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Plant-based diets benefit aerobic performance and do not compromise strength/power performance: a systematic review and meta-analysis

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Abstract

Plant-based diets have emerged as athletic performance enhancers for various types of exercise. Therefore, the present study evaluated the effectiveness of plant-based diets on aerobic and strength/power performances, as well as on BMI of physically active individuals. This systematic review and meta-analysis was conducted and reported according to the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement. A systematic search of electronic databases, including PubMed, Web of Science and SPORTDiscus, was performed. On the basis of the search and inclusion criteria, four and six studies evaluating the effects of plant-based diets on aerobic and strength/power performances in humans were, respectively, included in the systematic review and meta-analysis. Plant-based diets had a moderate but positive effect on aerobic performance (0·55; 95 % CI 0·29, 0·81) and no effect on strength/power performance (–0·30; 95 % CI −0·67, 0·07). The altogether analyses of both aerobic and strength/power exercises revealed that athletic performance was unchanged (0·01; 95 % CI −0·21, 0·22) in athletes who adopted plant-based diets. However, a small negative effect on BMI (–0·27; 95 % CI −0·40, −0·15) was induced by these diets. The results indicate that plant-based diets have the potential to exclusively assist aerobic performance. On the other hand, these diets do not jeopardise strength/power performance. Overall, the predicted effects of plant-based diets on physical performance are impactless, even though the BMI of their adherents is reduced.

Keywords: **Plant-based: Performance: Vegan: Aerobic exercise**

Plant-based diets are growing in popularity as they are considered environmentally sustainable and have a reduced environmental impact[1,2]. These diets mostly consist of plant foods such as fruits, vegetables, legumes, grains and oilseeds. Within this principle, vegans and vegetarians share the non-consumption of meat but differ regarding the use of dairy products and eggs. Plant-based diets are richer in carbohydrates, antioxidants, fibre, vitamins, minerals and phytochemicals, free from cholesterol and saturated fat, and less energetic when compared with omnivorous diets, which represent health benefits.

Common sense has long advocated that meat and other animal-derived proteins are a crucial component of athletes' diets, igniting the debate over the impact of plant-based diets on physical performance. The potential influence of plant-based diets on aerobic performance has been investigated; however, the results are conflicting[3–5]. While VO_2 has been described to improve in physically active vegans of both sexes[3,4] during an aerobic performance test, it was unchanged in vegetarian men who underwent an exhaustion test on a cycle ergometer[5].

Another scenario is illustrated during strength/power exercise, possibly because of the differences in training and fuel needs for aerobic exercises. Studies that have related plant-based diets with strength and power exercises have shown similar physical performance between omnivores and vegetarians. As also recently demonstrated, gains of 10–38 % in mean muscle strength were observed in both groups after 12 weeks of training[3,6–8].

Abbreviation: ES, effect size.

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Another important aspect regarding physical performance is the choice of plant-based diets as a weight loss tool[9,10]. Differences in body mass between vegetarian and omnivorous athletes have been shown[4], but not confirmed by other studies[3] among vegan women. However, BMI reduction has been reported among male athletes who use plant-based diets[4,11]. Despite these findings, plant-based diets have been used as a strategy to maintain lean mass in overweight physically active women[9].

In face of the increasing adherence to plant-based diets by athletes and physical exercise practitioners, the potential benefits and risks of plant-based diets on physical performance need to be further elucidated. Therefore, this study aims to identify whether plant-based diets influence aerobic and strength/power performances, as well as the body composition of vegan and vegetarian individuals when compared with omnivores.

Methods

Search strategy

This systematic review and meta-analysis was conducted and reported according to the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)[12] and protocol in PROSPERO (CRD42021248682). The systematic search was performed without date restriction in August 2020 and updated in June 2022. The following electronic databases were used: PubMed, Web of Science and SPORTDiscus. The search strategy used a combination of the following descriptors: vegan diet OR vegetarian diet OR plant-based diet AND exercise, physical training, sports, aerobic, strength, resistance, effort, performance, power, running, speed, hypertrophy and BMI.

Study selection

After excluding duplicates, the decision to include or exclude studies was made by two independent investigators after reading the studies in the following order: (I) study title; (II) study abstract and (III) study complete manuscript. Eligible studies that met all of the inclusion criteria were included in this systematic review: (I) plant-based dieters as subjects (vegans and vegetarians); (II) assessment of a physical performance protocol; (III) sports practitioners; (IV) omnivorous subjects as a control group and (V) written in English. Animal studies, studies addressing minors, or reviews of disease states, abstracts and case studies were excluded from the analysis. Reviews, systematic reviews, case studies and letters were not included but were analysed. As a result, ten studies were included in this systematic review. Lacto-ovo-vegetarian and vegan diets will be analysed in the present study when used by athletes and physically active individuals in aerobic and resistance training.

Data extraction

All data were extracted from eligible studies by two independent investigators. In the case of conflicting opinions among the researchers, the disagreement was resolved through discussion with other authors. The following characteristics were recorded: (I) first author, (II) year of publication, (III) sample size, (IV) subject characteristics, (V) time and type of diet, (VI) exercise protocol and (VII) results of the variables analysed.

The extracted data were grouped according to the different types of diet and the type of training (aerobic and resistance) and later organised based on the variables analysed. Corresponding numerical values were extracted using the WebPlotDigitizer program (version 4.3, Ankit Rohatgi) for those studies whose results were presented graphically and were not described in the text.

Risk of bias assessment

The risk of bias assessment was performed by independent reviewers using an adaptation of the Grading of Recommendations Assessment, Development and Evaluation (GRADE) instrument[13–16]. Discrepant assessments were resolved through discussion with an independent reviewer. Thus, it was possible to assess the risk of bias in each study included in the present systematic review. The domains evaluated in the studies were absence of allocation concealment, absence of blinding, incomplete follow-up, selective reporting of outcomes and other limitations. After this evaluation, the quality of the articles was classified according to the number of negative responses into high quality (5 no), moderate quality (4 no), low quality (3 no) and very low quality (1 or 2 no). Very low-quality articles were excluded from the work.

Statistical analysis

The mean and standard deviation results of the variables of interest were obtained from the included studies. The χ^2 test and the I^2 statistic were used for the meta-analysis of the heterogeneity of the studies. The effect size (ES) (Cohen's d or Hedges' g) was calculated for all studies. The weighted mean of the ES was calculated taking into account the differences in sample sizes. The unweighted mean ES was also calculated and associated with a 95 % CI. The Cohen classification was used to assess the magnitude of the ES, where $d < 0{\cdot}20$ indicates a negligible effect, $d = 0{\cdot}20$–$0{\cdot}49$ indicates a small effect, $d = 0{\cdot}50$–$0{\cdot}79$ indicates a moderate effect and $d > 0{\cdot}8$ indicates large effect[17].

Results

Systematic review

A total of 2282 articles were identified through the database and references. After removing duplicates (*n* 1300 articles) and deleting articles that not met eligibility criteria according to their titles (*n* 898 articles), abstracts (*n* 41 articles) and full texts (*n* 33 articles), ten studies (*n* 293 individuals) were selected for inclusion in the systematic review (Fig. 1).

Subject characteristics, including information regarding the type of diet and the type of exercise protocol used in each study, are summarised in Table 1. Most studies used vegetarian diets in their protocols. Some characteristics were different among studies such as the type of plant-based diet, the diet adherence period and the physical test used to determine exercise capacity

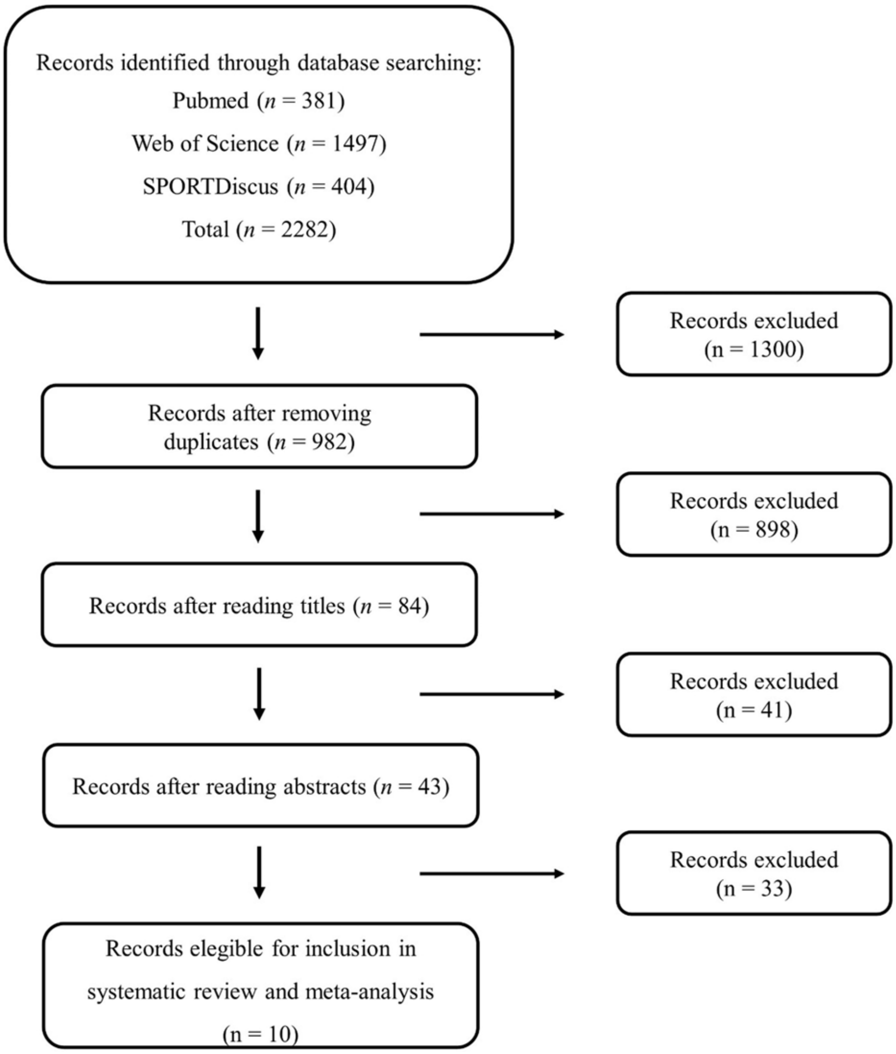

Fig. 1. Summary of the study selection process.

(knee flexion and extension, bench press, rowing and VO_2 test) (Table 1).

Among the ten selected studies, three evaluated aerobic and seven strength/power performances; four had a vegan diet and six had a lacto-ovo-vegetarian diet as its basis; and two had women and eight had men as subjects. Due to the limited number of studies, a separate meta-analysis between sexes could not be carried out.

Meta-analysis

A total of ten studies (36 trials and 293 subjects) were included in the meta-analysis.

Analysis of the influence of plant-based diet on aerobic performance

After pooling the data from seven trials that evaluated aerobic performance, it was identified that plant-based diet adherents showed higher aerobic physical performance, with moderate ES (0·50, 95 % CI 0·22, 0·77, $P < 0·05$). According to the fixed effects analysis, no heterogeneity was observed between these studies ($I^2 = 10·0$ %, $Q = 6·67$, df = 6, $P = 0·353$) (Fig. 2).

Analysis of the influence of plant-based diet on strength/power performance

After pooling the data from seventeen trials that evaluated strength/power performance, it was identified that the plant-based diet adherents showed similar performance to non-adherents (ES: −0·30, 95 % CI −0·67, 0·07, $P > 0·05$). According to the fixed effects analysis, heterogeneity was observed between these studies ($I^2 = 72·3$ %, $Q = 57·83$, df = 16, $P = 0·000$) (Fig. 3).

Analysis of the influence of plant-based diet on overall physical performance

After pooling the data of thirty-six trials that evaluated overall physical performance (aerobic and strength/power), it was

Table 1. Characterisation of aerobic and strength/power performance related to diet type

Reference	N of subjects	Characteristics of subjects	Diet time	Diet type	Protocol	Duration	Variable	Results
Boutros et al. 2020[3]	56	Physically active	+ 24 months	Vegans	Cycle ergometer	–	VO_2 (ml/kg/min)	ONI: 41·6 ± 4·6 VEG: 44·5 ± 5·2
Boutros et al. 2020[3]	56	Physically active	+ 24 months	Vegans	Exercise resistance	–	Time (min/week)	ONI: 8·8 ± 3·0 VEG: 12·2 ± 5·7
Boutros et al. 2020[3]	56	Physically active	+ 24 months	Vegans	Muscle strength	–	Leg press (kg/kg LBM)	ONI: 2·5 ± 0·5 VEG:2·4 ± 0·4
Boutros et al. 2020[3]	56	Physically active	+ 24 months	Vegans	Muscle strength	–	Arm pull (kg/kg LBM)	ONI: 1·4 ± 0·3 VEG: 1·3 ± 0·2
Campbell et al. 1999[6]	19	Overweight subjects	12 weeks	Lacto-ovo-vegetarian	Resistance training	12 weeks	Right knee extension (Nm)	ONI: 189 ± 12 LOV: 179 ± 7
Campbell et al. 1999[6]	19	Overweight subjects	12 weeks	Lacto-ovo-vegetarian	Resistance training	12 weeks	Left knee extension (Nm)	ONI: 185 ± 6 LOV: 181 ± 6
Campbell et al. 1999[6]	19	Overweight subjects	12 weeks	Lacto-ovo-vegetarian	Resistance training	12 weeks	Right knee flexion (Nm)	ONI: 157 ± 11 LOV: 167 ± 7
Campbell et al. 1999[6]	19	Overweight subjects	12 weeks	Lacto-ovo-vegetarian	Resistance training	12 weeks	Left knee flexion (Nm)	ONI: 154 ± 25 LOV: 164 ± 7
Campbell et al. 1999[6]	19	Overweight subjects	12 weeks	Lacto-ovo-vegetarian	Resistance training	12 weeks	Chest press (N)	ONI: 627 ± 31 LOV: 576 ± 25
Campbell et al. 1999[6]	19	Overweight subjects	12 weeks	Lacto-ovo-vegetarian	Resistance training	12 weeks	Arm pull (N)	ONI: 713 ± 34 LOV: 669 ± 27
Campbell et al. 1999[6]	19	Overweight subjects	12 weeks	Lacto-ovo-vegetarian	Resistance training	12 weeks	Leg press (N)	ONI: 1694 ± 96 LOV: 1564 ± 67
Durkalec-Michalski et al. 2022[18]	10	Trained	4 weeks	Vegans	Squat 70 % (1RM)	–	Repetitions	ONI: 21·9 ± 0·9 VEG: 26·1 ± 2·1
Durkalec-Michalski et al. 2022[18]	10	Trained	4 weeks	Vegans	Deadlift 70 % (1RM)	–	Repetitions	ONI: 19·1 ± 1·4 VEG: 18·0 ± 1·2
Haub et al. 2005[7]	21	Physically active	14 weeks	Lacto-ovo-vegetarian	Power test	12 weeks	Leg press (N)	ONI: 1900 ± 381 LOV: 1958 ± 170
Haub et al. 2005[7]	21	Physically active	14 weeks	Lacto-ovo-vegetarian	Power test	12 weeks	Arm pull (N)	ONI:1248 ± 137 LOV: 1283 ± 150
Hevia-Larraín et al. 2021[19]	19	Physically active – men	–	Vegans	Leg press	12 weeks	Muscle strength (kg.10^3)	ONI: 186 ± 43 VEG: 177 ± 54
Hevia-Larraín et al. 2021[19]	19	Physically active – men	–	Vegans	Leg extension	12 weeks	Muscle strength (kg.10^3)	ONI: 58 ± 14 VEG: 52 ± 13
Hietavala et al. 2012[5]	9	Physically active	–	Diet vegetarian of low protein	Cycle ergometer	4 d	VO_2 (l/min) – workload (100 % of VO_{2max})	ONI: 3·65 ± 0·65 DVBP: 3·87 ± 0·9
Hietavala et al. 2012[5]	9	Physically active	–	Diet vegetarian of low protein	Cycle ergometer	4 d	Duration (min) in 100 % of VO_{2max}	ONI: 2·89 ± 1·91 DVBP: 1·81 ± 0·8
Lynch et al, 2016[4]	40	Athletes – men	+ 24 months	Lacto-ovo-vegetarian	Cycle ergometer	–	VO_{2max} (mL/kg/min)	ONI: 55·7 ± 8·4 LOV: 62·6 ± 15·0
Lynch et al, 2016[4]	40	Athletes – men	+ 24 months	Lacto-ovo-vegetarian	Leg extension and flexion	–	Muscle strength (ft-lbs)	ONI: 124·2 ± 24·5 LOV: 114·4 ± 26·2
Lynch et al, 2016[4]	30	Athletes – women	+ 24 months	Lacto-ovo-vegetarian	Cycle ergometer	–	VO_{2max} (mL/kg/min)	ONI: 47·1 ± 8·6 LOV: 53·0 ± 6·9
Lynch et al, 2016[4]	30	Athletes – women	+ 24 months	Lacto-ovo-vegetarian	Leg extension and flexion	–	Muscle strength (ft-lbs)	ONI: 73·6 ± 18·6 LOV: 65·5 ± 12·8

Table 1. (*Continued*)

Reference	N of subjects	Characteristics of subjects	Diet time	Diet type	Protocol	Duration	Variable	Results
Nebl et al. 2019[8]	26	Recreational runners	6 months	Vegan and lacto-ovo-vegetarian	Graded exercise test	1 session	Max power (W/kg)	ONI: 4·15 ± 0·48 LOV: 4·20 ± 0·47 VEG: 4·16 ± 0·55
Nebl et al. 2019[8]	26	Recreational runners	6 months	Vegan and lacto-ovo-vegetarian	Graded exercise test	1 session	Max power (W/kg)	ONI: 5·29 ± 0·48 LOV: 5·39 ± 0·52 VEG: 5·26 ± 0·58
Nebl et al. 2019[8]	16	Recreational runners	6 months	Vegan and lacto-ovo-vegetarian	Graded exercise test	1 session	Max power (W/kg)	ONI: 3·99 ± 0·46 LOV: 4·06 ± 0·44 VEG: 4·06 ± 0·53
Nebl et al. 2019[8]	16	Recreational runners	6 months	Vegan and lacto-ovo-vegetarian	Graded exercise test	1 session	Max power (W/kg)	ONI: 4·41 ± 0·41 LOV: 4·46 ± 0·43 VEG: 439 ± 0·52
Pfeffeir et al. 2021[20]	18	Physically active	+ 12 months	Vegans	Cycle ergometer	2 sessions	Max power (W/kg)	ONI: 7·58 ± 1·51 VEG: 8·13 ± 1·21
Pfeffeir et al. 2021[20]	18	Physically active	+ 12 months	Vegans	Cycle ergometer	2 sessions	Mean power (W/kg)	ONI: 5·37 ± 0·84 VEG: 5·74 ± 0·81
Pfeffeir et al. 2021[20]	18	Physically active	+ 12 months	Vegans	Cycle ergometer	2 sessions	Time to reach maximal power output (s)	ONI: 1·88 ± 0·39 VEG: 1·86 ± 0·38
Pfeffeir et al. 2021[20]	18	Physically active	+ 12 months	Vegans	Cycle ergometer	2 sessions	Fatigue index (%)	ONI: 47·5 ± 16·1 VEG: 52·7 ± 6·0
Raben et al. 1992[21]	8	Endurance athletes	6 weeks	Lacto-ovo-vegetarian	Endurance	1 d	Resistance (time)	ONI: 78·2 ± 10·2 LOV: 75·3 ± 9·0

ONI, omnivore; LOV, lacto-ovo-vegetarian; VEG, vegan; W, Watt; N, Newtons.
Results are presented as mean values and standard deviations.

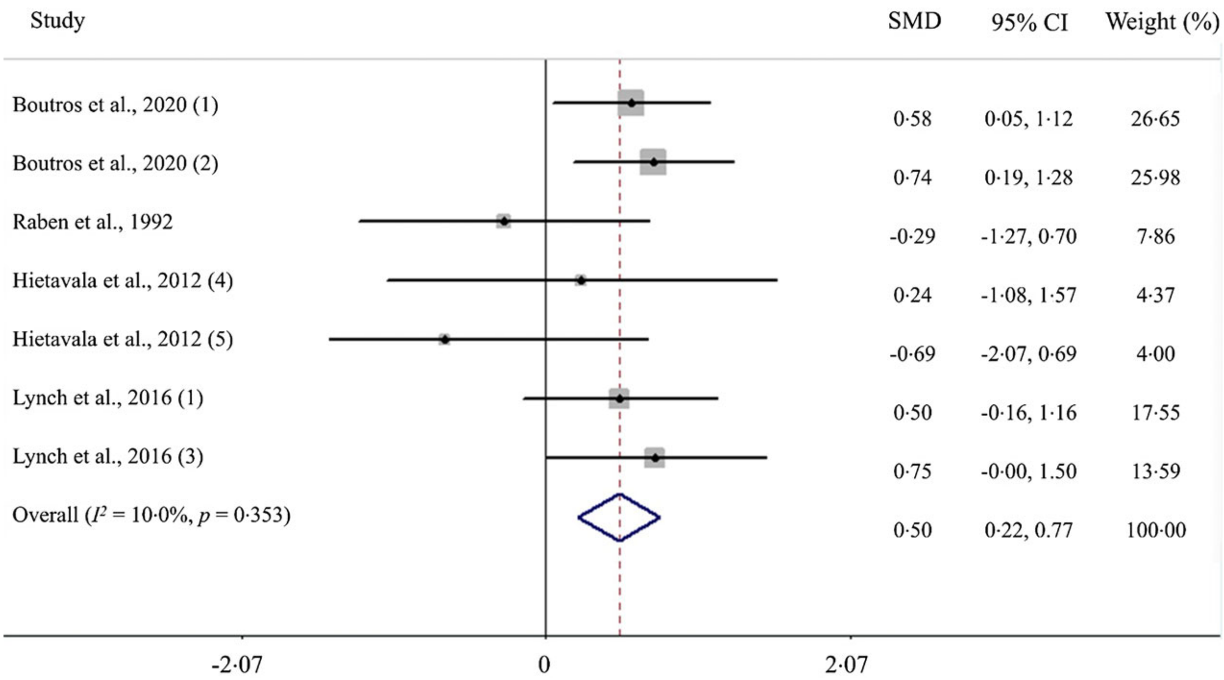

Fig. 2. Forest plot of aerobic physical performance of plant-based diet adherents. SMD, standardised mean difference.

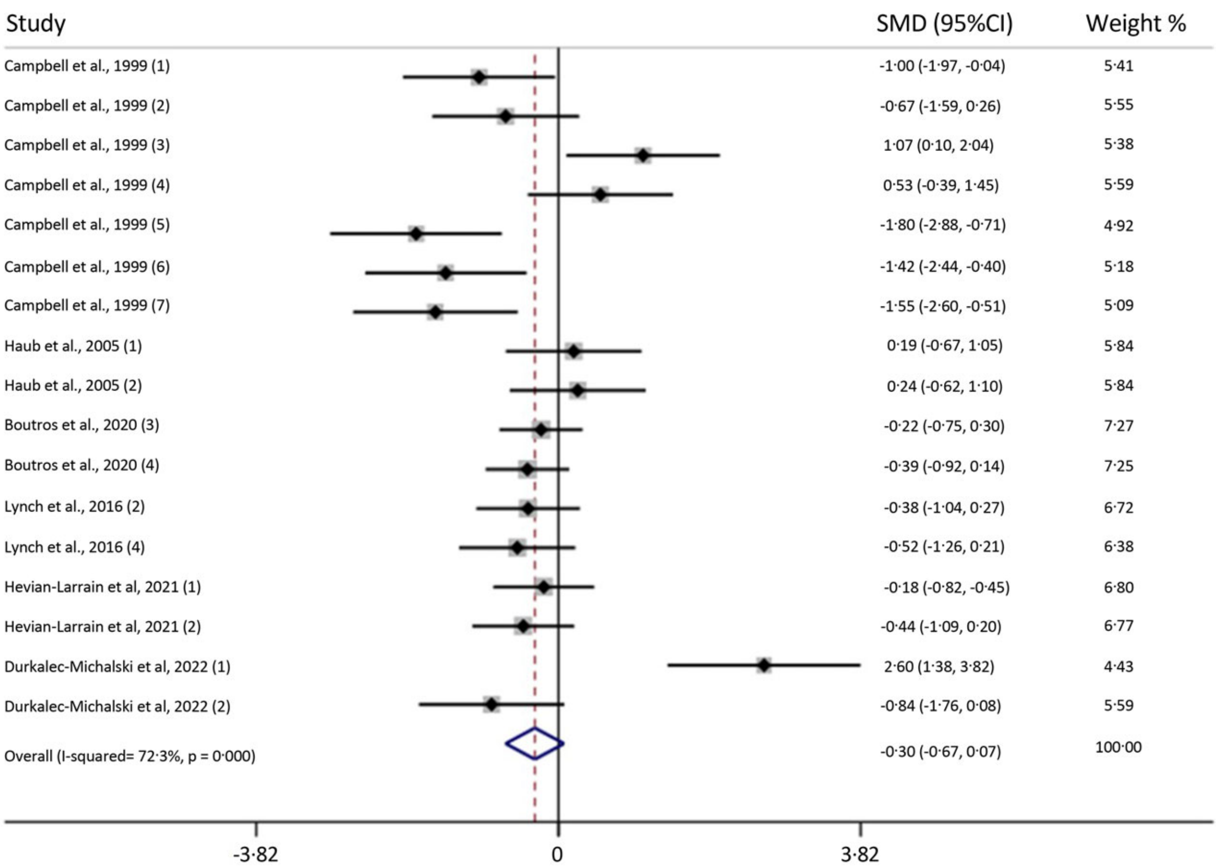

Fig. 3. Forest plot of strength/power physical performance of plant-based diet adherents. SMD, standardised mean difference.

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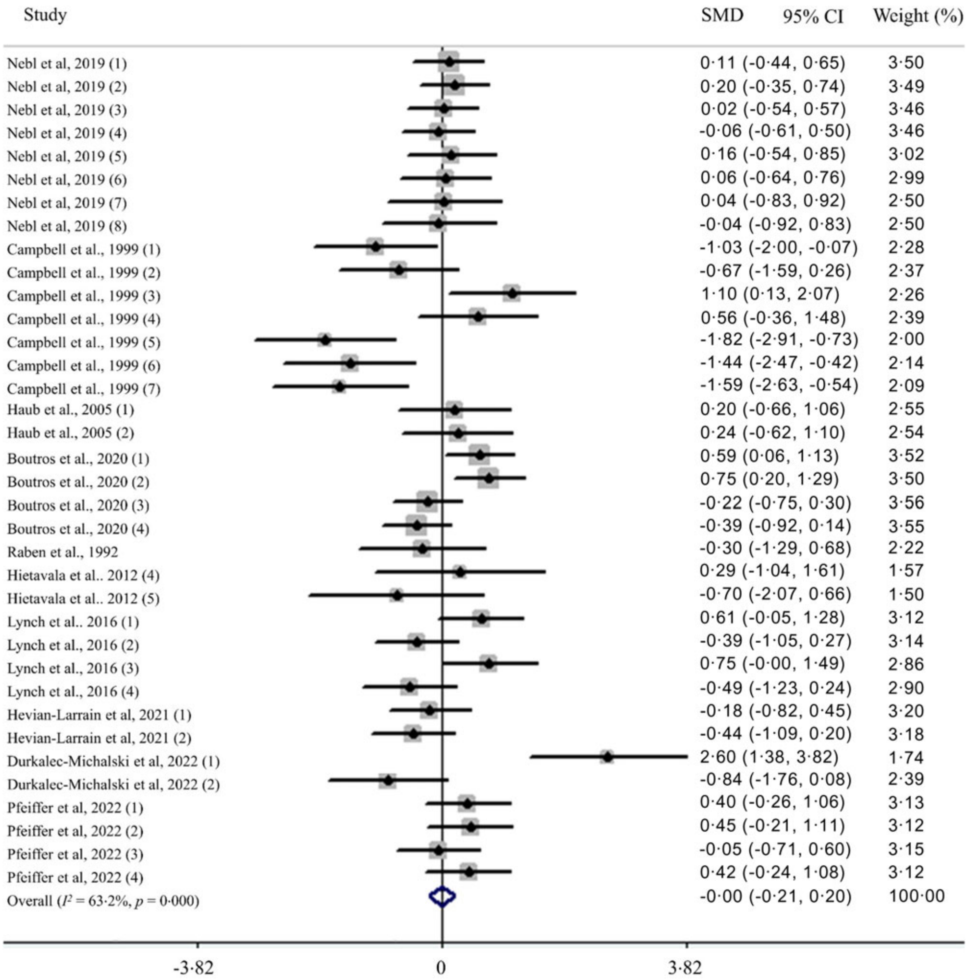

Fig. 4. Forest plot of general physical performance of plant-based diet adherents. SMD, standardised mean difference.

identified that the plant-based diet adherents showed similar performance to non-adherents (ES: 0·00, 95 % CI −0·21, 0·20, $P > 0·05$). According to a fixed effects analysis, heterogeneity was observed between these studies ($I^2 = 63·2$ %, $Q = 95·16$, df = 35, $P = 0·000$) (Fig. 4).

Analysis of the influence of plant-based diet on BMI

After pooling the data of nine trials that evaluated BMI, it was identified that plant-based diet adherents showed lower BMI, with small ES (−0·27, 95 % CI −0·40, −0·15, $P < 0·05$). According to a fixed effects analysis, no heterogeneity was observed between these studies ($I^2 = 0·0$ %, $Q = 1·25$, df = 8, $P = 0·996$) (Fig. 5).

Analysis of the influence of vegan diet on aerobic performance

After pooling the data from two trials that evaluated aerobic performance, it was identified that vegan diet adherents showed higher aerobic physical performance, with moderate ES (0·66, 95 % CI 0·28, 1·04, $P < 0·05$). According to the fixed effects analysis, no heterogeneity was observed between these studies ($I^2 = 0·0$ %, $Q = 0·16$, df = 1, $P = 0·693$) (Fig. 6).

Analysis of the influence of vegan diet on strength/power performance

After pooling the data from ten trials that evaluated strength/power performance, it was identified that the vegan diet adherents showed similar performance to non-adherents (ES: −0·07, 95 % CI −0·41, 0·28, $P > 0·05$). According to the fixed effects analysis, heterogeneity was observed between these studies ($I^2 = 62·8$ %, $Q = 24·20$, df = 9, $P = 0·004$) (Fig. 7).

Analysis of the influence of vegan diet on overall physical performance

After pooling the data of sixteen trials that evaluated overall physical performance (aerobic and strength/power), it was identified that the vegan diet adherents showed similar performance to non-adherents (ES: 0·13, 95 % CI −0·13, 0·38, $P > 0·05$). According to a fixed effects analysis, heterogeneity was observed between these studies ($I^2 = 60·6$ %, $Q = 38·04$, df = 9, $P = 0·001$) (Fig. 8).

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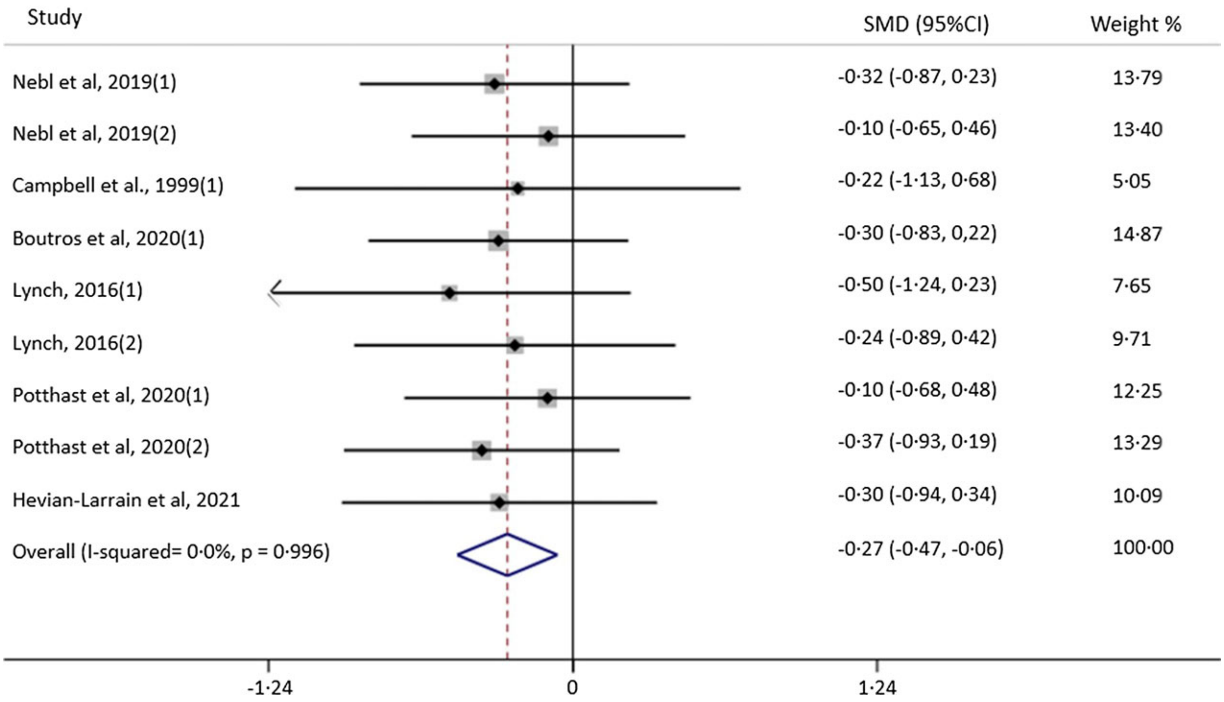

Fig. 5. Forest plot of BMI of plant-based diet adherents. SMD, standardised mean difference.

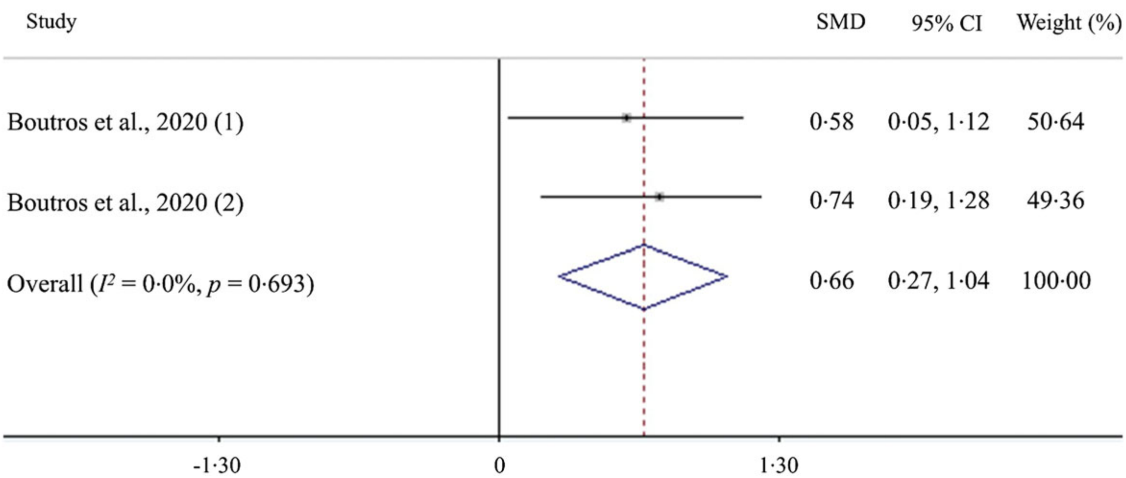

Fig. 6. Forest plot of aerobic physical performance of vegan diet adherents. SMD, standardised mean difference.

Analysis of the influence of vegan diet on BMI

After pooling the data of three trials that evaluated BMI, it was identified that the vegan diet adherents showed similar BMI to non-adherents (ES: −0·31, 95 % CI −0·63, 0·02, $P < 0·05$). According to a fixed effects analysis, no heterogeneity was observed between these studies ($I^2 = 0·0$ %, $Q = 0·00$, df = 2, $P = 0·999$) (Fig. 9).

Risk of bias

The risk of bias was assessed in the ten included studies. Seven studies did not present any major risk of bias. Three studies showed low methodological quality. Thus, 70·0 % of the studies showed consistent control of the risk of bias and were classified as high and moderate quality (online Supplementary Table 1).

Discussion

The present systematic review and meta-analysis present evidence that plant-based diets, including the vegan diet, positively affect aerobic performance but on the other hand do not modify strength/power performance. Moreover, the joint analysis of both aerobic and strength/power capacities shows no significant changes induced by plant-based diets. Thus, despite the controversy surrounding the adoption of non-carnivorous diets by athletes, when considering the practical effects of

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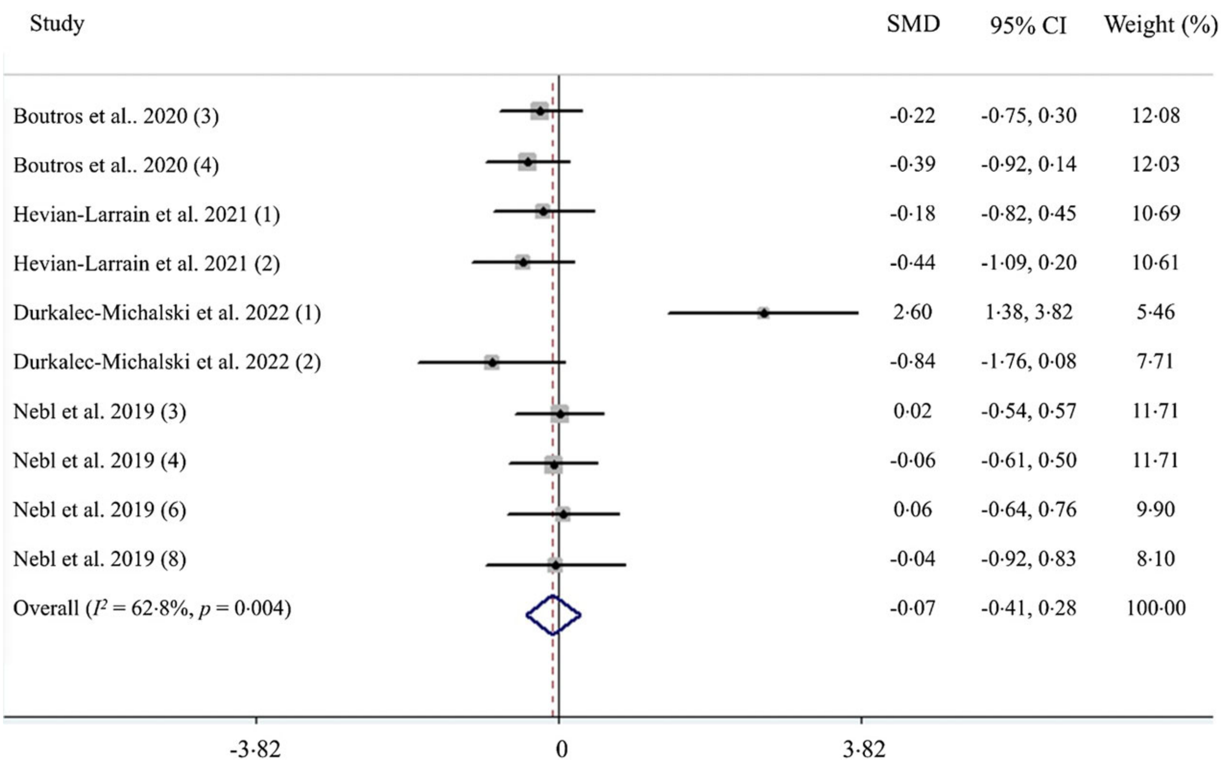

Fig. 7. Forest plot of strength/power physical performance of vegan diet adherents. SMD, standardised mean difference.

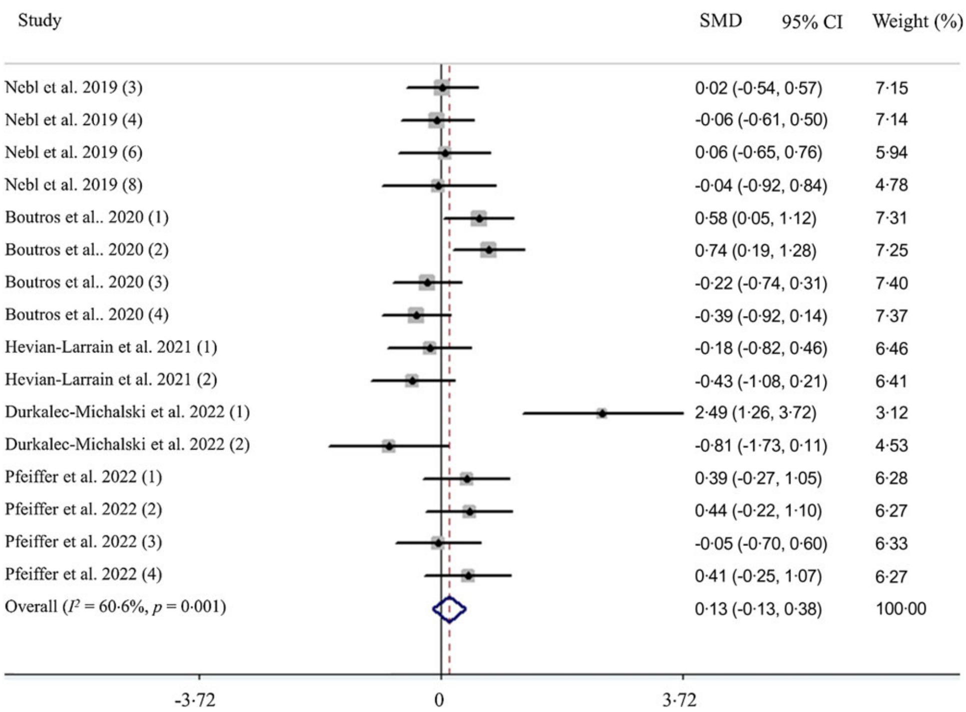

Fig. 8. Forest plot of general physical performance of vegan diet adherents. SMD, standardised mean difference.

plant-based diets on physical activity, it seems that these diets do not compromise exercise performance.

Although it has been shown that vegan and vegetarian diets are healthy and nutritionally adequate, some adverse effects have also been described[21,22]. Hyperhomocysteinemia, protein deficiency, anaemia and decreased creatinine content in muscles are among the changes that could jeopardise the ability to perform physical effort[23,24]. In fact, when it comes to the practice of physical exercise, a lack of nutrients and vitamins can be even more felt by the body, which supports a prejudice

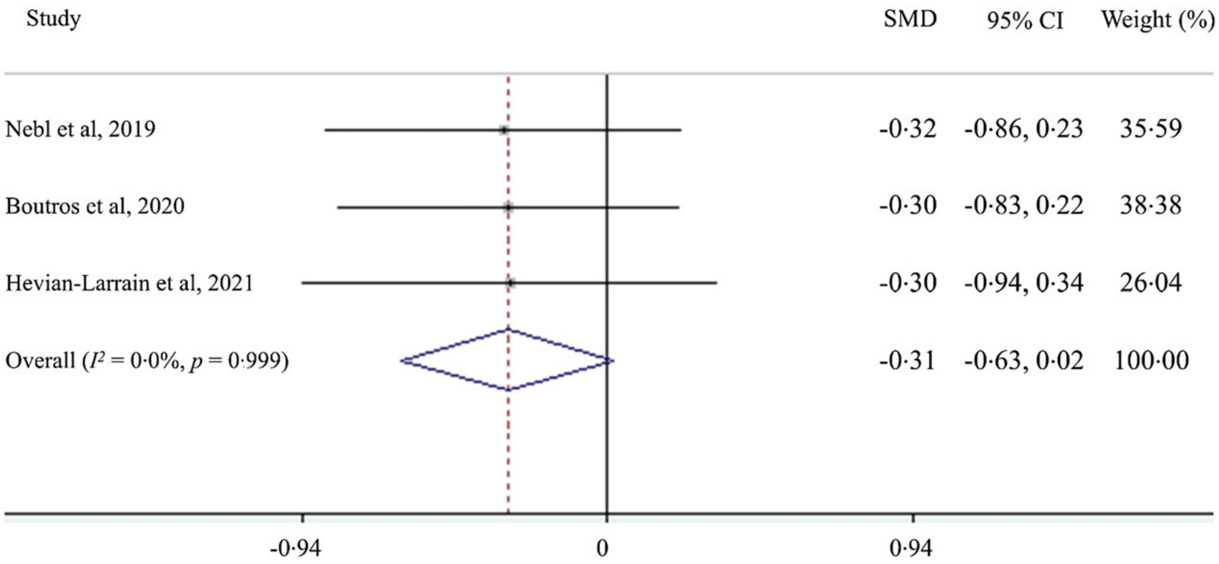

Fig. 9. Forest plot of BMI of vegan diet adherents. SMD, standardised mean difference.

against the use of plant-based diets by athletes *v.* a balanced omnivorous diet[22,25]. As a consequence, it is commonly stated that diets with animal protein restriction could negatively impact physical performance mainly due to protein and lipid deficits, in addition to hypovitaminosis, especially vitamin B_{12} deficiency[21,26]. However, the present results show an advantage on aerobic performance. Moreover, although negative, no significant effect on strength/power performance was induced by plant-based diets, which also comprises the vegan diet. This last evidence goes in agreement with the finding that strength and muscle mass can be built without prejudice regardless of the protein source, since a high-protein plant-based diet is not different than an omnivores diet in supporting muscle strength and mass accrual[27]. Thus, the beneficial effects of plant-based diets on health seem to balance the adverse effects when addressing physical potential. These diverse effects on performance outcomes may also be the result of different training and fuelling needs required by athletes training for endurance *v.* strength sports activities.

The adherents of plant-based diets usually have health consciousness and assume other behaviours towards a healthy lifestyle that go beyond their eating habit[28]. Therefore, non-dietary factors, such as regular physical activity, non-smoking, non-consumption of alcohol and consistent sleep schedule may optimise the efficacy of plant-based diets on health, and as a consequence, on exercise performance, and a decreased BMI[29] is usually shown in plant-based diet adherents. In fact, the current data indicate that individuals consuming plant-based diets have lower BMI, which is linked not only to physical health but also to body composition optimisation, a key performance goal in fitness and sport[30,31]. Our results indicate that when the vegan diet is analysed in isolation, no statistical differences were found in BMI, unlike the analysis with all plant-based diets. Thus, in the context of physical exercise, factors other than the dietary practice but also inherent with healthy everyday living may positively impact performance outcomes[32].

Some limitations that may affect the interpretation of the results need to be addressed, particularly in face of the small number of studies focusing on plant-based diets and exercise. For this reason, differences between the sexes were not examined in spite of evidences that vegan diet seems to induce more favourable changes in weight loss and lipid profile in women[33], while a lacto-ovo vegetarian diet may be more appropriate for males due to its effectiveness in lowering LDL-cholesterol[34]. Moreover, the present analysis did not discern athletes taking or not taking supplements in order to meet any dietary needs, which could eventually optimise exercise performance[35]. Thus, the potential effect of vegan and vegetarian diets on physical performance still remains a question of debate and more examinations are needed in this area. Athletes in general should address carefully the results presented herein when adopting a plant-based dietary pattern for the purpose of physical endurance or hypertrophy and strength.

Despite the controversy that athletes adopting animal food restriction necessarily show reduced exercise capacity[36], the current study presents evidence that plant-based diets, among which the vegan diet, have no effect on physical performance, including on strength/power performance. It is noteworthy that aerobic performance may be even benefitted by these diets. This is especially relevant for vegan and vegetarian athletes because, regardless of their ecological, economic, religious, ethical and/or health reasons to adopt a plant-based diet, their cause can be defended without the burden of having exercise performance disadvantages. Given the limited literature comparing the physical performance of omnivore and plant-based diet followers, the results should be considered with caution at all levels of training and athletic performance.

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The authors declare no conflict of interest.

Supplementary material

For supplementary material/s referred to in this article, please visit https://doi.org/10.1017/S0007114523002258

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