supplementation. Neither internal training load nor dietary intake showed differences between groups at W0 and W7 (**Table 3**).

<< Please insert table 3 here >>

Table 4 illustrates the ICC of vertical jump and speed measures. Excellent relative reliability was observed for these measures.

<< Please insert table 4 here >>

Anthropometric data and body composition

At W0, all anthropometric measurements and body composition did not differ between groups. For anthropometric data, a significant main effect of “Time” was observed only for FM ($p<0.01$). The FM percentage was significantly reduced in both groups (-5%, $p<0.05$). No significant main effect of “Group” or “Group \times Time” interaction was observed for all anthropometric parameters. Thus, spirulina supplementation did not potentiate the loss of FM induced by training.

Physical Fitness

At W0, physical fitness measurements did not differ between groups.

Isokinetic Leg strength and power

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No significant main effect of “Time” or “Group” and no significant “Group × Time” interaction were detected for the concentric and eccentric peak torque and power in knee extensors and flexors meaning that, neither training alone (PLA) nor training associated with spirulina supplementation affects leg maximal strength and power. Data are presented in **Table 5**.

<< Please insert table 5 here >>

Vertical jump

A significant “Time” main effect was observed for SJ ($p<0.01$) and CMJ ($F=13.03$, $p<0.01$). Within-groups analysis showed significant improvements in SJ only for the SPI group ($p<0.05$) and for both groups in CMJ ($p<0.05$) (**Fig. 2A and 2B**). Moreover, the percentage change in vertical jump parameters was always higher in SPI group compared to the PLA group (SJ: 3.4 vs 2.3 %; CMJ: 4.4 vs 3.6 %, respectively). Despite this, no significant “Group × Time” interaction or main effect of “Group” was observed for vertical jump measurements.

Speed

The statistical analysis indicated a significant main effect of “Time” for 10-m ($p<0.05$) and 30-m ($p<0.05$) sprint measurements. Within-groups analysis showed significant improvements in 10- and 30-m sprint time only for the SPI group ($p<0.05$) (**Fig. 2C and 2D**). Moreover, the percentage change in both sprint measurements was higher for SPI compared to the PLA group (10-m: -2.2 vs -0.8 %; 30-m: -1.1 vs -0.5 %, in SPI and PLA, respectively). However, no main significant effect of “Group” and “Group × Time” interaction was detected for speed measurements.

<< Please insert Figure 2 here >>

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6 296 *Aerobic fitness*
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8 297 No significant main effect of “Time” or “Group” and no significant “Group \times Time” interaction
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10 298 was detected for the total distance covered in the yoyo IRT-1 meaning that neither training
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12 299 alone (PLA) nor training associated with spirulina supplementation affect aerobic fitness
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15 300 (1871.1-1993.3 vs 1940-1947.5 m at W0-W7 for SPI and PLA, respectively).
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Discussion

To our knowledge, this is the first study to examine the effects of *Arthrospira platensis* supplementation on anthropometric measurements as well as on physical performance using a battery of tests (leg strength, vertical jump, speed, and yoyo IRT-1 performances) in elite rugby players. Our hypothesis is partially verified since spirulina had no effect on anthropometric parameters and had only modest effects on performance (increase in vertical jump and sprint performance only for the SPI group without significant differences between groups). Intense training has been shown to decrease the availability of essential amino acids, which may slow the rate of tissue repair and growth [35]. Athletes need to ingest enough high-quality protein in their diet to maintain essential amino acid availability during training and competition [36] and to generate a greater stimulus for muscle growth and enhanced recovery, potentially resulting in greater strength gains [37, 38]. The supposed effects of spirulina on muscle development are based on its high protein content, especially in essential amino acids such as leucine, valine, isoleucine. For these reasons, athletes use spirulina to improve body composition (especially LBM) and physical performance. Few studies have documented the effects of spirulina supplementation on anthropometric measurements and physical performance in athletes. To our knowledge, only one study [15] examined the effects of 2-weeks of spirulina *platensis* supplementation on anthropometric parameters and body composition in athletes and reported no significant effect. Our results confirm the latter, because even with a longer time supplementation (7-weeks), we did not report any additive effect of spirulina supplementation to the training program since rugby players had similar FM loss (-5%) in both groups. The general consensus is that FM decreases with higher levels of play [39]. Moreover, the intensive training program of elite rugby players induces a significant decrease in FM, which makes it difficult to highlight the synergistic effect of spirulina. In pathological subjects, literature reported a decrease in BM and FM [40] after

326 spirulina *platensis* supplementation. The underlying mechanism of the anti-obesity effects of
 327 spirulina have been rarely discussed, but it seems that spirulina may be effective in lowering
 328 BM and FM by reducing appetite [14]. These discrepancies between elite and pathological
 329 subjects are not so paradoxical because it is more difficult to highlight anthropometric effects
 330 of spirulina in elite athletes compared to obese or diabetic subjects who exhibit deleterious body
 331 composition before supplementation.

332
 333 Concerning spirulina effects on performance, due to its high protein content and nutritional
 334 quality compared to animal and vegetable proteins [41, 42], spirulina could be of interest to
 335 improve the LBM of athletes and consequently to increase strength, power and also field
 336 performances requiring elevated muscle mass such as vertical jump, sprint performance and
 337 distance covered during the Yo-Yo IRT-1. We showed no significant effects of spirulina on
 338 concentric and eccentric peak torques and power of the quadriceps and hamstring muscles.
 339 Contrary to our results, Sandhu et al. [18] reported significant improvements in isometric peak
 340 force, average force, and fatigue index after eight weeks of spirulina supplementation (2g/day)
 341 in trained and untrained subjects. These apparent contradictory results could be explained by
 342 differences in assessment method (isokinetic dynamometer vs the HUR1* 5340 Leg
 343 Extension/Curl), the type of contraction (concentric and eccentric vs isometric) and subject's
 344 training level (elite vs. university competitive level). No other study examined the effects of
 345 spirulina supplementation on muscular strength.

346 With regards to power proxies, Juskiewicz et al. [19] recently showed that spirulina *platensis*
 347 supplementation (1.5g/d for 6 weeks) was not able to enhance the mean power output during a
 348 2000-m test on a rowing ergometer with a Polish rowing team. These findings are in accordance
 349 with our results showing no effects of SPI on knee extensors and flexors isokinetic power.

Concerning vertical jump and sprint performance, to our knowledge, no study has examined the effects of spirulina supplementation. Our results did not demonstrate any significant difference between groups but showed a significant increase in vertical jump performance with greater percentage changes in the SPI group for SJ (3.4 vs 2.3 %) and CMJ (4.4 vs 3.6 %) compared to PLA. Concerning sprint performance, only significant improvements were found for both 10-m and 30-m sprint but within-groups effects were significant only in the SPI group. Similarly, to vertical jump performance, better improvement magnitudes were found in the SPI compared to PLA group for 10-m (-2.7 vs -0.8 %) and 30-m sprint time (-1.6 vs -0.5 %). As previously reported, it is more difficult to highlight the synergistic effects of spirulina on performance in this elite population since physical qualities involved in sprint and vertical jump were already reinforced in their training program.

Regarding aerobic performance, our results showed no significant effects of SPI (“Time” and “Group” main effects or “Group × Time” interaction) on the total distance covered in the yoyo IRT-1. Our hypothesis was not confirmed. This is not so surprising because spirulina had no synergistic effect with training on BM and FM. In literature, spirulina supplementation effect on aerobic fitness was documented by only a few studies. Lu et al. [16] reported in untrained men a within-group increase in all-out treadmill time to exhaustion after 3-weeks of spirulina *platensis* supplementation without significant “Group × Time” interaction. Similarly, Kalafati et al. [17] also reported in moderately trained men a significant higher time to fatigue at 95% $\text{VO}_{2\text{max}}$ after spirulina *platensis* supplementation. Perhaps, these conflicting findings may be due to the intermittent character of the test and the different training status of our subjects (elite vs. untrained and moderate trained).

To summarize, the effects of spirulina on body composition and performance using a battery of tests are modest in elite rugby players. The limited beneficial effects only concern vertical jump

and sprint performance. We cannot consider spirulina as a nutritional ergogenic aid in this population. Our study does not confirm the assertions mentioned by the various commercial sites, in particular, those specialized for elite athletes. With speculation, it is possible that the results could be different with a longer duration (> 7 weeks) and a higher dose ($> 5.7\text{g/day}$). Indeed, to our knowledge, no study has investigated the spirulina dose-response relationship in athletes taking into account their training load. Since the optimal dose for such a population with high training loads remains unclear, the dose used in this study might have influenced the results. Further studies are required to verify spirulina consumption effects among athletes of different sports, age, sex, and athletic level with longer durations and higher dosages taking into account the relationship between the training load and the selected supplementation dose.

Conclusion

Seven weeks of spirulina supplementation in elite athletes did not improve body composition nor substantially increase physical performance evaluated by a battery of tests (muscle strength, power, speed, and aerobic fitness). We only observed a small advantage in vertical jump and sprint performance in the SPI group. The assertions mentioned by commercial sales sites are far from scientific reality. It is preferable to await further studies before recommending spirulina supplementation to high-level athletes in order to improve body composition and physical performance.

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16 404 **Authors’ contribution**

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21 406 Validation, Roles/Writing - original draft - review & editing, Validation;
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23 407 **Gautier Sandrine, Moison Yann, and Collin Tom:** Data curation, Investigation;
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26 408 **Carnot Yoann:** Data curation, Investigation, Software;
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28 409 **Bideau Nicolas:** Data curation, Investigation, Software, Methodology;
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30 410 **Guillemot Pierrick:** Data curation, Investigation, Methodology;
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44 416 **Conflict of interest**

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REFERENCES

1. Deng, R. and T.J. Chow, *Hypolipidemic, antioxidant, and antiinflammatory activities of microalgae Spirulina*. Cardiovasc Ther, 2010. **28**(4): p. e33-45.
2. Koncic, M.Z. and M. Tomczyk, *New insights into dietary supplements used in sport: active substances, pharmacological and side effects*. Curr Drug Targets, 2013. **14**(9): p. 1079-92.
3. Vicat, J.-P., J.-C.D. Mbaigane, and Y. Bellion, *Teneurs en éléments majeurs et traces de spirulines (Arthrospira platensis) originaires de France, du Tchad, du Togo, du Niger, du Mali, du Burkina-Faso et de République centrafricaine*. Comptes Rendus Biologies, 2014. **337**(1): p. 44-52.
4. Serban, M.C., et al., *A systematic review and meta-analysis of the impact of Spirulina supplementation on plasma lipid concentrations*. Clin Nutr, 2015. **35**(4): p. 842-851.
5. Thengodkar, R.R. and S. Sivakami, *Degradation of Chlorpyrifos by an alkaline phosphatase from the cyanobacterium Spirulina platensis*. Biodegradation, 2010. **21**(4): p. 637-44.
6. Khan, Z., P. Bhadouria, and P.S. Bisen, *Nutritional and therapeutic potential of Spirulina*. Curr Pharm Biotechnol, 2005. **6**(5): p. 373-9.
7. Sotiroudis, T.G. and G. Sotiroudis, *Health aspects of Spirulina (Arthrospira) microalga food supplement*. Journal of the Serbian Chemical Society, 2013. **78**(3): p. 395-405.
8. Marzieh Hosseini, S., et al., *Spirulina paltensis: Food and function*. Current Nutrition & Food Science, 2013. **9**(3): p. 189-193.
9. Kulshreshtha, A., et al., *Spirulina in health care management*. Curr Pharm Biotechnol, 2008. **9**(5): p. 400-5.
10. Wu, Q., et al., *The antioxidant, immunomodulatory, and anti-inflammatory activities of Spirulina: an overview*. Arch Toxicol, 2016. **90**(8): p. 1817-40.
11. Miczke, A., et al., *Effects of spirulina consumption on body weight, blood pressure, and endothelial function in overweight hypertensive Caucasians: a double-blind, placebo-controlled, randomized trial*. Eur Rev Med Pharmacol Sci, 2016. **20**(1): p. 150-6.
12. Zeinalian, R., et al., *The effects of Spirulina Platensis on anthropometric indices, appetite, lipid profile and serum vascular endothelial growth factor (VEGF) in obese individuals: a randomized double blinded placebo controlled trial*. BMC Complement Altern Med, 2017. **17**(1): p. 225.
13. Lee, E.H., et al., *A randomized study to establish the effects of spirulina in type 2 diabetes mellitus patients*. Nutr Res Pract, 2008. **2**(4): p. 295-300.
14. Mazokopakis, E.E., et al., *The hypolipidaemic effects of Spirulina (Arthrospira platensis) supplementation in a Cretan population: a prospective study*. J Sci Food Agric, 2014. **94**(3): p. 432-7.
15. Milasius, K., R. Malickaite, and R. Dadeliene, *Effect of Spirulina food supplement on blood morphological parameters, biochemical composition and on the immune function of sportsmen*. Biology of Sport, 2009. **26**(2): p. 157-172.
16. Lu, H.K., et al., *Preventive effects of Spirulina platensis on skeletal muscle damage under exercise-induced oxidative stress*. Eur J Appl Physiol, 2006. **98**(2): p. 220-6.
17. Kalafati, M., et al., *Ergogenic and antioxidant effects of spirulina supplementation in humans*. Med Sci Sports Exerc, 2010. **42**(1): p. 142-51.
18. Sandhu, J., B. Dheera, and S. Shweta, *Efficacy of Spirulina Supplementation on Isometric Strength and Isometric Endurance of Quadriceps in Trained and Untrained Individuals--a comparative study*. Ibmossina Journal of Medicine & Biomedical Sciences, 2010. **2**(2): p. 79-86.

19. Juskiewicz, A., et al., *An attempt to induce an immunomodulatory effect in rowers with spirulina extract*. J Int Soc Sports Nutr, 2018. **15**: p. 9.
20. Schröder, H., et al., *The type, amount, frequency and timing of dietary supplement use by elite players in the First Spanish Basketball League*. J Sports Sci, 2002. **20**(4): p. 353-8.
21. Sekulic, D., et al., *Substance use and misuse and potential doping behaviour in rugby union players*. Res Sports Med, 2014. **22**(3): p. 226-39.
22. Fox, R.D., *Spirulina: Production & Potential*. 1996, Aix-en-Provence: Edisud.
23. Bovenschen, H.J., et al., *Evaluation of a gastrointestinal symptoms questionnaire*. Dig Dis Sci, 2006. **51**(9): p. 1509-15.
24. Siri, W.E., *The gross composition of the body*. Adv Biol Med Phys, 1956. **4**: p. 239-80.
25. Comyns, T. and E.P. Flanagan, *Applications of the session rating of perceived exertion system in professional rugby union*. Strength Cond J, 2013. **35**(6): p. 78-85.
26. Haddad, M., et al., *Validity and psychometric evaluation of the French version of RPE scale in young fit males when monitoring training loads*. Science & Sports, 2013. **28**(2): p. e29-e35.
27. Maffiuletti, N.A., et al., *Reliability of knee extension and flexion measurements using the Con-Trex isokinetic dynamometer*. Clin Physiol Funct Imaging, 2007. **27**(6): p. 346-53.
28. Lehance, C., J.-L. Croisier, and T. Bury, *Optojump system efficiency in the assessment of lower limbs explosive strength*. Science & Sports, 2005. **20**(3): p. 131-135.
29. Glatthorn, J.F., et al., *Validity and reliability of Optojump photoelectric cells for estimating vertical jump height*. J Strength Cond Res, 2011. **25**(2): p. 556-60.
30. Chaouachi, M., et al., *Within Session Sequence of Balance and Plyometric Exercises Does Not Affect Training Adaptations with Youth Soccer Athletes*. J Sports Sci Med, 2017. **16**(1): p. 125-136.
31. Krstrup, P., et al., *The yo-yo intermittent recovery test: physiological response, reliability, and validity*. Med Sci Sports Exerc, 2003. **35**(4): p. 697-705.
32. Bangsbo, J., F.M. Iaia, and P. Krstrup, *The Yo-Yo intermittent recovery test : a useful tool for evaluation of physical performance in intermittent sports*. Sports Med, 2008. **38**(1): p. 37-51.
33. Shrout, P.E. and J.L. Fleiss, *Intraclass correlations: uses in assessing rater reliability*. Psychol Bull, 1979. **86**(2): p. 420-8.
34. Hopkins, W.G., et al., *Progressive statistics for studies in sports medicine and exercise science*. Med Sci Sports Exerc, 2009. **41**(1): p. 3-13.
35. Kreider, R.B., *Dietary supplements and the promotion of muscle growth with resistance exercise*. Sports Med, 1999. **27**(2): p. 97-110.
36. Kerksick, C.M., et al., *The effects of protein and amino acid supplementation on performance and training adaptations during ten weeks of resistance training*. J Strength Cond Res, 2006. **20**(3): p. 643-53.
37. Kraemer, W.J. and B.A. Spiering, *Skeletal muscle physiology: plasticity and responses to exercise*. J Hormone Research in Paediatrics, 2006. **66**(Suppl. 1): p. 2-16.
38. Ratamess, N.A., et al., *The effects of amino acid supplementation on muscular performance during resistance training overreaching*. J Strength Cond Res, 2003. **17**(2): p. 250-8.
39. Duthie, G., D. Pyne, and S. Hooper, *Applied physiology and game analysis of rugby union*. Sports Med, 2003. **33**(13): p. 973-91.
40. Moradi, S., et al., *Effects of Spirulina supplementation on obesity: A systematic review and meta-analysis of randomized clinical trials*. Complement Ther Med, 2019. **47**: p. 102211.

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2
3 518 41. Becker, E.W., *Micro-algae as a source of protein*. Biotechnol Adv, 2007. **25**(2): p. 207-
4 519 10.
5 520 42. Lupatini, A.L., et al., *Potential application of microalga Spirulina platensis as a protein*
6 521 *source*. J Sci Food Agric, 2017. **97**(3): p. 724-732.
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Table 1. Participant anthropometric characteristics.

	SPI (n=11)	PLA (n=11)
Age (year)	25.8 ± 3.4	26.3 ± 4.4
BM (kg)	100.0 ± 13.6	99.1 ± 19.9
Height (cm)	184.1 ± 7.7	182.4 ± 7.7
FM (%)	19.7 ± 4.6	19.3 ± 4.8
FM (kg)	20.2 ± 6.5	19.8 ± 8.0
LBM (kg)	79.8 ± 8.0	79.4 ± 12.7

Values are presented as mean ± standard deviation. BM, body mass; FM, Fat Mass; LBM, lean body mass.

Table 2. Composition of *Arthrospira platensis* produced by AGV (100 g).

Unity Amount			Unity Amount		
Energy			Vitamins		
	kJ	1530	Vitamin A	µg	<20
	kcal	363	β-carotene	mg	24,902
Fat			Vitamin C	mg	<2,5
Total fat	g	6,3	Vitamin B3	mg	8,5
Saturated fat	g	3,8	Vitamin B5	mg	0,05
Unsaturated fat	g	2,5	Vitamin B6	mg	0,09
Monounsaturated fat	g	0,4	Vitamin B9	µg	156
Polyunsaturated fat	g	2	Vitamin B12	µg	61,3
Omega 3	%	0,12	Vitamin E	mg	6,84
Omega 6	%	14,31	Minerals		
Carbohydrates			Sodium	mg	1338,2
Total Carbohydrates	g	16,5	Phosphorus	mg	1353,8
Dietary Fiber	g	7,4	Calcium	mg	310,4
Proteins and amino acids			Copper	mg	1,83
Proteins	g	63,7	Iron	mg	76,43
Leucine	g	5,56	Magnesium	mg	434,2
Isoleucine	g	3,47	Manganese	mg	7,06
Valine	g	4,02	Potassium	mg	1932
			Zinc	mg	7,43

Table 3. Participant’s dietary intake and internal training load.

		SPI (n=11)	PLA (n=11)	p-value
Caloric intake (kcal)	W0	2680.8 ± 495.4	2844.8 ± 495.4	0.508
	W7	2788.3 ± 535.6	2646.8 ± 523.6	0.558
Carbohydrates (g)	W0	2.83 ± 0.91	2.85 ± 0.96	0.948
	W7	3.05 ± 0.99	2.64 ± 0.89	0.350
Proteins (g)	W0	1.37 ± 0.38	1.66 ± 0.66	0.243
	W7	1.43 ± 0.36	1.62 ± 0.64	0.416
Fat (g)	W0	1.15 ± 0.32	1.09 ± 0.37	0.718
	W7	1.16 ± 0.33	1.10 ± 0.45	0.735
Internal training load (AU)	W1	1408.1 ± 434.2	1258.9 ± 579.4	0.531
	W2	1317.4 ± 358.9	1218.2 ± 695.2	0.696
	W3	1192.0 ± 244.9	1206.5 ± 424.9	0.927
	W4	675.0 ± 200.1	809.5 ± 192.3	0.143
	W5	1296.4 ± 399.2	1562.6 ± 631.0	0.268
	W6	1592.6 ± 316.0	1740.8 ± 414.8	0.372

Values are presented as mean ± standard deviation.

Table 4: ICC of vertical jump and speed measurements

Measures	ICC	Interpretation
SJ	0.958	Excellent
CMJ	0.980	Excellent
10-m Sprint	0.900	Excellent
30-m Sprint	0.937	Excellent

ICC, intraclass correlation coefficient; SJ, squat jump; CMJ, countermovement jump.

Table 5. Isokinetic leg strength and power before and after supplementation

		Peak torque (Nm)		Maximal power (W)	
		W0	W7	W0	W7
CON 60 E	PLA	263.20 ± 22.72	273.82 ± 27.68	275.61 ± 23.80	286.75 ± 28.99
	SPI	278.42 ± 15.64	271.96 ± 26.97	291.57 ± 16.37	284.79 ± 28.24
CON 60 F	PLA	183.59 ± 30.18	192.37 ± 43.81	192.27 ± 31.60	201.46 ± 45.88
	SPI	190.32 ± 30.81	184.55 ± 30.29	199.31 ± 32.26	193.25 ± 31.71
CON 240 E	PLA	213.55 ± 24.41	213.21 ± 31.77	947.28 ± 162.39	906.83 ± 103.02
	SPI	226.15 ± 38.76	216.49 ± 24.59	849.51 ± 102.25	893.08 ± 133.07
CON 240 F	PLA	170.03 ± 34.97	179.25 ± 43.45	727.23 ± 141.31	724.69 ± 166.01
	SPI	173.61 ± 33.73	173.01 ± 39.63	712.22 ± 146.46	750.83 ± 181.99
ECC 30 E	PLA	287.28 ± 38.64	308.75 ± 29.95	111.82 ± 12.77	111.64 ± 16.63
	SPI	316.67 ± 16.53	319.83 ± 23.07	118.40 ± 20.28	113.36 ± 12.89
ECC 30 F	PLA	200.25 ± 37.18	186.38 ± 42.51	89.02 ± 18.31	93.85 ± 22.76
	SPI	195.58 ± 19.27	196.55 ± 25.39	90.90 ± 17.66	90.58 ± 20.75

Nm, Newton metre; W, Watt ; CON, Concentric; ECC, Eccentric; E, extensors; F, Flexors; 60, 60°/s; 240, 240°/s; 30, 30°/s.

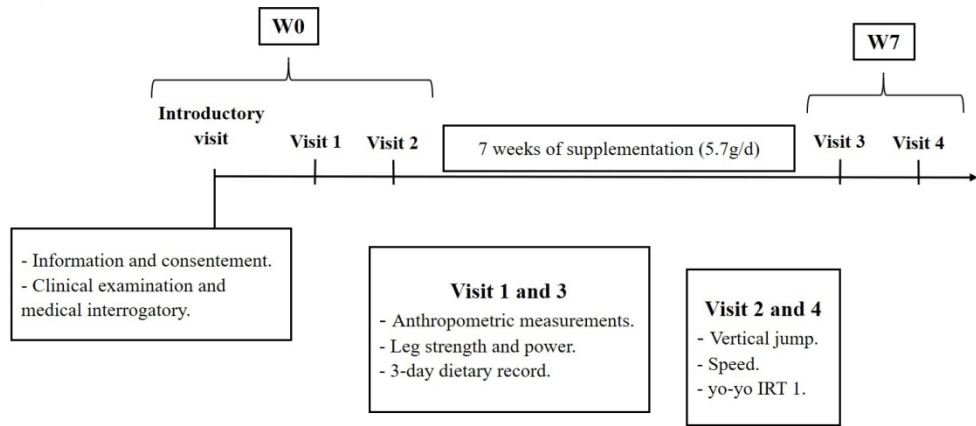


Figure 1. Study design

Figure 1. Study design
64x31mm (600 x 600 DPI)

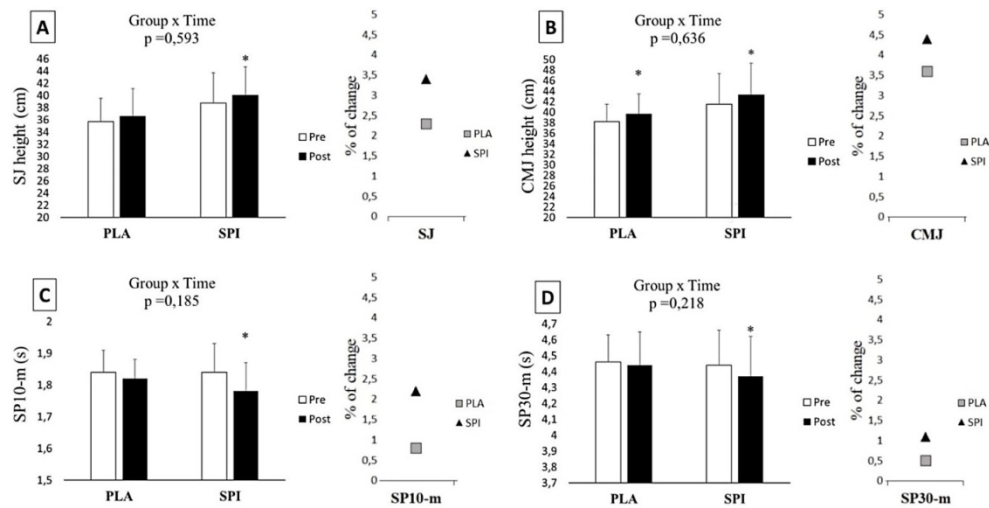


Figure 2. Effects of supplementation on Vertical jump and Speed measurements.
* $p<0.05$

Figure 2. Effects of supplementation on Vertical jump and Speed measurements. * $p<0.05$
97x57mm (600 x 600 DPI)