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Review Article / Derleme Makalesi

The effect of Ashwagandha *(Withania somnifera)* on sports performance: a systematic review and meta-analysis

Ashwagandha (Withania somnifera)'nın Spor Performansı Üzerine Etkisi: Sistematik Bir Derleme ve Meta-Analiz

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ABSTRACT

Ashwagandha is well known for its health benefits, including anti-inflammatory, immunomodulatory, and cardioprotective properties, as well as its potential to enhance physical fitness and improve sports performance. This review aims to systematically assess the existing literature regarding the effect of Ashwagandha on sports performance within the athletic community. A thorough literature search was performed using databases including SciVerse Scopus®, PubMed®, Web of Science®, Medline, Embase, SPORTDiscus, and AYUSH. A meta-analysis was conducted to evaluate the impact of Ashwagandha on aerobic fitness levels using RevMan 5.3 software. The screening of 781 potentially relevant articles for eligibility resulted in the inclusion of eight studies assessing the effect of Ashwagandha on sports performance in the present review. All trials originated in India. The sports categories involved were athletics, hockey, cycling, boxing, and sprinting. The results demonstrate that Ashwagandha supplementation, at a dosage of 300 mg to 500 mg of aqueous root extract daily, taken twice a day for a duration ranging from 8 to 12 weeks, is effective in enhancing sports performance comparing with control or placebo groups. This includes improvements in cardiorespiratory fitness, muscle strength, recovery, and various physical fitness parameters. The primary finding of the meta-analysis indicates that, in comparison to a placebo, Ashwagandha significantly improved VO_2max in athletes by 4.09 ml/min/kg (95% CI, 2.55-5.63, p<0.001; I2=92%, p< 0.001). The analyzed studies did not reveal any adverse impact; however, seeking guidance from medical professionals before commencing Ashwagandha supplementation in competitive sports is recommended.

Keywords: *Indian ginseng, sports supplementation, Withania somnifera, sports performance*

ÖZ

Ashwagandha, anti-inflamatuar, immünomodülatör ve kardiyoprotektif özellikleriyle tanınan bir bitkidir ve ayrıca fiziksel formu artırma ve spor performansını iyileştirme potansiyeline sahiptir. Bu derleme, atletik toplulukta Ashwagandha'nın spor performansı üzerindeki etkisini değerlendiren mevcut literatürü sistematik olarak incelemeyi amaçlamaktadır. SciVerse Scopus®, PubMed®, Web of Science®, Medline, Embase, SPORTDiscus ve AYUSH gibi veri tabanlarında kapsamlı bir literatür taraması gerçekleştirilmiştir. RevMan 5.3 yazılımı kullanılarak Ashwagandha'nın aerobik fitness seviyeleri üzerindeki etkisini değerlendiren bir meta-analiz yapılmıştır. Uygunluk açısından incelenen 781 makale arasından, Ashwagandha'nın spor performansı üzerindeki etkisini değerlendiren sekiz çalışma bu derlemeye dahil edilmiştir. Tüm çalışmalar Hindistan'dan kaynaklanmaktadır. İncelenen spor dalları arasında atletizm, hokey, bisiklet, boks ve sprint yer almaktadır. Sonuçlar, günlük 300 mg ile 500 mg arasında değişen sulu kök ekstresi dozajının, 8 ila 12 hafta boyunca günde iki kez alınmasının, kontrol veya plasebo gruplarıyla karşılaştırıldığında spor performansını önemli ölçüde artırdığını göstermektedir. Bu gelişmeler arasında kardiyorespiratuvar fitness, kas gücü, toparlanma süreci ve çeşitli fiziksel uygunluk parametrelerindeki iyileşmeler yer almaktadır. Meta-analizin temel bulgusu, Ashwagandha'nın plaseboya kıyasla sporcuların VO2max değerini 4.09 ml/dk/kg artırdığını göstermektedir (95% CI, 2.55-5.63, p<0.001; I2=92%, p<0.001). Analiz edilen çalışmalar herhangi bir olumsuz etki bildirmemiştir; ancak, rekabetçi sporcuların Ashwagandha takviyesine başlamadan önce tıbbi uzmanlardan rehberlik alması önerilmektedir.

Anahtar Sözcükler: *Hint ginsengi, spor takviyesi, Withania somnifera, spor performansı*

INTRODUCTION

Withania somnifera, generally known as Ashwagandha (Indian ginseng), is a traditional Indian herb categorized under the Solanaceae family (1). While deeply embedded in its Indian heritage, it has also extended its presence to the lands of the Mediterranean, Africa, and Australia (2). Various components of Ashwagandha, encompassing the root, seeds, stem, and leaves, have been employed for more than 3000 years, providing diverse health-related benefits (2). Currently, Ashwagandha has been repackaged for modern consumers in the form of capsules, powders, gummies, and liquid extracts, marking its adaptability to changing times (3). The worldwide market for Ashwagandha extract reac–

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hed a value of 864.3 million USD in 2021. It is anticipated to surge to 2.5 billion USD by 2031 within the United States and Europe (4). Ashwagandha demonstrates promising health benefits, particularly in stress management, anxiety reduction, cognitive enhancement, addressing sleep disorders, erectile dysfunction and physical performance by improving muscular strength (2). Additionally, there is supporting evidence indicating the positive impact of Ashwagandha on infertility, and serum testosterone levels among males with lower sexual desire (5). Furthermore, it exhibits neuroprotective, anti-inflammatory, immunomodulatory, cardioprotective, anti-bacterial, anti-cancer, and anti-diabetic properties (6).

A double-blind randomized controlled trial (RCT) was performed to evaluate the anti-inflammatory effect of Ashwagandha in 60 patients with knee joint pain and discomfort. Following 12 weeks, significant reductions in knee pain and swelling were observed in the Ashwagandha 250 mg ($p<0.001$) and Ashwagandha 125 mg ($p<0.05$) groups, comparing to the placebo group. Disability and stiffness exhibited a notable decrease in both the Ashwagandha 250 mg ($p<0.001$) and Ashwagandha 125 mg ($p<0.01$) groups (1). Chauhan and co-workers reported a significant elevation of serum testosterone levels (66.5 ng/dl; $p<0.0001$) following Ashwagandha supplementation in men (5). In addition, Ashwagandha is important in reducing stress, enhancing focus and memory, psychological well-being, and enhancing sleep quality, as well as lowering stress levels (7).

Besides its use in health and well-being treatments, Ashwagandha supplementation has been highlighted in literature for its role in enhancing physical performance in healthy adults. In an 8-week RCT led by Wankhede et al. (8), individuals who ingested 300 mg of Ashwagandha root extract twice daily confirmed noteworthy enhancements in bench-press muscle strength (Ashwagandha group: 46.0 kg, placebo: 26.4 kg; $p=0.001$), accompanied by a significant growth in arm muscle size. In a separate trial, it was documented that a 500 mg dosage of aqueous Ashwagandha extract substantially enhanced both upper and lower-body strength, promoted a favourable body composition, and provided benefits for healthy, active men throughout a 12-week supplementation period (9). In a comparable study, Sandhu and collaborators (10) observed a noteworthy positive influence of Ashwagandha supplementation on maximum velocity, average absolute and relative power, maximum oxygen consumption (VO_2max) and balance within a group of 40 healthy participants.

Considering the potential impact of Ashwagandha on improving physical parameters among healthy adults, several interventional studies have been carried out on athletes to assess its efficacy in sports performance. Tiwari et al. (11) conducted an 8-week, double-blind trial to evaluate the efficacy of 300 mg of Ashwagandha root extract capsules (twice daily) in enhancing cardiorespiratory endurance (VO_2max) and recovery among athletes. An interventional study conducted by Shenoy et al. (12) assessed the effectiveness of 500 mg capsules of aqueous Ashwagandha root taken twice daily for eight weeks in elite cyclists, revealed a significant improvement in various anaerobic parameters. Similarly in another trial, a substantial impact of Ashwagandha was observed among sprinters, particularly in relation to their standing broad jump, 50-yard dash, sit-ups, shuttle run, 12-min run/walk and pull-ups (13). Besides, Ashwagandha supplementation has been approved by various health and nutrition organizations, reflecting its safety and efficacy in appropriate contexts (14). Furthermore, it is not classified as a doping substance by the World Anti-Doping Agency (WADA), ensuring its acceptability in competitive sports (15).

While many herbal and nutritional supplements claim to improve sports performance, Ashwagandha stands out due to its unique adaptogenic properties, which may contribute to enhanced physical performance, recovery, and overall well-being (16). Unlike some other supplements, Ashwagandha is considered unique because it positively affects various performance parameters such as cardiorespiratory fitness, muscle strength, and recovery (8-13).

There has been growing interest in Ashwagandha, leading to several systematic reviews on its effects on physical function and performance in both athletes and non-athletes (16-18). However, no systematic reviews or meta-analyses have specifically evaluated Ashwagandha supplementation in athletes. Given the widespread interest and potential benefits of Ashwagandha on sports performance, it is crucial to conduct a comprehensive review focusing on its impact on athletic performance. This study aims to fill this gap by systematically assessing the efficacy of Ashwagandha supplementation in athletes, addressing its potential benefits and providing insights into its role in enhancing sports performance.

MATERIAL and METHODS

Following the guidelines established in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (19), a systematic review and meta-analysis were carried out. The protocol for this review was registered prospectively in the international systematic reviews register (PROSPERO registration no. CRD42023460949).

Search strategy

A comprehensive electronic literature search was conducted in five phases using PubMed®, Web of Science®(v.5.4) (Thomson Reuters, USA), SciVerse Scopus® (Elsevier Properties S.A, USA), Embase® (Excerpta Medica), Medline (U.S. National Library of Medicine, USA), SPORTDiscus, and AYUSH Research Portal. The search encompassed articles published prior to September 1, 2023. Databases were searched using Medical Subject Headings (MeSH) terms when possible or keywords when otherwise appropriate, and the terms '*Withania somnifera*' OR 'ashwagandha' OR 'Indian Ginseng' AND 'sports' OR 'exercise' OR 'endurance' OR 'strength' OR 'running' OR 'performance' OR 'athletic' were included.

An advanced search was carried out in the PubMed database, using the specified MeSH terms and keywords within the article title and abstract. In the Web of Science® database, the advanced search operator TS (Title, abstract, author keywords, keywords plus) was utilized to search for the specified terms within article topics. The Scopus® database was examined for the mentioned terms within the article title, abstract, or keywords. The Embase® database was explored using the keywords in the title or abstract. For Medline, a search was done using the specified keywords in the abstracts. In the case of the SPORTDiscus database, the search was limited to keywords associated with ashwagandha within abstracts, excluding the term 'sport performance' due to the sport-centric nature of the database. On the AYUSH research portal (https://ayushportal.nic.in/), the query was narrowed down to 'clinical research (evidence grade-A, B, and C)' within the 'Ayurveda' subcategory, focusing on abstracts. The only limit set for these database searches was the English language.

The search strategy was independently carried out by two co-authors (RJ and PS), and any discrepancies were resolved by discussion. In the second step, the total citations collected from seven databases were consolidated, and duplicate entries were eliminated. The remaining articles underwent eligibility assessment through successive stages: the third stage involved reviewing the article 'title', the fourth stage involved examining the 'abstract', and the fifth stage involved assessing the 'full text'. This process utilized the inclusion and exclusion criteria outlined below. Additionally, a manual search was executed to identify supplementary articles from the reference lists of involved articles.

Inclusion and exclusion criteria

The study employed the population, intervention, comparison, outcomes, and study (PICOS) design strategy to include studies that met the specified criteria (20).

Population (P): Professional athletes or individuals participating in competitive sports activities were considered. Studies involving non-athlete populations, healthy individuals, recreational sports personals, or patients were excluded.

Intervention (I): The intervention was supplementation with Ashwagandha, irrespective of dosage, formulation, or duration. Studies where Ashwagandha was combined with other supplements were removed.

Comparator/Control (C): No supplementation or receiving a placebo. Studies with active substance were given as comparator were excluded.

Outcomes (O): Studies measuring any sports performance-related outcome, anthropometric, biochemical, physical etc. Studies that did not measure sports performance outcomes directly (e.g., studies focusing solely on stress, and anxiety without linking to performance) were excluded.

Study design (S): Using the PICO strategy, human interventional studies assessing the effectiveness of Ashwagandha on sports performance across any study duration were included. Excluded from consideration were observational studies (such as cohort, case-control, and cross-sectional studies), animal studies, in-vitro models, case reports, case series, letters to the editor, reviews, and unpublished data.

Data extraction

An investigator (KW) extracted and tabulated the following variables: first author, publication year, country, study design, sport type, gender, and age of the study population, sample size, supplementation, duration, and significant outcomes. A second investigator (RJ) independently verified the accuracy of the extracted data, and any discrepancies were resolved through discussion. Furthermore, when interpreting the level of statistical significance, as signified by the p-value, comparisons between the test and control groups rather than those between the pre-and post-interventions of each group were considered.

Assessment of quality

Two independent investigators conducted the quality assessment for the selected studies using the Modified Jadad Scale. Each study was assigned a score ranging from 0 to 8. Subsequently, studies were categorized as high-quality (scoring 6-8 points), moderate quality (4-5 points), or poor quality (<4 points) based on a maximum possible score of eight (21).

Data analysis

The impact of Ashwagandha on maximal oxygen consumption (VO_2max) was evaluated and analyzed by the RevMan 5.3 software (Cochrane Collaboration, Oxford, UK). The meta-analysis included studies that met the eligibility criteria and involved a comparison between an experimental group and a control group concerning VO_2max. Changes from the baseline (mean change and SDs of the changes) were extracted for both the experimental and control groups. Continuous variables were assessed using weighted mean differences (WMDs) and 95% CI. Data heterogeneity was examined through the X^2 test and I^2 test. In cases of homogeneity ($p>0.05$, $I^2<60\%$), a fixed-effects model was applied (22); else, the random effects model was used. A $p<0.05$ was considered statistically significant. In addition, publication bias was assessed by funnel plots.

RESULTS

The primary systematic literature search in each database resulted in the following number of studies: SciVerse Scopus® (n=561), PubMed® (n=145), Web of Science® (n=267), Medline (n=116), Embase (n=202), SPORTDiscus (n=21) and AYUSH (n=73). Following the removal of duplicates, 781 potentially relevant articles underwent eligibility assessment. During the initial screening based on titles and abstracts, 12 articles remained for further full-text evaluation. After retrieving the full-text for detailed assessment, six studies met all inclusion criteria. Two additional articles were identified through manual search, resulting in a total of eight papers included in the current review. Figure 1 provides a summary of the search strategy.

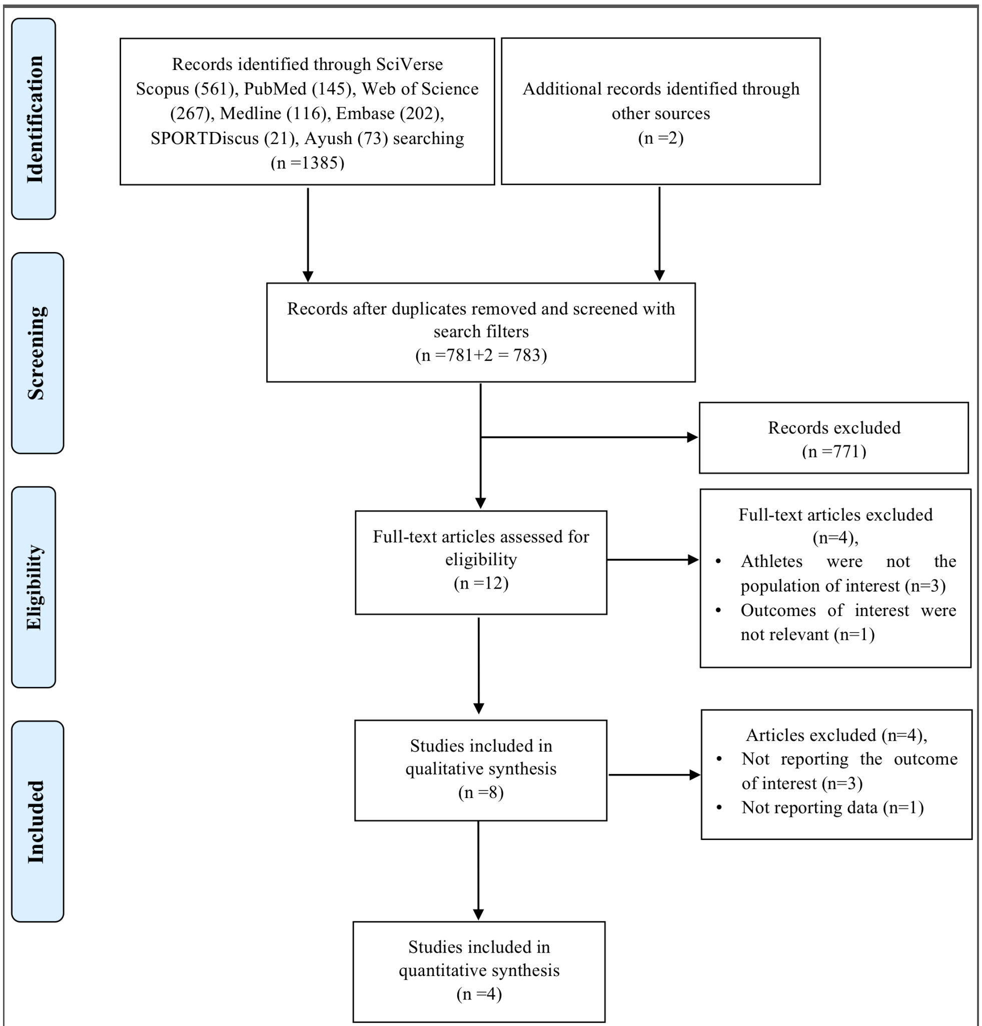

Figure 1. Preferred reported items for systematic reviews and meta-analysis flow diagram detailing the review filtering process

All eight manuscripts involved in this systematic review were RCTs published between 2002 and 2021 in India. The quality of the selected trials was assessed using the Modified Jadad Scale, resulting in two high-quality studies (7,11) four of moderate quality (12,24-26), and two of poor quality (13,27) (Supplementary Table). The age range of the athletes involved in the studies ranged from 17 to 45 years. When considering the number of athletes recruited in the selected RCTs, the sample sizes ranged from 15 to 50 subjects. The included RCTs involved a range of sports categories, including athletics (7,11), hockey (25,26), cycling (12,27), boxing (24), and sprinting (13). Different doses and forms of Ashwagandha supplementation have been administered, as illustrated in Table 1, with supplementation durations ranging from 8 to 12 weeks. When examining the potential side effects of Ashwagandha supplementation, only two studies reported no adverse effects (11,13). Other studies did not indicate the evaluation of side effects associated with the supplement.

Table 1. Evidence of the effects of Ashwagandha supplementation on sports performance

Author, year	Study design, MJS	Sport type	Gender, age	Sample size, supplementation		Duration, side effects	Significant outcomes
				IG	PG/CG		
Ahuja et al. 2002 (24)	R, 4 pts	Boxers	M, 21-30	n=8, dose NM, daily, BD	n=7, placebo capsule daily, BD	12 wk, NM	1. VO_2max ↑ (IG: 68.5 ml/min/kg, CG: 58.5 ml/min/kg); p=0.01, 2. Basal heart rate ↓ (IG: 57±6 bpm, CG: 58±4 bpm); p=0.05, 3. Heart rate recovery after exercise at the end of 1st min↓ (IG: 147 bpm, CG: 153 bpm), 4. WBC ↑ (IG: 8500±10 /µl, CG: 8005±11 /µl); p<0.05.
Choudhary et al. 2015, (7)	R, DB, P, 7 pts	Athletics	Both, 20-45	n=25, 300 mg root extract daily, BD	n=25, sucrose capsules	12 wk, NM	Mean change from baseline, 1. VO_2max↑ (IG:5.67, PG: 1.86); p<0.0001, 2. QoL scores for physical health ↑ (IG: 9.3±7.6, PG: −2.3±5.7); p<0.05.
Malik et al. 2013 (25)	R, SB, P, 4.5 pts	Hockey	M, 17.4±1.7	n=16, 500 mg roots of WS; BD	n= 16, 500 mg of sugar powder; BD	8 wk, NM	1. VO_2max ↑ (IG: 51.5±2.9, PG: 49.3±3.1); p<0.01, 2. Haemoglobin ↑ (IG: 13.9±0.7, PG: 13.4±0.7); p<0.01.
Malik et al. 2014 (26)	R, SB, P, 4.5 pts	Hockey	M, 17.3±1.8	n=24, 500 mg of WS roots ; BD	n=24, 500 mg starch capsules; BD	8 wk, NM	Core muscle strength and stability↑ (IG: 65.7±6.8, PG: 51.5±4.2); p<0.01.
Shenoy et al. 2012 (12)	R, 5 pts	Cyclists	Both, 20.0±2.0	n=20, 500 mg aqueous root capsules, BD	n=20, starch capsules	8 wk, NM	1. VO_2max↑ (IG: 52.0±4.8 ml/min/kg, PG: 44.4±5.7 ml/min/kg); p<0.001, 2. Time for exhaustion on the treadmill↑ (IG: 16.9±1.3 min, PG: 15.6±1.0 min);p<0.001.
Shenoy et al. 2012 (27)	R, 3 pts	Cyclists	Both, 20±2.0	n=20, 500 mg aqueous root capsules, BD	n=20, starch capsules	8 wk, NM	1. Peak power↑ (IG: 297.8±53.5 W, PG: 242.6±32.1 W); p<0.05, 2. Average power↑ (IG: 198.4±33.1 W, PG: 147.5±39.0 W); p<0.05.
Tiwari et al. 2021(11)	R, DB, P, 8 pts	Athletics	Both, 18-45	n=25, 300 mg root extract capsules daily, bd	n=25, starch capsules	8 wk, None	1. VO_2max↑ (IG: 46.8±5.0 ml/min/kg, PG: 42.7±5.5 ml/min/kg); (p=0.007), 2. Exhaustion recovery rate↑ (TQR scores) (IG: 17.1±1.0, PG: 15.2±1.1); p<0.0001, 3. Lack of energy ↑; p<0.0001, 4. Antioxidant level↑ p<0.0001.
Yadav et al. 2014 (13)	R, P, 3 pts	Sprinting	M, 18-25	n=10, For 50-59kg BW-2.5 g of WS; >60kg BW-3.0 g of WS; td alternate days with milk	N=10, None was given	12 wk, None	1. Standing broad jump (m) ↑ (IG; 2.68, CG: 2.07); p<0.05, 2. 50-yard dash↑ (s) (IG: 6.28, CG: 6.67); p<0.05), 3. Pull-ups (/min) ↑ (IG: 9.8, CG: 9.1); p<0.05, 4. Sit-ups (/min) ↑ (IG: 39.3, CG: 40.3); p<0.05, 5. Shuttle run (s) ↑ (IG: 9.67, CG: 9.98); p<0.05, 6. 12- min. run/walk (min) ↑ (IG: 23.2, CG: 24.2); p<0.05.

BD: twice a day, BW: body weight, CG: control group, CO: cross-over, DB: double-blinded, IG: intervention group, MJS: Modified Jadad Score (out of 8), NM: not mentioned, P: parallel, PG: placebo group, QoL: quality of life, R: randomized, SB: single blinded, WS: *Withania somnifera.*

Regarding the significant outcomes of interest, five studies included in this review confirmed that Ashwagandha was more effective than placebo in enhancing VO_2max (7,11,12,24,25). Furthermore, another study involving hockey players, reported that Ashwagandha supplementation was superior to placebo in enhancing core muscle strength and stability (IG: 65.7±6.8, PG: 51.5±4.2; p<0.01) (26). Tiwari et al. (11) presented direct evidence suggesting that Ashwagandha supplementation positively affected stress management capability (IG: 46.8±5.1 ml/min/kg, PG: 42.7±5.5 ml/min/kg) and the level of antioxidants in athletes. Ashwagandha supplementation was determined to be more effective than a placebo in enhancing the anaerobic capacity of elite cyclists, as reported by Shenoy et al. (27). Also, Yadav observed a significant improvement in physical fitness parameters among sprinters following supplementation; p<0.05 (13).

The effect of Ashwagandha on VO_2max was studied in five studies (7,11,12,24,25). Out of the five studies initially considered, one study had to be left out due to inadequate data for meta-analysis, resulting in only four studies being included in the final analysis (7,11,12,25). A random-effects analysis was employed due to elevated I^2 values from the fixed-effects analysis, indicating substantial heterogeneity among studies. Comparing with the placebo, Ashwagandha demonstrated a significant increase in VO_2max value among athletes by 4.09 ml/min/kg (95% CI, 2.55-5.63, p<0.001; I^2=92%, p<0.001) (Fig. 2). Funnel plots revealed symmetrical distribution of studies around the aggregate effect size, suggesting the absence of publication bias (Fig. 3).

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Tiwari et al. 2021	6.6	1.464	25	2.03	1.298	25	25.4%	4.57 [3.80, 5.34]
Shenoy et al. 2012	5.7	1.36	18	-0.2	1.638	19	24.5%	5.90 [4.93, 6.87]
Malik et al. 2013	3.22	1.084	16	1.09	1.158	16	25.4%	2.13 [1.35, 2.91]
Choudhary et al. 2015	5.67	1.686	25	1.85	1.627	24	24.7%	3.82 [2.89, 4.75]
Total (95% CI)			**84**			**84**	**100.0%**	**4.09 [2.55, 5.63]**

Heterogeneity: Tau² = 2.28; Chi² = 39.24, df = 3 (P < 0.00001); I² = 92%
Test for overall effect: Z = 5.20 (P < 0.00001)

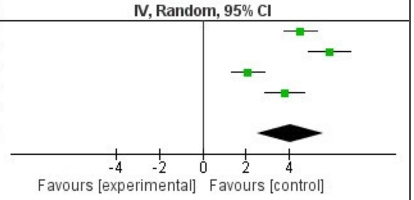

Figure 2. Effect of Ashwagandha supplementation (experimental) on VO_2max

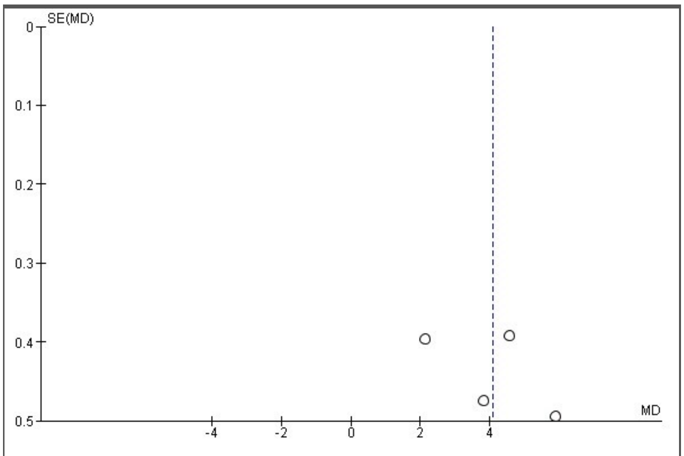

Figure 3. Funnel plot showing the bias of the studies used in the meta-analysis

DISCUSSION

To our knowledge, this is the first systematic review and meta-analysis undertaken to evaluate the impact of Ashwagandha supplementation on sports performance within the sports population. In conclusion, the results of this study demonstrate that Ashwagandha supplementation, at a dosage of 300 to 500 mg of aqueous root extract daily, taken twice a day for a duration ranging from 8 to 12 weeks, is effective in enhancing sports performance compared to the control or placebo group. This includes improvements in VO_2max, core muscle strength and stability, peak and average power, exhaustion recovery rate, and physical fitness variables such as sit-ups, standing broad jumps, pull-ups, and the shuttle run.

Our review shows that Ashwagandha significantly improves VO_2max, with an increase of 4.09 ml/min/kg (95% CI, 2.55-5.63, p<0.001; I^2=92%, p<0.001) comparing to the placebo. This finding is consistent with the results obtained by Bonilla et al. (16) in their systematic review and meta-analysis on the effect of Ashwagandha supplementation on physical performance in healthy individuals. In a separate review and meta-analysis conducted by Didio and research team (18), the overall findings suggest that the supplementation of Ashwagandha appears to elevate VO_2max in adults by 3.45 ml/min/kg (95% CI, 0.30-6.60; I^2=74%; p=0.03), comparing with the control group. These results also align with the findings of a systematic review and meta-analysis by Pérez-Gómez et al. (17), where they demonstrated a significant enhancement in VO_2max in healthy adults and athletes by 3.00 ml/min/kg (95% CI, 0.18-5.82). Hence, it is evident that Ashwagandha increases

VO_2max in athletic populations, similar to non-athletic populations. Hence, it can be considered an ergogenic supplement that enhances VO_2max among athletes.

Beyond VO_2max, our review also revealed significant improvements in other performance parameters. For instance, we noted reductions in basal heart rate and heart rate recovery after exercise (24). Additionally, Ashwagandha supplementation led to improvements in white blood cell counts (24), haemoglobin count (25) and quality of life scores for physical health (23). Other performance parameters such as core muscle strength and stability (26), peak and average power (27), exhaustion recovery rate (6) and various physical fitness tests were also enhanced.

Maximal oxygen uptake, often referred to as VO_2max signifies an athlete's potential to intake, transport, and effectively use oxygen, and stands out as one of the most robust indicators of an athlete's endurance capabilities (17). Having an optimal VO_2max is crucial for athletes, as it increases the oxygen amount that can be used by the muscles. Some sports supplements have demonstrated the ability to enhance VO_2max among athletes. Notably, studies have highlighted the effectiveness of caffeine supplementation in increasing VO_2max among elite athletes, leading to improvements in high-intensity endurance performance (28). Besides, β-alanine was revealed to significantly improve VO_2max while simultaneously reducing lactate concentrations during exercise, thus potentially enhancing exercise performance, especially in endurance athletes (29).

Research indicates that Ashwagandha supplementation leads to a significant rise in haemoglobin levels and red blood cell markers (25). Additionally, Ashwagandha is linked to growth-promoting and anti-anaemic properties (30). The increased concentration of haemoglobin and red blood cell counts may enhance VO_2max by improving the capacity to transport oxygen to muscles (17). Furthermore, Ashwagandha exhibits anti-fatigue and anti-stress properties (31), potentially contributing to a notable improvement in time to exhaustion, and consequently, enhancing endurance capabilities. Certain chemical components in Ashwagandha, including flavonoids, alkaloids, and steroidal lactones (withanolides), along with antioxidants like superoxide dismutase, catalase, and glutathione peroxidase, may play a role in VO_2max improvements (32). Notably, Ashwagandha positively influences energy levels and mitochondrial functions, affecting Mg^{2+} dependent ATPase activity and reducing succinate dehydrogenase enzyme activity in mitochondrial granulation tissue, as demonstrated in an experimental study (33).

Beyond the enhancements in VO_2max, compelling evidence indicates that Ashwagandha supplementation positively influences various variables associated with physical performance. One possible mechanism could be the increase in muscle mass and strength due to improved testosterone levels upon Ashwagandha supplementation. A study reported that Ashwagandha intake was associated with nearly a 15% increase in testosterone in men (34). Another potential explanation for performance improvements is favourable changes in body composition, including increased muscle mass, strength, and reduced adiposity with Ashwagandha supplementation, possibly through elevated testosterone levels (8). A clinical trial revealed that, in comparison to the placebo group, the Ashwagandha-treated group exhibited significantly greater increases in muscle strength, particularly in the arms and chest. Furthermore, there was notable growth in muscle size. While extensive research exists on the effects of Ashwagandha on testosterone levels in men, the scarcity of studies on its impact in women highlights a need for future research to better understand its potential benefits and mechanisms in female athletes.

The Ashwagandha-treated group also demonstrated a substantial reduction in exercise-induced muscle damage, along with the stabilization of serum creatine kinase levels (8). Notably, bioactive molecules in Ashwagandha, such as withanone, play a role in promoting muscle differentiation, suggesting their potential application in muscle repair (35). Additionally, the positive effects of the aqueous root extract of Ashwagandha on physical performance may in part be attributed to the antioxidant properties of the plant, assisting in safeguarding against cellular damage caused by free radicals (16). The maintenance of appropriate physiological levels of reactive oxygen species facilitated by this supplement could be associated with the processes of physiological adaptation during exercise training (36).

Nevertheless, the findings of the current review should be interpreted with caution, considering various factors. Initially, the studies included utilized different Ashwagandha preparations, including aqueous extracts of the root or dry capsules, and were administered at varied doses among a diverse sports population. Additionally, it is established that South Asians generally exhibit a lower mean VO_2max comparing to white Caucasians (37). Consequently, these findings may not be readily generalized to other ethnic groups. Thirdly, none of the studies included elite-level athletes, and the adaptability of Ashwagandha supplementation may differ between semi-elite and international-level athletes. Additionally, although the results are positive, none of the studies were conducted in a 'real-life' competitive setting, making it challenging to ascertain how these results translate into actual sports performance during competitions. Lastly, only 25% (n=2) of studies met the criteria for high-quality RCTs, and this also underscores the need for caution when interpreting the results.

Safety and adverse effects

Although the majority of studies incorporated in this systematic review did not disclose any adverse effects linked to Ashwagandha supplementation, there is evidence suggesting the potential for adverse effects associated with Ashwagandha. A prospective, double-blind, RCT documented by Chandrasekhar et al. (38) reported mild adverse effects linked to Ashwagandha supplementation. The Ashwagandha supplementation group experienced effects such as nasal congestion, constipation, cough and cold, drowsiness, and reduced appetite. Additionally, Ziegenfuss and colleagues (9) also documented adverse effects within the group receiving the Ashwagandha, specifically the occurrence of arthralgia, myalgia, and abdominal pain. A few case studies have reported iatrogenic thyrotoxicosis with serious complications, including supraventricular tachycardia, in individuals who supplemented with Ashwagandha (40, 41). However, the safety of Ashwagandha supplementation has been examined across various dosages. Typically, dosages ranging from 300 to 500 mg of aqueous root extract daily, taken twice a day for durations of 8 to 12 weeks, were well-tolerated. Although adverse effects following supplementation are rare, it is advisable for competitive athletes considering higher doses or prolonged use to seek medical advice before initiating Ashwagandha supplementation. Further research is warranted to establish comprehensive safety profiles and hazard doses for different populations.

Strengths and limitations

The current review and meta-analysis have several notable strengths. Initially, an extensive search was carried out, covering major health-related databases such as SciVerse Scopus®, PubMed®, Web of Science®, Medline, Embase, SPORTDiscus, and AYUSH. Additionally, sport-specific databases were included to ensure thorough coverage. Thirdly, the largest research database for Ayurvedic medicine was thoroughly searched. Moreover, additional manuscripts were identified through reference lists. Furthermore, searches were performed using both MESH terms and title/abstract level search criteria to identify all potentially relevant articles in PubMed and Medline.

The generalizability of these results is subject to certain limitations. One of them is the limited number of studies available on this topic and the significant heterogeneity in study populations and sports variables measured. Different studies have assessed various parameters, and no similar outcomes were reported, restricting our meta-analysis to only VO_2max. Variations in Ashwagandha preparations and doses among the studies, the lower mean VO_2max in South Asians compared with other ethnic groups, and the absence of elite athletes in the included studies may affect the generalizability of the results. Additionally, the lack of studies conducted in competitive settings limits our understanding of Ashwagandha's impact on real-world sports performance. Furthermore, another limitation of the study concerns our emphasis on studies conducted in the English language. Finally, the quality of included RCTs was varied, with only 25% meeting high-quality criteria, emphasizing the need for further research. Nevertheless, Ashwagandha is a traditional medicine in India, and all included studies originate from India, where English is widely used. Therefore, the likelihood of missing high-quality studies is minimal.

Practical recommendations

Considering the benefits of Ashwagandha for athletes, several practical recommendations can be suggested. It's essential for sportspersons to determine the best dosage suited to their specific needs, considering the herb's varied therapeutic responses. Synchronizing supplementation with rigorous training can potentially amplify physical performance and recovery benefits. Further, it is important to be aware of any interactions, especially those that can influence hormone levels, given the variety of supplements that athletes frequently use. Combining Ashwagandha with a nutritious diet can increase its beneficial effects. Athletes are typically advised to speak with sports nutritionists/dietitian or a medical professional, to make sure the supplement supports their unique physiological needs and athletic goals.

Nevertheless, it is important to conduct studies aimed at investigating the impact of various preparations and dosage regimens of Ashwagandha supplementation across diverse populations. To obtain a more robust estimation of the genuine underlying effect of Ashwagandha, there is a need for high-quality studies with larger sample sizes that are followed up for an extended period.

To conclude, results of this systematic review and meta-analysis confirm that Ashwagandha supplementation is efficacious in improving sports performance, including enhancements in cardiorespiratory fitness, muscle strength, recovery, and various physical fitness parameters. The primary finding of the meta-analysis indicates that Ashwagandha significantly increased VO_2max in athletes by 4.09 ml/min/kg. Although no negative effects were documented, it is recommended to utilize Ashwagandha supplements under healthcare professional guidance.

Conflict of Interest / Çıkar Çatışması

The authors confirm the absence of any financial or personal relationships that could potentially impact the integrity of the work presented in this paper.

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Author Contributions / Yazar Katkıları

RJ: conceptualization, methodology; PS: software, data curation; KW: writing original draft preparation; RJ: supervision; PS, RJ: validation; KW, PS, RJ: writing, reviewing and editing. All authors contributed to the final version of the manuscript and discussed the results and contributed to the final manuscript.

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Supplementary Table. Modified Jadad scores of the included studies

Author, Year	Described as randomized	Appropriate randomization	Described as blind	Appropriate blinding	Withdrawals & drop-outs represented	Incl/excl criteria represented	Adverse effects described	Statistical approach described	Total score
Ahuja et al. 2002(24)	1	0	0	0	1	1	0	1	4
Choudhary et al. 2015 (7)	1	1	1	1	1	1	0	1	7
Malik et al. 2013 (25)	1	1	0.5	1	0	0	0	1	4.5
Malik et al. 2014 (26)	1	1	0.5	1	0	0	0	1	4.5
Shenoy et al. 2012 (12)	1	1	0	0	1	1	0	1	5
Shenoy et al. 2012 (27)	1	-1	0	0	1	1	0	1	3
Tiwari et al. 2021(11)	1	1	1	1	1	1	1	1	8
Yadav et al. 2014 (13)	1	0	0	0	0	1	0	1	3