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The Role of Ashwagandha in Exercise Performance and Recovery: An Evidence-Based Review

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ABSTRACT

Background: Withania somnifera (Ashwagandha) is a well-known adaptogenic herb with a growing body of evidence supporting its role in enhancing physical performance. This review aims to evaluate the effects of Ashwagandha supplementation on key aspects of exercise capacity, including aerobic performance, muscle strength, and post-exercise recovery.

Material and methods: A literature review was conducted using databases such as PubMed and Google Scholar, including studies from 2012 to 2025 that examined the effects of Ashwagandha supplementation in physically active individuals.

Results: Most randomized controlled trials report that daily supplementation with Ashwagandha (500–1250 mg) over 8–12 weeks leads to significant improvements in VO_2max, muscular strength, and time to exhaustion. Additional benefits include reduced cortisol levels, improved recovery rates, and decreased markers of muscle damage and inflammation. Positive effects were observed in both trained and untrained individuals.
Conclusions: Ashwagandha supplementation appears to support various aspects of physical performance and recovery, offering practical value for both amateur and professional athletes. However, limitations such as small sample sizes and variability in study design highlight the need for further research to confirm these findings and better understand the underlying mechanisms.

Keywords: Ashwagandha, Withania somnifera, physical performance, endurance, strength, recovery, supplementation, adaptogen

INTRODUCTION

Ashwagandha (*Withania somnifera*), commonly referred to as Indian ginseng, is a medicinal plant widely used in Ayurvedic medicine for over 3,000 years due to its adaptogenic properties - enhancing the body's resilience to physical and psychological stress (1,2). The primary bioactive components in ashwagandha, particularly withanolides and saponins, are responsible for its pharmacological effects, including modulation of the hypothalamic–pituitary–adrenal (HPA) axis, support of reproductive health, and neuroprotective activity (3).

Ashwagandha has long been regarded in Ayurvedic medicine as a *Rasayana* - a rejuvenating tonic believed to promote longevity, vitality, and resistance to disease. Traditionally, powdered root or decoctions were used to combat fatigue, enhance fertility, and support the nervous system (1).

In modern formulations, standardized extracts such as KSM-66 and Sensoril have gained popularity due to their high withanolide content and clinical validation (4–9). These products are widely used for stress reduction, hormonal balance, sleep improvement, and enhanced athletic recovery. They are available as capsules, powders, or tinctures, often as part of pre-workout or adaptogen blends.

In the last decade, ashwagandha has received increased scientific attention for its potential to enhance exercise performance and recovery. Early trials demonstrated its ability to improve strength, body composition, and testosterone levels. For instance, Wankhede et al. found that eight weeks of supplementation with 600 mg/day of ashwagandha root extract significantly improved muscle strength and recovery in young men undergoing resistance training (10). Similarly, Ziegenfuss et al. reported improved upper and lower body strength, greater increases in muscle mass, and enhanced recovery markers in resistance-trained men following a 12-week supplementation period (11).

More recent studies have expanded on these findings by evaluating athletic and physically active populations. A systematic review and Bayesian meta-analysis by Bonilla et al. concluded that Ashwagandha supplementation produces significant improvements in VO_2max, muscular strength, and fatigue, with a high probability of clinically meaningful effects (12). These benefits are attributed to ashwagandha's potential to reduce cortisol, enhance mitochondrial function, and regulate inflammation.

Additional RCTs support these outcomes. For example, a 2024 double-blind, placebo-controlled trial found that supplementation with 600 mg/day of standardized ashwagandha root extract for eight weeks led to significant improvements in strength (bench press and leg extension), VO_2max, and muscular size in healthy adults undergoing structured training, without adverse events (13).

Studies among elite athletes are more limited but promising. Shenoy et al. observed increased cardiorespiratory endurance and reduced markers of oxidative stress in elite cyclists following an eight-week ashwagandha regimen (14). Długołęcka et al. also noted enhanced physical performance in wrestlers, suggesting potential applications in weight-class sports where physical strain and metabolic stress are high (6).

Despite the generally good safety profile of Ashwagandha - recognized as GRAS (Generally Recognized As Safe) by the U.S. FDA - there are growing concerns about rare cases of herb-induced liver injury, particularly with long-term use or poorly standardized supplements (15–18). Therefore, the safety and standardization of extracts remain crucial, especially among athletic populations using high-dose regimens.

Nevertheless, current literature lacks large-scale trials involving elite athletic populations, standardized dosing protocols, and robust long-term safety data. These limitations underscore the need for further research to elucidate ashwagandha's mechanisms of action and its practical relevance in athletic contexts. This review aims to synthesize and critically evaluate the existing scientific evidence on ashwagandha supplementation for enhancing exercise performance and recovery, with a particular emphasis on physiological mechanisms and safety considerations in both recreational and competitive athletes.

CHAPTER 1: Pharmacological And Physiological Mechanisms Of Ashwagandha (*Withania Somnifera*)

1) Active Compounds and Mechanisms of Action

Ashwagandha (*Withania somnifera*) is a medicinal plant renowned for its diverse pharmacological properties. The bioactive compounds most prominently include withanolides - steroidal lactones with a core ergostane structure - such as withaferin A, withanolides A–Y, withanone, and sitoindosides IX and X, which contribute to Ashwagandha's anticancer, anti-inflammatory, and antioxidant effects (19,20). Additionally, alkaloids like withanine, somniferine, tropine, and pseudotropine play important roles in neuroendocrine regulation and modulation of the stress response (20).

Ashwagandha influences various signaling pathways, including NF-κB, Nrf2/HO-1, JAK-STAT, MAPK, and NLRP3, which are implicated in inflammation and oxidative stress (19,20). Its antioxidant properties stem from the activation of endogenous enzymes such as catalase and superoxide dismutase, enhancing cellular resilience (20). Of particular interest is withaferin A, which exhibits pro-apoptotic effects through activation of the JNK pathway. This cascade upregulates pro-apoptotic proteins (e.g., Bad, Bim, Bax) while downregulating anti-apoptotic markers (e.g., Bcl-2, Bcl-XL), ultimately inducing mitochondrial-mediated apoptosis in cancer cells, including T-cell acute lymphoblastic leukemia lines (19,21).

2) Effects on Stress, Inflammation, and Hormonal Balance

Stress and the HPA Axis

The hypothalamic – pituitary - adrenal (HPA) axis is a central component of the physiological stress response. Under chronic stress, sustained activation of this axis leads to elevated levels of cortisol and DHEA-S, which are associated with metabolic, psychiatric, and inflammatory disorders. Ashwagandha has demonstrated the ability to regulate the HPA axis by reducing cortisol and DHEA-S secretion in both animal and human studies (22–24). For instance, 60-day supplementation with Ashwagandha significantly lowered morning cortisol and DHEA-S levels in stressed yet otherwise healthy adults (23). In a randomized controlled trial, cortisol levels dropped by 23% in the Ashwagandha group compared to 0.5% in the placebo group (23). These effects are likely mediated by alkaloids that improve neurotransmitter balance, contributing to reduced anxiety, enhanced memory, and protection against stress-induced ulcers .

Anti-Inflammatory and Antioxidant Effects

Chronic inflammation underlies many non-communicable diseases, including cardiovascular, neurodegenerative, and autoimmune disorders. This state, often termed "inflammaging," is characterized by persistent low-grade immune activation (20). Ashwagandha suppresses pro-inflammatory cytokines such as TNF-α, IL-4, IL-13, and IgE, thus reducing allergic responses (e.g., asthma, dermatitis) and systemic inflammation (20,21). It acts by inhibiting NF-κB signaling and downregulating CCL2 and CCL5 gene expression in immune cells (21). The herb's antioxidant activity involves scavenging free radicals and enhancing the body's endogenous antioxidant defense mechanisms. This reduces oxidative damage and supports homeostasis at the cellular level (20).

Immunomodulatory Effects

Ashwagandha modulates both innate and adaptive immune responses. It enhances natural killer (NK) cell activity and promotes the proliferation of CD3+ T cells and CD19+ B cells (21,25). It also shifts the T-helper cell balance toward a Th1 phenotype by increasing IL-2 and IFN-γ production while suppressing IL-4 expression (21). In hepatitis C-infected lymphocytes, Ashwagandha significantly reduced TNF-α levels, suggesting both antiviral and anti-inflammatory effects (21). Moreover, the herb stimulates NK cell degranulation, promoting the release of perforin and granzyme - key elements in cytotoxic immunity (21).

3) Anti-Cancer Activity

Ashwagandha and its bioactive compounds have shown potential in cancer therapy, especially in hematologic malignancies such as T-cell acute lymphoblastic leukemia (T-ALL) (19,21). These effects include induction of apoptosis, cell cycle arrest, and immunogenic cell death. Withaferin A is a major compound responsible for these actions. It promotes mitochondrial-mediated apoptosis via JNK phosphorylation, ROS generation, calcium accumulation, and upregulation of pro-apoptotic proteins while inhibiting survival pathways such as NF-κB (19,24). These mechanisms position Ashwagandha as a candidate for adjunctive therapy in oncology, though further clinical validation is needed.

4) Safety and Recommended Dosage

Ashwagandha is considered safe when used at recommended dosages. Animal studies show high tolerability; for example, hydroalcoholic root extracts administered at doses up to 2000 mg/kg/day in Wistar rats produced no adverse effects (26). Aqueous extracts also demonstrated safety at doses up to 3000 mg/kg/day, although intraperitoneal administration exceeding 1100 mg/kg in mice resulted in mortality, indicating a route- and dose-dependent toxicity threshold [7].

Human clinical trials generally support the safety of daily supplementation with standardized Ashwagandha extract in the range of 250–600 mg for 4 to 12 weeks (7,22–24). Benefits include reductions in stress, improved cognitive and hormonal function, and enhanced well-being. For example, an 8-week study using 600 mg/day reported significant cortisol reductions and better stress adaptation (23).

An analysis of 77 registered clinical trials revealed a consistent design: randomized, double-blind, placebo-controlled, interventional studies - often conducted at single centers with Phase 2 registration. Most trials were conducted in India, particularly in Maharashtra, and commonly employed solid dosage forms such as tablets or capsules. In 10 trials focused on arthritis, a dosage of 6 grams of Ashwagandha powder or 500–1000 mg of extract in capsules/tablets taken for 8–12 weeks showed potential in managing symptoms effectively (27).

CHAPTER 2: Ashwagandha And Physical Performance: Impact On Strength, Endurance, And Aerobic Capacity; Differences Across Training Types And Populations

1) Effects of Ashwagandha on Muscle Strength

Muscle strength, often defined as the maximal force a muscle or muscle group can generate, is a critical component of physical fitness and athletic performance. Several clinical trials have investigated the effects of Ashwagandha supplementation, often in conjunction with resistance training programs, on various measures of muscle strength and power.

One key measure is the one-repetition maximum (1-RM), representing the maximal weight an individual can lift for a single repetition of a specific exercise (10,11). Wankhede et al. conducted an 8-week, randomized, prospective, double-blind, placebo-controlled trial involving 57 young men (18-50 years old) with little experience in resistance training (10). Participants received either 300 mg of Ashwagandha root extract (KSM-66, standardized to 5% withanolides) twice daily (total 600 mg/day) or a starch placebo while following a structured resistance training program (10). Following the 8-week intervention, the group treated with Ashwagandha demonstrated significantly greater increases in muscle strength compared to the placebo group. Specifically, the increase in 1-RM for the bench-press exercise was substantially higher in the Ashwagandha group (Mean change: 46.0 kg, 95% CI: 36.6, 55.5) compared to the placebo group (Mean change: 26.4 kg, 95% CI: 19.5, 33.3; p=0.001). Similarly, for the leg-extension exercise, the Ashwagandha group showed a significantly greater increase in 1-RM (Mean change: 14.5 kg, 95% CI: 10.8, 18.2) versus the placebo group (Mean change: 9.8 kg, 95% CI: 7.2, 12.3; p=0.04) (10). These findings strongly suggest that Ashwagandha root extract supplementation enhances strength adaptations resulting from resistance training, particularly in individuals new to such training.

Further supporting these findings, Ziegenfuss et al. examined the impact of a standardized aqueous extract of Ashwagandha roots and leaves (Sensoril®, ≥10% withanolides, ≤0.5% withaferin A) in 38 recreationally active men (mean age 26.5 years) over a 12-week period involving a progressive overload resistance-training program (11). Participants were randomized to receive either 500 mg/day of Sensoril® or a placebo (11). The results indicated that gains in 1-RM squat strength were significantly greater in the Sensoril® group (Mean change: +19.1 ± 13.0 kg) compared to the placebo group (Mean change: +10.0 ± 6.2 kg; p=0.009). Likewise, improvements in 1-RM bench press strength were also significantly greater in the Sensoril® group (Mean change: +12.8 ± 8.2 kg) versus the placebo group (Mean change: +8.0 ± 6.0 kg; p=0.048) (11). This study extends the positive findings on 1-RM improvements to a population with some prior training experience and utilizes a different type of Ashwagandha extract (root and leaf).

Verma et al. conducted another 8-week, randomized, double-blind, placebo-controlled study, this time including 80 healthy, active male and female participants (aged 18-45 years) who were engaged in regular physical activity and underwent resistance training during the study (13). The treatment group received 300 mg of standardized Ashwagandha root extract (>5% withanolides, KSM-66) twice daily (600 mg/day), while the control group received an identical placebo (13). The results demonstrated that Ashwagandha supplementation led to significantly greater improvements in 1-RM bench press compared to placebo in both males (p=0.0084) and females (p=0.0005). Similarly, improvements in 1-RM leg press were significantly greater in the Ashwagandha group for both males (p=0.0049) and females (p=0.018) compared to the placebo group (13). This study is crucial as it provides evidence for the strength-enhancing benefits of Ashwagandha in both men and women participating in resistance training.

Beyond maximal strength (1-RM), other studies have examined Ashwagandha's effect on different aspects of strength, such as grip strength and muscle power. Raut et al., in an open-label exploratory study without a concurrent resistance training program, administered increasing doses (750 mg/day, 1000 mg/day, 1250 mg/day, each for 10 days sequentially) of an aqueous root extract to 18 healthy volunteers (28). They observed statistically significant improvements from baseline in hand grip strength (from 34.46 ± 9.96 kg to 37.23 ± 11.66 kg by day 30), quadriceps force (from 28.02 ± 8.23 to 34.05 ± 10.80 by day 30), and back extensor force (from 26.00 ± 8.83 to 30.02 ± 8.10 by day 30) (28). This suggests that Ashwagandha might possess inherent strength-promoting properties, potentially dose-dependent, even in the absence of a structured resistance training stimulus.

Tripathi et al. also assessed hand grip strength using a Jammer's hand-held dynamometer in healthy male volunteers receiving either placebo, 330 mg/day, or 500 mg/day of Ashwagandha aqueous extract for 28 days (29). Both Ashwagandha groups showed significant increases in hand grip strength compared to their baseline values by day 28 (330 mg group: from 42.82 ± 5.86 kg to 44.94 ± 5.70 kg, P=0.0002; 500 mg group: from 39.41 ± 5.84 kg to 41.36 ± 4.71 kg, P<0.0001). However, when compared to the placebo group at day 28, these increases were not statistically significant, although the authors noted an increasing trend in the magnitude of grip strength in both Ashwagandha groups which was absent in the placebo group (29).

Muscle power, the ability to exert force rapidly, was assessed by Ziegenfuss et al. using a TENDO power analyzer during bench press (at 65% of 1-RM) and bodyweight jump squats (11). While no significant group × time interaction effects (i.e., between-group differences in change over time) were found for power variables, the study reported that only the Ashwagandha (S500) group experienced statistically significant within-group improvements (compared to baseline) in average squat power (+4.6%, p=0.007) and peak bench press power (+11.4%, p=0.007) (11). This suggests a potential benefit for power development that warrants further investigation with studies specifically designed and powered to detect changes in muscular power. Sandhu et al., in an 8-week study comparing Ashwagandha (500 mg/day), Terminalia arjuna (500 mg/day), their combination, and placebo in healthy young adults, reported significant within-group increases in velocity, average absolute power, and average relative power only in the Ashwagandha group compared to baseline, although direct between-group statistical comparisons were not explicitly detailed for these power metrics in the provided text (30).

Muscle size or hypertrophy is another common adaptation to resistance training. Wankhede et al. measured muscle size using circumference measurements at the arm, chest, and upper thigh (10). They found that the increases in muscle size were significantly greater in the Ashwagandha group compared to the placebo group for the arms (Mean change: 8.6 cm2 vs. 5.3 cm2; p=0.01) and chest (Mean change: 3.3 cm vs. 1.4 cm; p<0.001). However, the difference in thigh muscle size increase was not statistically significant between the groups (Mean change: 8.71 cm2 vs. 6.22 cm2; p=0.36) (10). Verma et al. also assessed muscle girth and found significantly greater improvements in the Ashwagandha group compared to placebo for arm circumference (total participants: p=0.014) and chest circumference (total participants: p=0.002). Thigh circumference improvement was significantly greater only in female participants in the Ashwagandha group compared to placebo (p=0.009) (13). Ziegenfuss et al., using DEXA, did not find significant between-group differences in lean mass or fat mass changes, although they did observe a significant difference favoring the Ashwagandha group in the change in android/gynoid ratio (p=0.03), suggesting a potentially more favorable body fat distribution (11).

Collectively, these studies provide compelling evidence that Ashwagandha supplementation, particularly using root extracts (like KSM-66) or root and leaf extracts (like Sensoril®) at doses ranging from 500-1250 mg per day, significantly enhances muscle strength gains when combined with resistance training programs lasting 8-12 weeks (11,13,30). This effect appears consistent in both untrained and recreationally active individuals, and has been demonstrated in both males and females (11,13,30). Evidence also suggests benefits for increasing muscle size/girth, particularly in the upper body (10,13). The effects on muscle power show potential but require more dedicated research (11,13).

2) Effects on Endurance and Aerobic Capacity

Cardiorespiratory endurance, the ability of the circulatory and respiratory systems to supply fuel during sustained physical activity, is fundamental to overall health and athletic performance, particularly in endurance sports. Maximal oxygen consumption (VO2max), the maximum rate at which oxygen can be taken up and utilized by the body during intense exercise, is the gold standard measure of aerobic capacity (8,13,31,32). Several studies have explored the impact of Ashwagandha supplementation on VO2max and other endurance-related parameters.

Choudhary et al. conducted a 12-week, randomized, double-blind, placebo-controlled study involving 50 healthy athletic adults (males and females, aged 20-45) (8). Participants received either 300 mg of KSM-66 Ashwagandha root extract twice daily (total 600 mg/day) or identical placebo capsules containing sucrose (8). Cardiorespiratory endurance was assessed by estimating VO2max using the 20-meter shuttle run test, a reliable field test for this purpose (32). The study found a significantly greater increase ($P<0.0001$) in mean VO2max from baseline in the Ashwagandha group compared to the placebo group at both the 8-week mark (Ashwagandha: +4.91 mL/kg/min vs. Placebo: +1.42 mL/kg/min) and the 12-week mark (Ashwagandha: +5.67 mL/kg/min vs. Placebo: +1.86 mL/kg/min) (33). This provides strong evidence for enhanced cardiorespiratory endurance in an athletic population using this specific root extract.

Shenoy et al. studied 40 elite Indian cyclists (male and female, aged 18-27) over an 8-week period (14). They were randomly assigned to receive either 500 mg capsules of aqueous Ashwagandha root extract twice daily (total 1000 mg/day) or placebo starch capsules, while continuing their regular training (14). VO2max was measured using a graded exercise test (GXT) on a treadmill (Bruce protocol) with metabolic gas analysis (14). The results showed a statistically significant improvement (13% increase) in VO2max from baseline in the Ashwagandha group (from a mean of 46.2 mL/kg/min to 52.0 mL/kg/min; $P<0.001$), whereas the placebo group showed no significant change (mean 44.6 mL/kg/min to 44.4 mL/kg/min) (14). The Ashwagandha group also demonstrated significant improvements in time to exhaustion (TTE) during the GXT (from 15.79 min to 16.93 min; +7.2%, $P<0.001$) and metabolic equivalents (METs) (from 13.2 to 14.8; $P<0.001$) compared to baseline, changes not observed in the placebo group (14). This study highlights Ashwagandha's potential benefits specifically in highly trained endurance athletes, a population where achieving further gains is often challenging.

Malik et al. investigated the effects of Ashwagandha root powder supplementation (500 mg/day) for 8 weeks in 32 young male hockey players (aged 16-19) (31). VO2max was assessed using Cooper's 12-minute run test (31). The group receiving Ashwagandha showed a significant improvement in estimated VO2max (+6.67%) compared to the placebo group. Notably, this study also found a significant increase in hemoglobin levels (+5.14%) in the Ashwagandha group (31). This finding suggests that enhanced oxygen-carrying capacity of the blood might be one mechanism contributing to the observed improvements in aerobic capacity (31).

Tripathi et al. evaluated physical performance in healthy adult male volunteers (aged 18-45) using several tests, including the YMCA cycle ergometer submaximal test to estimate VO2max (29). Participants received placebo, 330 mg/day, or 500 mg/day of Ashwagandha aqueous extract for 28 days (29). Both Ashwagandha groups demonstrated significant increases in estimated VO2max compared to their baseline values by day 28 (330 mg group: +5.40%; 500 mg group: +6.09%; both $P<0.0001$) (29). Although a direct comparison to the placebo group at day 28 did not reveal a statistically significant difference for VO2max itself, an increasing trend was observed in the Ashwagandha groups that was absent in the placebo group (29). Furthermore, in a 6-minute cycle ergometer test (fixed resistance, maximal effort), both Ashwagandha groups showed significant increases from baseline in mean distance traveled (+15.7% for 330 mg, +15.9% for 500 mg) and mean average speed (+15.9% for 330 mg, +16.2% for 500 mg). Crucially, these increases were significantly greater than those seen in the placebo group on day 28 ($P<0.005$ for distance, $P<0.05$ for speed) (29). This indicates improved short-term aerobic performance and work capacity under physical stress.

Verma et al. also assessed cardiorespiratory endurance via VO2max estimation using the Bruce protocol treadmill test in their 8-week study on active adults (males and females, 18-45 years) receiving 600 mg/day Ashwagandha root extract (KSM-66) or placebo alongside resistance training (13). They reported significantly greater improvements in estimated VO2max in the Ashwagandha group compared to the placebo group for both males (Mean change: +3.6 vs. +1.4 ml/kg/min; $p<0.0001$) and females (Mean change: +2.0 vs. +1.0 ml/kg/min; $p<0.0001$) (13). This demonstrates that the aerobic benefits can occur even when the primary training focus is resistance exercise.

Ziegenfuss et al., in their 12-week resistance training study on recreationally active men, included a 7.5 km cycling time trial as an endurance measure (11). While the between-group difference in improvement was not statistically significant ($p=0.48$), only the Ashwagandha group (Sensoril® 500 mg/day) experienced a statistically significant within-group improvement in performance time (-21% faster, $p<0.001$) compared to baseline (11). This hints at a potential benefit in longer aerobic endurance performance, although more targeted studies are warranted.

Bargale et al. utilized the Harvard Step Test, a submaximal test used to estimate cardiovascular fitness, in healthy subjects (males and females, 18-40 years) (34). Participants received a relatively high dose of Ashwagandha powder (12 grams/day) mixed with milk, or milk alone (control), for 60 days (34). The results showed a statistically significant improvement in the Harvard Step Test Fitness Index score in the Ashwagandha group compared to the control group both immediately after the 60-day intervention ($p=0.003$) and at the 90-day follow-up ($p=0.030$) (34).

Systematic reviews and meta-analyses further consolidate these findings. Pérez-Gómez et al. (2020), analyzing five RCTs (four in meta-analysis), concluded that Ashwagandha supplementation significantly enhanced VO2max in both healthy adults and athletes (Mean Difference = 3.00 mL/kg/min, 95% CI [0.18, 5.82], $p=0.04$) (32). They observed high heterogeneity, potentially related to dose variations, and suggested higher doses might yield greater improvements (32). Bonilla et al. (2021), in a Bayesian meta-analysis including seven studies, also found a large pooled treatment effect favoring Ashwagandha for cardiorespiratory fitness variables (VO2max and hemoglobin concentration) (12).

In summary, the available evidence strongly suggests that Ashwagandha supplementation, typically with root extracts at doses between 600 mg and 1250 mg per day for 8 to 12 weeks, can significantly improve cardiorespiratory endurance. This is demonstrated by consistent increases in VO2max across various populations (athletes, active adults) and assessment methods (shuttle run, treadmill GXT, Cooper's test), as well as improvements in related performance metrics like time to exhaustion and performance in timed tests (13,14,29,31–34).

3) Variations Across Training Types

The ergogenic effects of Ashwagandha may manifest differently depending on the type of physical training undertaken concurrently with supplementation. The reviewed studies encompassed diverse training contexts, allowing for an exploration of these potential variations.

3.1) Resistance Training Focus:

Several studies specifically paired Ashwagandha supplementation with structured resistance training programs, primarily evaluating strength and hypertrophy adaptations (10,11,13).

- In these contexts (Wankhede et al., Ziegenfuss et al., Verma et al.), Ashwagandha consistently demonstrated significant enhancements in maximal strength (1-RM bench press, leg extension/press) compared to placebo (10,11,13).
- Improvements in muscle size/girth (arm, chest) were also frequently reported as being significantly greater with Ashwagandha supplementation during resistance training (10,13).
- Interestingly, Verma et al. (13) found that even within a resistance training protocol, Ashwagandha supplementation significantly improved estimated VO2max compared to placebo, suggesting aerobic benefits can occur alongside strength training. Ziegenfuss et al. (11) also noted within-group improvements in cycling time trial performance only in the Ashwagandha group.
- Enhanced recovery, evidenced by lower creatine kinase levels (10) and improved perceived recovery scores (11), was also noted in resistance training studies, which could facilitate better training quality and adaptation.

3.2) Endurance Training Focus:

Studies involving populations primarily engaged in endurance sports highlighted benefits related to aerobic capacity and endurance performance (14,31,33).

- Shenoy et al. (14) showed significant VO2max and time-to-exhaustion improvements in elite cyclists supplementing with Ashwagandha while maintaining their cycling training.
- Malik et al. (31) observed enhanced VO2max (via Cooper's test) and hemoglobin levels in hockey players, a sport demanding high levels of both aerobic and anaerobic endurance.
- Choudhary et al. (33) found improved VO2max (via shuttle run test) in generally athletic adults, indicating broad applicability for aerobic fitness enhancement.

3.3) Mixed or Non-Specific Training/Activity:

Some studies did not involve a specific concurrent training program but used various physical stress tests or included generally active individuals (28–30,34).

- Tripathi et al. (29) subjected healthy volunteers to acute physical stressors (cycle ergometer tests, dynamometry). Ashwagandha improved performance metrics like distance covered, speed, hand grip strength, and estimated VO2max compared to baseline, with some measures significantly better than placebo, indicating enhanced performance under acute stress.
- Raut et al. (28) demonstrated strength improvements (handgrip, quadriceps, back extensors) with Ashwagandha alone, suggesting potential benefits independent of a specific training stimulus.
- Bargale et al. (34) found improved Harvard Step Test scores in healthy subjects without mentioning a concurrent training program, indicating enhanced general cardiorespiratory fitness.
- Sandhu et al. (30) reported within-group improvements in power and VO2max in healthy young adults, though the training status/activity level during the study wasn't specified.

3.4) Synthesis and Interpretation:

Ashwagandha appears to exert beneficial effects relevant to both resistance and endurance training. When combined with resistance training, the primary benefits observed are enhanced gains in muscle strength and size, along with potentially improved recovery (10,11,13).When used by endurance athletes or in studies focusing on aerobic parameters, Ashwagandha consistently improves VO2max and related endurance metrics (30,31,33). Studies involving general physical activity or acute stress tests also show performance improvements (28,29,34). This suggests that Ashwagandha does not exclusively benefit one type of training over the other but rather possesses properties that can support adaptations across the performance spectrum.

4) Variations Across Populations

The effectiveness of Ashwagandha supplementation can also be influenced by the characteristics of the individuals involved, including their initial training status, age, and gender.

4.1) Training Status (Athletes vs. Amateurs/Untrained):

- **Elite/Trained Athletes:** Studies involving elite cyclists (14) and hockey players (31) demonstrated significant improvements in VO2max and related endurance parameters. Choudhary et al. (33) also found enhanced VO2max in "healthy athletic adults." This is significant because eliciting further improvements in highly trained individuals is typically more challenging than in novices (14). Ashwagandha appears capable of providing an ergogenic edge even at high levels of fitness, particularly for cardiorespiratory endurance.
- **Recreationally Active / Resistance-Trained Adults:** Individuals with some training experience but not at an elite level also show clear benefits. Ziegenfuss et al. (11) observed greater strength gains in recreationally active men undergoing resistance training. Verma et al. (13) found strength, girth, and VO2max improvements in active adults performing resistance training. This suggests Ashwagandha is effective for enhancing adaptations in regular exercisers.

- **Untrained / Healthy Volunteers / Sedentary:** Studies involving participants with little or no prior training experience often show robust responses. Wankhede et al. (10) documented significant strength and muscle size gains in untrained men starting a resistance program. Raut et al. (28) found strength improvements in healthy volunteers without specific training. Tripathi et al. (29) and Bargale et al. (34) observed enhanced performance in physical tests in healthy volunteers/subjects. Untrained individuals generally have more room for improvement, and Ashwagandha appears to effectively augment these initial adaptations to exercise or physical stress (10).

4.2) Age:

The vast majority of performance-focused studies included in this review recruited young to middle-aged adults, typically within the 18-50 year age range (10,11,13,29,30,30,31,33,34).

- Malik et al. (31) specifically studied adolescents/young adults (16-19 years).
- Wankhede et al. (10) included participants up to 50 years old.
- Studies focusing primarily on stress, vitality, or sleep have included older populations. Lopresti et al. (4) studied overweight men aged 40-70, noting trends towards increased testosterone. Kelgane et al. (35) studied individuals aged 65-80 for well-being and sleep. While direct evidence on physical performance enhancement in older adults (e.g., >60 years) is limited within these specific documents, the established benefits in younger and middle-aged adults, coupled with its traditional use as a rejuvenator ("Rasayana") and potential effects on strength and hormonal balance, suggest Ashwagandha could be a valuable supplement for maintaining physical function and counteracting age-related decline (sarcopenia) (10,11,13,14,28–31,33–35). This remains an important area for future research.

4.3) Gender:

Several studies explicitly included both male and female participants, allowing for some gender-based comparisons.

- Verma et al. (13) provided the clearest comparison, finding significant benefits over placebo for both males and females in 1-RM bench press, 1-RM leg press, and VO2max. While baseline strength values were higher in males, the *improvement* due to Ashwagandha was significant in both sexes. They did note a significant improvement in thigh girth only in females compared to placebo.
- Shenoy et al. (14) included elite male and female cyclists. Although the overall Ashwagandha group improved significantly, subgroup analysis suggested a greater *magnitude* of improvement in VO2max (+16.1% vs. +9.0%) and time to exhaustion (+10.7% vs. +4.3%) in males compared to females. The authors speculated this might be due to differential effects on the endocrine system, potentially related to testosterone.
- Choudhary et al. (33), Sandhu et al. (30), and Bargale et al. (34) included both genders but reported combined group results or did not perform specific gender subgroup analyses for performance outcomes in the provided texts.
- The meta-analyses by Pérez-Gómez et al. (32) and Bonilla et al. (12) concluded that Ashwagandha was effective in improving performance variables (VO2max in Pérez-Gómez; broader performance in Bonilla) in studies including both men and women.

5) Summary Table

Study Authors & Year	Population Type	Training Type / Activity	Main Effects of Ashwagandha Supplementation
Sandhu et al., 2010 (30)	Healthy young adults (M&F)	General physical performance tests	Within-group increase in velocity, power, VO2max* (*note: reported VO2max values very low)
Raut et al., 2012 (28)	Healthy volunteers (M&F)	None (strength assessed)	Increased handgrip strength, quadriceps force, back extensor force (significant vs baseline).
Shenoy et al., 2012 (14)	Elite Indian cyclists (M&F)	Endurance (cycling)	Increased VO2max, time to exhaustion, METs (significant vs baseline, not seen in placebo). Greater effect magnitude noted in males vs females.
Malik et al., 2013 (31)	Young male hockey players (16-19 yrs)	Endurance/Mixed (hockey)	Increased VO2max (Cooper's test), increased hemoglobin (significant vs placebo).
Choudhary et al., 2015 (33)	Healthy athletic adults (M&F, 20-45 yrs)	Assessed via 20m shuttle run test	Increased VO2max (significant vs placebo). Improved Quality of Life scores.
Wankhede et al., 2015 (10)	Young males (18-50 yrs, untrained in resistance)	Resistance Training	Increased 1-RM bench press & leg extension, increased muscle size (arm,

			chest), increased testosterone, decreased exercise-induced muscle damage (CK) (significant vs placebo).
Tripathi et al., 2016 (29)	Healthy male volunteers (18-45 yrs)	Physical stress tests (cycle ergometer, dynamometer)	Increased distance & speed (6-min cycle), handgrip strength, VO2max (YMCA test) (significant vs baseline; distance/speed significant vs placebo). Decreased Systolic BP during fixed workload exercise.
Ziegenfuss et al., 2018 (11)	Recreationally active males (~26 yrs)	Resistance Training	Increased 1-RM squat & bench press (significant vs placebo). Within-group increase in avg squat power, peak bench press power, 7.5km time trial performance, perceived recovery. Favorable android/gynoid ratio.
Verma et al., 2024 (13)	Healthy active adults (M&F, 18-45 yrs)	Resistance Training	Increased 1-RM bench press & leg press, increased VO2max, increased muscle girth (arm, chest, thigh-F) (significant vs

			placebo for both M&F).
Bargale et al., 2021 (34)	Healthy subjects (M&F, 18-40 yrs)	Harvard Step Test	Improved Harvard Step Test Fitness Index score (significant vs control).
Pérez-Gómez et al., 2020 (32)	Healthy adults & athletes (M&F)	Varied (Endurance focus in meta-analysis)	Meta-analysis: Significant enhancement in VO2max vs placebo.
Bonilla et al., 2021 (12)	Healthy adults (M&F), mixed training status	Varied (Resistance, Endurance, General in meta-analysis)	Bayesian Meta-analysis: Pooled effect sizes favoured Ashwagandha for strength/power, cardiorespiratory fitness, and fatigue/recovery variables vs placebo.

Note: M=Male, F=Female, VO2max *= Maximal Oxygen Consumption, 1-RM = One-Repetition Maximum, METs = Metabolic Equivalents, CK = Creatine Kinase.*

CHAPTER 3: Ashwagandha and Recovery

1) The Effects of Ashwagandha on Muscle Recovery, Cortisol Regulation, and Oxidative Stress

Recent scientific findings highlight ashwagandha as a promising supplement for supporting post-exercise muscle recovery. Research indicates that ashwagandha can lessen muscle damage caused by intense physical activity, as reflected by more stable and lower levels of serum creatine kinase, a marker of muscle injury.(36,37) The root extract, rich in withanolides and other bioactive compounds, appears to stimulate the formation and differentiation of muscle cells, which may accelerate tissue repair and growth following exercise.(36,38)

Studies investigating delayed onset muscle soreness (DOMS) have demonstrated that ashwagandha supplementation helps maintain peak power output even after strenuous training sessions.(36) This suggests that the herb not only aids in muscle repair but also contributes to better preservation of performance and reduction of post-exercise fatigue.(39) Systematic reviews further support these benefits, reporting improvements in perceived recovery, increased time to exhaustion, and enhanced sleep quality among those supplementing with ashwagandha.(39)

The underlying mechanisms of these effects are likely multifaceted. Ashwagandha's secondary metabolites are thought to play a role in improving physical performance by modulating both metabolic and physiological processes.(37) Its anti-inflammatory and antioxidant properties help reduce inflammation and oxidative stress at the muscular and central nervous system levels.(37,40) The herb's ability to lower lactic acid and blood urea nitrogen concentrations may also contribute to faster recovery and less muscle soreness.(40)

Another important aspect is ashwagandha's impact on the body's stress response. By reducing cortisol, the primary stress hormone, ashwagandha may help protect muscle tissue from the catabolic effects of chronic stress, thereby supporting strength development and adaptation to training.(41) The plant's rich content of flavonoids and phenolic compounds further enhances its antioxidant capacity, enabling it to repair oxidative cellular damage and limit lipid peroxidation.(42)

It is also recognized that reactive oxygen species (ROS), while potentially harmful in excess, are essential for physiological signaling during exercise and necessary for optimal adaptation to training.(42) Ashwagandha's ability to balance ROS production and support antioxidant defenses may therefore contribute to a healthier and more effective recovery process.(42)

In summary, ashwagandha supplementation appears to support muscle regeneration, reduce fatigue and soreness, regulate stress hormones, and maintain oxidative balance, making it a valuable tool for individuals seeking to optimize recovery and adaptation after physical exercise.

2) The Effects of Ashwagandha on Sleep Quality and Stress

Given the essential role that rest and sleep play in adaptation to physical exertion, recent literature indicates that ashwagandha supplementation may be beneficial for optimizing sleep quality.(39) Supplementation with ashwagandha has been associated with improvements in various sleep parameters, including increased sleep efficiency, longer total sleep time, and reduced sleep latency.(43) These findings suggest that ashwagandha not only helps individuals fall asleep faster but also enhances the overall restorative quality of sleep.(39,43)

The efficacy and safety of ashwagandha root extract have been confirmed in subjects diagnosed with both insomnia and anxiety.(44) Importantly, ashwagandha has also demonstrated effectiveness in relieving stress and depression, as well as reducing fatigue and inflammation - factors commonly implicated in sleep disturbances.(44)

The mechanisms underlying ashwagandha's positive influence on sleep are multifactorial. Its active constituents have been shown to reduce oxidative stress, particularly under conditions of sleep deprivation.(45) Ashwagandha exerts its sleep-promoting effects, in part, through the modulation of GABAergic neurotransmission, which facilitates relaxation and sleep induction.(45) Triethylene glycol, a compound present in ashwagandha, has been identified as a principal agent responsible for its somnogenic action.(45)

Ashwagandha's stress-relieving effects are largely attributed to its ability to lower circulating cortisol levels and modulate neurotransmitter systems in the central nervous system.(46) As an adaptogen, ashwagandha supports physiological homeostasis during periods of stress by regulating the hypothalamic-pituitary-adrenal (HPA) axis, a central component of the body's stress response.(46) By attenuating excessive cortisol secretion, ashwagandha may counteract the negative physiological consequences of chronic stress.(46)

Moreover, ashwagandha's bioactive compounds exhibit significant anti-inflammatory and antioxidant properties within the central nervous system, contributing to its neuroprotective profile.(46) These effects may further ameliorate oxidative stress and neuroinflammation, thereby supporting both sleep quality and stress resilience.(46)

SUMMARY

1) Key findings and practical implications

The analysis of current literature indicates that Withania somnifera (Ashwagandha) supplementation has a positive influence on physical performance parameters, particularly aerobic capacity, muscle strength, and recovery. Doses ranging from 500 to 1250 mg daily over 8–12 weeks significantly improve VO_2max, time to exhaustion, and resistance training outcomes in both trained and untrained individuals. Moreover, Ashwagandha supports post-exercise recovery, as evidenced by reduced levels of creatine kinase and perceived fatigue. It also appears to lower oxidative stress, inflammation, and cortisol levels, which may contribute to enhanced adaptation to training and improved sleep quality. These findings suggest that Ashwagandha may serve as a valuable adaptogen in the context of sports nutrition and exercise physiology, particularly for individuals aiming to enhance endurance, strength, and recovery efficiency.

2) Limitations of current evidence

The reviewed studies vary in methodology, population characteristics, and supplementation protocols, which may limit the consistency of findings. Most research to date includes relatively small sample sizes, short intervention periods, and heterogeneous training backgrounds, often excluding elite athletes. Additionally, many trials rely on subjective measures of performance or recovery, which can affect data reliability. The biological mechanisms through which Ashwagandha exerts its ergogenic effects remain incompletely understood, necessitating further investigation.

3) Recommendations for future research

Future studies should employ larger randomized controlled trials with standardized extracts, clearly defined dosages, and longer intervention periods. Inclusion of diverse populations, including women and elite athletes, is recommended. Moreover, future research should explore the underlying mechanisms of Ashwagandha's adaptogenic and performance-enhancing properties, ideally through biomarker analysis and objective performance metrics. Investigating synergistic effects with other training interventions or nutritional strategies could offer further insights into its potential application in professional sport and exercise programs.

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Conceptualization: [MK], [MJ], [DZ], [HW]
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Software: [MJ], [DS], [AT]
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Formal analysis: [MK], [DS]. [NS]
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Data curation: [DS], [DZ], [JS]
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Writing-review and editing: [MK], [DS], [AG], [JS]
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