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Review

The Impact of Royal Jelly on Athletic Performance, Lactate Levels, Anthropometric Parameters, and Muscle Damage: A Systematic Review

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ABSTRACT: Recently, there has been increasing interest in exploring the effects of royal jelly on athletic performance. This systematic review examined existing literature on the effects of royal jelly on athletic performance. We conducted a detailed search in the Institute for Scientific Information, PubMed/Medline, Cochrane Library, and Scopus databases. We meticulously selected nine studies from an initial pool of 97 studies up to June 2024. Our findings will provide evidence supporting the beneficial effects of royal jelly in reducing blood lactate levels and enhancing athletic performance. Additionally, royal jelly does not affect muscle damage or its associated markers. However, the influence of royal jelly on athletes' body composition measurements remains inconclusive, highlighting the need for further research.

Keywords: antioxidants, athletes, athletic performance, lactic acid, royal jelly

INTRODUCTION

Achieving optimal sports performance requires specific skills and abilities to adapt to environmental factors and consistently deliver them in competitive situations (Kendellen et al., 2017; Kellmann and Beckmann, 2018). An athlete's performance is influenced by psychological (e.g., volition, motivation, and concentration) and physical factors (e.g., flexibility, endurance, and speed) (Halson, 2014; Mujika, 2017). Nutritional supplements, particularly sports nutrition products, can help maintain the physiological homeostasis of athletes and improve their competitive performance before, during, and after exercise (Chen and Liu, 2022). These supplements contain combinations of natural nutrients and biologically active substances that increase physical strength, endurance, concentration, and work capacity and have fewer side effects compared with pharmaceutical drugs (Logan et al., 2015; Rosenbloom, 2015).

Royal jelly is a milk-like secretion produced by nurse bees; it has been used as a dietary supplement since ancient times because of its health-enhancing effects (Knecht and Kaatz, 1990; Bogdanov, 2011). Royal jelly comprises water, proteins, sugars, lipids, minerals, essential amino acids, vitamins, enzymes, hormones, polyphenols, nucleotides, and other compounds (Sabatini et al., 2009; Ramadan and Al-Ghamdi, 2012; Melliou and Chinou, 2014). Moreover, royal jelly has anti-inflammatory and antioxidant properties and several nutrients that may promote human health (Collazo et al., 2021). Royal jelly has shown promise in several areas, including mental health, cancer, heart disease, and liver disease. Some studies suggest that royal jelly may possess anticancer characteristics because it may hinder the proliferation of specific cancer cells and boost immune responses (Miyata et al., 2020). It is also believed to offer cardioprotective benefits because of its ability to reduce blood pressure and cholesterol levels and improve heart function (Bt Hj Idrus et al., 2020; Eleiwa et al., 2024). In addition, royal jelly exerts hepatoprotective properties by improving liver function and protecting against toxicity-induced liver damage (Dosoky et al., 2022). It has also been found to have neuroprotective qualities that may help treat mental health issues (e.g., depression and Alzheimer's dis-

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ease) by enhancing cognitive performance and lowering oxidative stress (Ahmad et al., 2020; Guardia de Souza et al., 2020).

Some studies suggest that royal jelly may improve muscle function, reduce muscle damage, and enhance exercise performance (Khalfan Saeed Alwali Alkindi et al., 2024). In addition, royal jelly may help mitigate exercise-induced muscle soreness and promote faster recovery by reducing inflammation (Ovchinnikov et al., 2022b). The immunomodulatory properties of royal jelly may bolster athletes' immune responses, potentially reducing the risk of illness (Taşdoğan et al., 2020).

The effects of royal jelly on athletic performance have attracted substantial interest. However, the results of various studies have been relatively contradictory (Collazo et al., 2021). Therefore, in this systematic review, we compiled and analyzed the findings of published research regarding the effects of royal jelly on athletic performance.

MATERIALS AND METHODS

Information sources and search strategy

This systematic review was conducted in accordance with the 2020 Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist. Two independent researchers conducted a detailed search in April 2023 on the following databases: Institute for Scientific Information, PubMed/Medline, Cochrane Library, and Scopus. No restrictions were placed on the language or publication date. The search strategy involved using combinations of keywords and medical subject headings terms in titles and abstracts, including "athlete," "sport," "exercise," "exercises," "physical exercise," "physical exercises," "exercise training," "physical activity," and "physical activities" along with the terms "royal jelly" and "RJ."

Eligibility criteria

Observational and experimental studies that examined the relationship between royal jelly and sports were included in this systematic review. Only English full-text articles were eligible for inclusion, and publications such as letters, reviews, and comments, as well as overlapping publications, were excluded.

Screening and data extraction

Two independent reviewers who selected articles based on the title and abstract screened the databases. The data were validated by a third independent researcher. The following information was extracted from eligible articles: author name; publication date; study country; study type; study population; type of sport; dose, route, and duration of royal jelly administration; and outcomes.

RESULTS AND DISCUSSION

The studies included in this systematic review are summarized in Table 1. Our search strategy initially yielded 97 potentially eligible studies. After removing duplicates and conducting title/abstract screening, 27 studies were retained. Nine studies (comprising four studies on swimmers, four studies on runners, and one study on football players) successfully fulfilled all the predetermined criteria for inclusion and exclusion (Fig. 1). Several lines of evidence support this assertion, which is discussed below.

Lactate

Four studies evaluated the effect of royal jelly on blood lactate concentrations. Two studies found that royal jelly statistically significantly decreased lactate concentrations (Aly et al., 2019; Ovchinnikov et al., 2022a). Ovchinnikov et al. (2022a) supplemented runners with 0.4 g of royal jelly and 0.06 g of coenzyme Q10 for 10 days and found that blood lactate levels were statistically significantly lower before and after the high-intensity intermittent exercise in athletes who received royal jelly and coenzyme Q10 ($P<0.05$). In Aly et al.'s (2019) study, royal jelly supplementation at a dose of 0.5 g per day for 1 week in runners showed a significant increase in blood lactate levels compared to control group ($P=0.010$). In line with these studies, Kamakura et al. (2001) found that mice given fresh royal jelly showed decreased serum lactate and ammonia accumulation and decreased depletion of muscle glycogen after swimming compared with other groups. Royal jelly influences athletes' performance by reducing lactic acid accumulation in their muscles. The buildup of lactic acid during high-intensity physical activity often causes fatigue and reduces the strength and power output of athletes. Royal jelly may effectively enhance athletes' performances by reducing fatigue. Moreover, royal jelly delays the depletion of glycogen reserves during prolonged periods of exercise (Aly et al., 2019; Ovchinnikov and Deryugina, 2020; Ovchinnikov et al., 2022a).

Muscle damage and its indicators

Four studies investigated the effects of royal jelly supplementation on muscle damage and its indicators. Ovchinnikov et al. (2022b) found that supplementation with 0.4 g of royal jelly and 0.06 g of coenzyme Q10 once a day for 10 days statistically significantly reduced plasmatic and salivary creatine kinase levels in swimmers (72.67±20.85 to 47.58±23.64 and 54.80±21.49 to 35.70±18.37, $P<0.05$). This finding suggests that royal jelly has a potential protective effect against muscle damage. In line with these findings, a study indicated that royal jelly can reduce exercise-induced muscle damage and mitigate physical fatigue, contributing to improved

Table 1. Studies that evaluated the effect of royal jelly on athletes' performance and health outcomes

Authors (year), country	Participants and their characteristic	Aim	Dose of RJ/sample	Duration/level of sport	Result	Outcome
Swimmers						
Sarita et al. (2011), Türkiye	N: 40 Sex: Male Groups: 4 Age: 18 - 25 years	Effect of RJ on biochemical parameters	0.5, 1, and 2 g/d Blood	4 weeks 20 km in 2 h, 5 days a week	-Increase: Blood urea nitrogen and creatinine levels -No change: Glucose, total cholesterol, HDL, LDL, LDH, CK, AST, and ALT levels	Different doses of RJ supplementation were not statistically significantly effective on biochemical parameters
Nazmı et al. (2014), Türkiye	N: 40 Sex: Male Groups: 4 Age:18 - 25 years	Effect of RJ on hematological blood markers	0.5, 1, and 2 g of RJ/d Blood	4 weeks 20 km in 2 h, 5 days a week	-Increase: MCV, MCH, MCHC, EO%, PLT, MPV, PCT, and PDW -Decrease: HCT, CHCM, CH, HDW, WBC, BA%, LY%, BA -No change: BMI, body fat%, body height, and body weight	Some differences in the hematological variables of swimmers were not due to RJ supplementation
Ovchinnikov and Deryugina, (2020), Russia	N: 40 Sex: Male Groups: 2 Age: 16 - 20 years	a) Correlation between the physiological and biochemical indicators affected by RJ and CoQ10 supplementation b) Effectiveness of functional test execution by highly qualified athletes affected by RJ and CoQ10 supplementation	Intervention: 0.4 g of RJ + 0.06 g of Q10/d + 9.54 g of honey Placebo: 10 g of honey/d Not mentioned	10 days Series of segments 4×50 m covered using the main stroke with 45 s of rest in between	-Increase: Vagosympathetic interaction index, centralization index, vegetative balance index, vegetative rhythm index, tension index, SB/(DC + TC), dienoic conjugates, trienoic conjugates, and Schiff base rates	The co-use of RJ and CoQ10 enhances control exercise effectiveness by improving heart rate variability and reducing hyperlactatemia
Ovchinnikov et al. (2022b), Russia	N: 20 Sex: Male Groups: 2 Age: Intervention group: 19.30±1.34 years Placebo group: 19.60±1.43 years	Effect of RJ and CoQ10 on HIIE performance	0.4 g of RJ + 0.06 g of CoQ10 a day Blood and saliva	10 days 4 sets of 50 m distance (in their preferred swimming style at the maximum possible speed interspersed with 45 s of recovery periods)	-Increase: Plasmatic DC, SB, and CK and HIIE performance -Decrease: Salivary DC, SB, and CK; muscle damage; lipid peroxidation	CoQ10 and RJ co-supplementation could statistically significantly reduce muscle damage and lipid peroxidation and improve HIIE performance
Runners						
Saritaş et al. (2017), Türkiye	N: 29 Intervention group: 15 Placebo group: 14 Sex: Male Groups: 2 Age: Intervention group: 22 years (21 - 22.25 years)[1)] Placebo group: 23 years (21 - 24 years)[1)]	Effect of RJ and honey mixture on hematological parameters in maximum weight training runners	Intervention group: 5 g of RJ + 45 g of honey mixture per day Placebo group: 50 g of corn starch per day Blood	8 weeks Running and straining stretching motions	-Increase: WBC -Decrease: Thrombolytic parameters; PLT, MPV, PCT, and PDW -No change: MCV, MCH, and MCHC	Supplementation with RJ and honey mixture did not affect hematological parameters

Table 1. Continued

Authors (year), country	Participants and their characteristic	Aim	Dose of RJ/sample	Duration/level of sport	Result	Outcome
Büyükipekçi et al. (2018), Türkiye	N: 29 Intervention group: 14 Placebo group: 15 Sex: Male Groups: 2 Age: 20 – 25 years	Effects of RJ and honey mixture on some hormones	Intervention: 5 g of RJ + 45 g of honey mixture Placebo: Corn starch Blood	4 and 8 weeks Running and stretching exercises + weight training sets	-No change: Weight-lifted performance-free T3, cortisol, insulin, total testosterone, ACTH, TSH, growth hormone, prolactin, FSH, and LH -Decrease: Free T4 (FT4)	Supplementation had no impact on weight lifting but decreased FT4 (P=0.03)
Aly et al. (2019), Egypt	N: 50 Sex: Male Groups: 2 Age: Intervention group: 20.80±0.92 years Placebo group: 20.77±0.57 years	Effect of honey formula on delaying some fatigue markers in 1,500-m runners	50 g of honey + 0.5 g of RJ + 0.5 g of bee pollen Blood	1 week	-Increase: LDH, delaying some fatigue markers -Decrease: Blood glucose -No change: Systolic BP, diastolic BP, CK-MB, pulse, and running performance	The administration of honey, RJ, and bee pollen had no impact on fatigue-delaying markers
Ovchinnikov et al. (2022a), Russia	N: 30 Sex: Male Groups: 2 Age: 19±1 years	Effect of RJ and CoQ10 on HIIE performance	0.4 g of RJ + 0.06 g of CoQ10 Blood	10 days 3 repetitions of 100 m distance at maximum possible speed interspersed with 45 s of recovery periods	-Increase: HRV variables (SDNN, RMSSD, pNN50, HF, LF, and VLF), HIIE performance, and prolonged sympathetic dominance -Decrease: Lactate level	Running enhanced the HIIE performance with modulation of sympathetic dominance, cardiac autonomic regulation, and blood lactate concentration
Football players						
Joksimović et al. (2009), Serbia	N: 25 Intervention group: 15 Placebo group: 10 Sex: Male Groups: 2 Age: 12 years	Effect of RJ on young football players	0.5, 1, and 2 g of RJ/d Not mentioned	8 weeks All examiners were exposed to regular training 4 times a week	-Increase: body height, muscle mass, circumference above the knee, and circumference of the lower leg -Decrease: Fat component -No effect: Body mass and bone component	The administration of RJ had favorable effects on the anthropometric parameters of teenagers

[1)]Median (percentile, 25% – 75%).

RJ, royal jelly; HDL, high-density lipoprotein; LDL, low-density lipoprotein; LDH, lactate dehydrogenase; CK, creatine kinase; AST, aspartate transferase; ALT, alanine transaminase; MCV, mean red cell volume; MCH, mean cell hemoglobin; MCHC, mean cell hemoglobin concentration; EO, eosinophil; PLT, platelet; MPV, mean platelet volume; PCT, procalcitonin; PDW, platelet distribution width; HCT, hematocrit; CHCM, cellular hemoglobin concentration mean; CH, cellular hemoglobin; HDW, hemoglobin concentration distribution width; WBC, white blood cell; BA, basophil; LY, lymphocyte; BMI, body mass index; CoQ10, coenzyme Q10; HIIE, high-intensity interval exercise; DC, dienoic conjugates; TC, trienoic conjugates; SB, Schiff bases; T3, triiodothyronine; ACTH, adrenocorticotropic hormone; TSH, thyroid-stimulating hormone; FSH, follicle-stimulating hormone; LH, luteinizing hormone; T4, thyroxine; BP, blood pressure; CK-MB, creatine kinase-MB; HRV, heart rate variability; SDNN, standard deviation of normal-to-normal intervals; RMSSD, root mean square of successive RR intervals differences; RRNN, mean RR normal-to-normal intervals; pNN50, percentage of successive RR intervals that differ by more than 50 ms; HF, absolute power of the high-frequency band; LF, absolute power of the low-frequency band; VLF, absolute power of the very-low-frequency band.

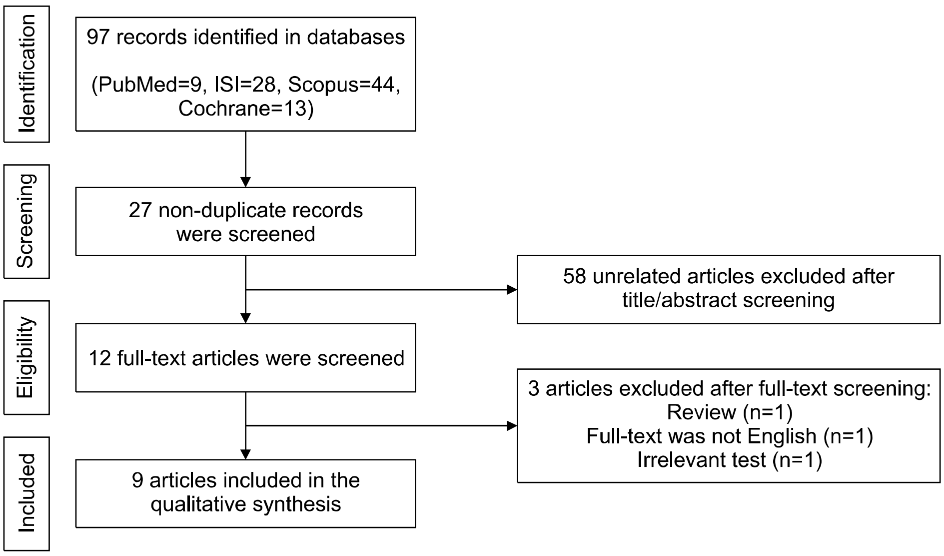

Fig. 1. Flow chart of the search and publication selection.

performance (Anugrah et al., 2023).

However, Saritas et al. (2011) and Nazmı et al. (2014) reported that royal jelly supplementation at a dose of 0.5, 1, and 2 g/d for 4 weeks lacked a statistically significant effect on creatine kinase levels in swimmers (P=0.63 and 1.35, respectively). In addition, Aly et al. (2019) found that supplementation with 50 g of honey, 0.5 g of royal jelly, and 0.5 g of bee pollen once a day for 1 week had no significant effect on creatine kinase (27.80±15.19 to 14.60±5.23, P=0.735) but had a statistically significant effect on lactate dehydrogenase in runners (220.0±67.45 to 311.3±55.40, P=0.002). This study suggests that the marginally faster race completion by the honey group may be because of honey's antioxidants, which improve blood flow and inflammation control. However, the varied results on muscle damage indicators highlight the complex nature of royal jelly's effects, which are influenced by personal differences, specific exercises, and other factors such as training intensity and genetics (Earnest et al., 2004). Elevated creatine kinase levels have been linked to enhanced exercise performance, indicating that creatine kinase functions as a signaling mechanism for the body to adapt, repair, and strengthen the affected muscles over time (Ovchinnikov and Deryugina, 2020).

Anthropometric parameters

***Body height*:** Three studies reported the effects of royal jelly on anthropometric parameters. Two studies evaluated the effects of royal jelly on body height. Joksimović et al. (2009) reported that royal jelly supplementation at a dose of 0.5, 1, and 2 g/d for 8 weeks increased the height of young football players (from an average 152.46 to 153.13 cm, mean change: 0.67 cm, P=0.0001). However, Nazmı et al. (2014) found that royal jelly supplementation at a dose of 0.5, 1, and 2 g/d for 4 weeks did not affect the height of swimmers (P>0.05). Several factors might explain the effects of royal jelly on participants' height. First is the study duration. The duration of Joksimović et al.'s study (2009) was longer than that of Nazmı et al.'s study (2014). Second, the increase in height observed in Joksimović et al.'s study (2009) may be attributed to the age group of participants rather than the effect of royal jelly.

***Body weight and body mass index*:** Nazmı et al. (2014) and Saritas et al. (2011) showed that royal jelly supplementation at a dose of 0.5, 1, and 2 g/d for 4 weeks had no significant effect on the weight and body mass index of swimmers (P>0.05). Moreover, Joksimović et al. (2009) reported that royal jelly supplementation at a dose of 0.5, 1, and 2 g/d for 8 weeks had a significant effect on the circumference above the knee and lower leg of young football players (P<0.05). In addition, two studies examined the effects of royal jelly administration on body fat. Joksimović et al. (2009) found that royal jelly supplementation at a dose of 0.5, 1, and 2 g/d for 8 weeks statistically significantly decreased body fat in young football players (from an average of 16.87 to 14.10, P= 0.0001). However, Saritas et al. (2011) showed that royal jelly supplementation at different doses (0.5, 1, and 2 g/d) had no effect on body fat in swimmers (P=0.17). In line with these results, a study reported that there is a significant reduction in body weight and body mass index for participants taking royal jelly in doses less than 3 g/d (Vajdi et al., 2023). The difference in the results regarding the effects of royal jelly on body fat mass can be due to differences in study duration. A study with a longer duration (a least 2 months) observed a significant effect, indicating that fat mass is not affected in the short term (Joksimović et al., 2009).

Performance

Five studies evaluated the effect of royal jelly on athletes' performances. Four studies showed positive effects.

Two studies by Ovchinnikov et al. (2022a; 2022b) found that supplementation with 0.4 g of royal jelly and 0.06 g of coenzyme Q10 for 10 days could enhance the high-intensity intermittent exercise performance of runners (P= 0.005 and 0.013, respectively). Ovchinnikov et al. (2022b) reported that supplementing with royal jelly and coenzyme Q10 enhanced swimmers' performance during high-intensity intermittent exercise, as reflected by an increase in Fédération Internationale de Natation (FINA) points from 594.6±31.63 to 623.1±30.33. The FINA Point Scoring system, developed by the International Swimming Federation, provides a standardized metric for comparing swimming performances. This scoring system assigns higher points to faster, more competitive performances—typically around 1,000 points for elite-level results— and lower points for slower times. In this study, the FINA points served as an objective measure of performance during the high-intensity exercise protocol.

The enhancements in high-intensity intermittent exercise performance may be linked to the metabolic changes induced by royal jelly and coenzyme Q10, particularly oxidative stress inhibition during exercise. In line with this study, Ovchinnikov et al.'s (2022a) study on runners found that supplementation with royal jelly and coenzyme Q10 enhanced the high-intensity intermittent exercise performance of athletes and reduced the duration required to finish high-intensity intermittent exercise (average of 11.14 s to 11.05 s). In addition, another study by Ovchinnikov and Deryugina (2020) found that supplementation with 0.4 g of royal jelly and 0.06 g of coenzyme Q10 per day for 10 days in swimmers showed an inverse correlation between principal component 1 (PC1) and FINA point after the functional test (R=−0.742) (Ovchinnikov and Deryugina, 2020). The PC1 in this study represents the main source of variation in the physiological and biochemical data, capturing the combined effects of coenzyme Q10 and royal jelly on athletes' performance and health metrics. This study suggests that the co-supplementation of royal jelly and coenzyme Q10 statistically significantly contributes to improving exercise execution technique by reducing the increase of indicators included in PC1 in response to physical load (Ovchinnikov and Deryugina, 2020). A lower PC1 value corresponds to better athletic performance as measured by the FINA point. In accordance with these studies, Kamakura et al. (2001) found that fresh royal jelly significantly improved swimming endurance in mice compared with the control group.

Moreover, Büyükipekçi et al. (2018) investigated the effect of a mixture containing 5 g of royal jelly and 45 g of honey on the maximal strength training of runners over 4 and 8 weeks. Their finding revealed a statistically significant increase in the weight lifted during bench press, squats, arm curls, deadlifts, and shoulder press movements across groups. This improvement was evident in the second and third assessments compared to the initial measurement (P<0.001). The study concluded that the observed augmentation in strength was attributed to the weight training regimen rather than royal jelly and honey supplementation. However, Aly et al. (2019) investigated the effect of supplementation with 50 g of honey, 0.5 g of royal jelly, and 0.5 g of bee pollen that was given 30 min before running for a week on runners. They found that the honey group had a shorter time to complete the 1,500-m run (5.01±0.24 min) compared with the placebo group (5.16±0.11 min), but there was no significant difference (P=0.221) (Aly et al., 2019). Also, Saritaş et al. (2017) studied the impact of a royal jelly and honey mixture on hematological parameters associated with exercise. Their findings indicated that both acute and chronic exercise caused increases in certain hematological measures, which were likely due to hemoconcentration and stimulation of the sympathetic nervous system. However, the 60-day treatment with the royal jelly and honey mixture did not show significant effects on the hematological parameters examined.

A summary of the quality assessments of the included studies is shown in Fig. 2, highlighting the risk of biased evaluations. Our analysis identified four studies (Saritas et al., 2011; Nazmı et al., 2014; Ovchinnikov and Deryugina, 2020; Ovchinnikov et al., 2022a) as having a high quality with a low risk of bias, and one study was assessed as having a moderate quality with a moderate risk of bias. By contrast, two studies (Joksimović et al., 2009; Aly et al., 2019) were deemed low quality, exhibiting a serious risk of bias.

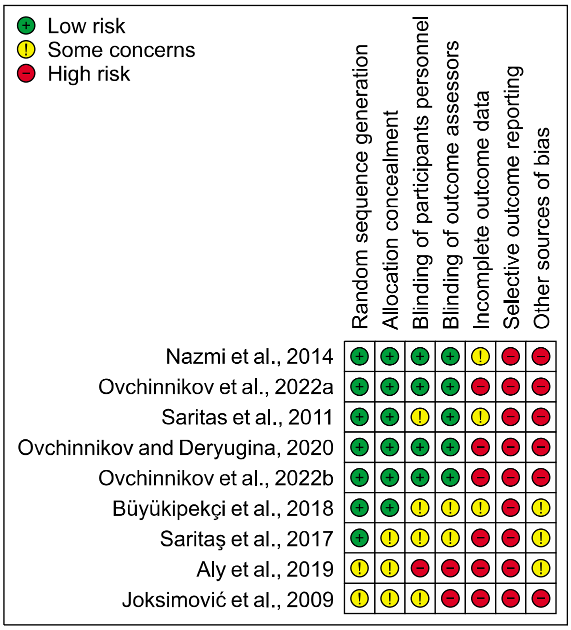

Fig. 2. Quality evaluation and bias assessment of randomized controlled trials.

Mechanisms

The emphasis on exercise and athletic performance in royal jelly is due to its rich biochemical profile and various physiological benefits. Royal jelly contains an array of proteins, vitamins, amino acids, and fatty acids that are essential for energy production, muscle functioning, and recovery—critical components for athletic success. Research shows that royal jelly can increase endurance and minimize muscle damage by reducing exercise-related oxidative stress because of its antioxidant properties (Ovchinnikov et al., 2022b). In addition, royal jelly has been associated with lower blood lactate levels and enhanced cardiac autonomic regulation, which can improve performance during high-intensity workouts (Ovchinnikov et al., 2022a). The antifatigue effects of royal jelly, as evidenced by decreased lactic acid and ammonia accumulation during extended exercise sessions, further demonstrate its ability to boost physical endurance (Kamakura et al., 2001). Although royal jelly is known for its other health advantages, including immune support and hormonal balance, its distinctive blend of antioxidants and bioactive compounds that promote energy production, alleviate inflammation, and facilitate muscle recovery is particularly advantageous for athletes and those looking to enhance their physical performance.

The connection between reduction of lactate levels and improvement of athletic performance has been well documented, especially in high-intensity and endurance activities. During intense exercise, the muscles primarily utilize anaerobic metabolism, which generates lactate as a byproduct of glucose breakdown. Although lactate itself is not harmful, its buildup in the bloodstream can decrease pH levels, leading to muscle fatigue, discomfort, and decreased muscle function, ultimately hindering performance (Cairns et al., 2006). Athletes can maintain high-intensity exercise for extended periods by lowering lactate levels or delaying its accumulation, thereby enhancing endurance and performance (Allen et al., 2008). Research has shown that royal jelly may help reduce blood lactate levels after intense physical activity. For example, Ovchinnikov et al. (2022a) indicated that taking royal jelly along with coenzyme Q10 significantly decreased postexercise lactate levels in runners, which improved their performance in high-intensity interval training. Royal jelly enables athletes to sustain higher-intensity workouts for longer periods of time before feeling fatigued by reducing lactate buildup, thus improving overall athletic performance. In addition, this reduction in lactate levels aids in faster recovery between exercise sessions, enabling more frequent and effective training, which further enhances performance.

Royal jelly has demonstrated its potential to enhance athletic performance through various mechanisms. Scientific evidence suggests that royal jelly possesses antioxidant, anti-inflammatory, and immune system-regulating properties because of its bioactive substances (Collazo et al., 2021). Although the molecular mechanisms underlying royal jelly's effects on athletes' performance are not yet fully understood, royal jelly may enhance mitochondrial adaptations in the skeletal muscles of mice, which could play a role in its beneficial effects (Takahashi et al., 2018). In the soleus muscle, which primarily comprises type I fibers, endurance exercise enhanced mitochondrial enzyme activity, which was further amplified by royal jelly therapy (Takahashi et al., 2018). Aside from its numerous benefits, royal jelly appears to possess an ergogenic effect by activating AMP-activated protein kinase (AMPK) in skeletal muscle cells. Royal jelly contains a unique fatty acid called 10-hydroxy-2-decenoic acid, which can activate AMPK in skeletal muscles. AMPK activation leads to Forkhead Box O_3 activation, which protects the cells against exercise-induced oxidative damage. Moreover, the activation of AMPK and subsequent expression of antioxidant enzymes, including manganese superoxide dismutase and catalase, suggest that royal jelly can enhance the body's defense against oxidative stress during exercise and promote overall health (Takikawa et al., 2013; Takahashi et al., 2018; Chang et al., 2019). However, royal jelly's effect on the muscles may depend on age and other factors (Meng et al., 2017).

During exercise, muscle contractions necessitate an increased demand for oxygen, consequently leading to the increased production of free oxygen species within the body. However, this upsurge in free oxygen species can result in membrane lipid peroxidation, causing oxidative damage to cellular components in the postexercise phase, particularly in damaged muscle tissues. When excessive levels of reactive oxygen species molecules are present, they can cause damage upon cells and tissues (Schieber and Chandel, 2014). Several studies have shown that royal jelly is rich in antioxidants, which can neutralize reactive oxygen species and protect against oxidative damage. For example, in a study conducted on rats with colitis, royal jelly supplementation effectively reduced oxidative stress and inflammation markers (Botezan et al., 2023). In addition, royal jelly has been shown to protect liver cells from oxidative damage by increasing the levels of important antioxidant enzymes such as superoxide dismutase and catalase (Kaynar et al., 2012). Remarkably, this oxidative stress-induced damage triggers an increase in plasma levels of muscle enzymes, including creatine kinase (Ovchinnikov and Deryugina, 2020). Collectively, these findings suggest that royal jelly may protect against damage induced by reactive oxygen species and may be beneficial in conditions associated with oxidative stress.

Although royal jelly shows promise in benefiting athletes, further research is needed to gain a comprehensive understanding of the underlying mechanisms and to explore its efficacy in different athletic populations and exercise modalities. This systematic review meticulously applies a structured method to impartially collate and analyze studies on the effects of royal jelly on athletes, offering a holistic overview and identifying areas for future research. It highlights the potential benefits of royal jelly supplementation for improving athletic performance, with implications for athletes, coaches, and healthcare practitioners. However, this review has limitations. There were not enough studies to conduct a quantitative analysis or meta-analysis of the data. Notably, the included studies exhibited several specific limitations: small sample sizes that hindered statistical power, varied dosages of royal jelly administered across studies, and inconsistent outcome measures that impeded direct comparisons. These factors collectively limit the generalizability of the findings and underscore the necessity for more rigorous and standardized research in this domain.

In conclusion, the existing evidence suggests that royal jelly holds promise for athletes, offering potential benefits in terms of enhancing exercise performance. To establish the mechanisms behind the effects of royal jelly on athletic performance and determine the optimal dosages, high-quality randomized controlled trials are needed. In addition, studies targeting female athletes are needed to expand our understanding of the potential benefits of royal jelly in the context of athletic performance.

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AUTHOR DISCLOSURE STATEMENT

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Concept and design: MM, YP. Analysis and interpretation: MM, FN. Data collection: MM, YP, VT, ES. Writing the article: MM, YP, VT, FN, ES. Critical revision of the article: MM, YP, VT, FN, ES. Final approval of the article: All authors. Statistical analysis: MM, FN, YP. Obtained funding: YP. Overall responsibility: YP, MM.

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