



THE EFFECT OF PESTICIDES ON MUSCLE MASS: A LITERATURE REVIEW

Ilham Muharram¹, Habibi², & Dwi Santy Damayanti³

^{1,2,3}Universitas Islam Negeri Alauddin Makassar, Indonesia

Correspondence Email: ilhammuharram4599@gmail.com

ABSTRACT

Pesticides are widely used in agriculture and environmental management to control pests; however, their extensive application has raised concerns regarding long-term adverse health effects. One emerging health issue associated with chronic pesticide exposure is the decline in muscle mass and function, which may lead to sarcopenia. Sarcopenia is a progressive muscle disorder characterized by the loss of skeletal muscle mass and strength, increasing the risk of physical disability, falls, and mortality, particularly among adults and older populations. This study aimed to review and synthesize existing scientific evidence on the effects of pesticide exposure on muscle mass and muscle function. A literature review was conducted using PubMed and Scopus databases, applying keywords related to pesticides and muscle health. From 274 identified articles, 19 studies met the inclusion criteria and were included in the analysis. The findings indicate that exposure to various pesticides, including organophosphates, glyphosate, atrazine, and related environmental chemicals, is consistently associated with reduced muscle strength, decreased muscle mass, and a higher prevalence of sarcopenia. Mechanistic evidence from experimental and observational studies suggests that oxidative stress, chronic inflammation, impaired energy metabolism, and increased muscle protein degradation play key roles in pesticide-induced muscle deterioration. Overall, this review highlights pesticide exposure as an important environmental risk factor for muscle health decline. Further longitudinal studies are needed to establish causal relationships and to support the development of preventive strategies and environmental health policies aimed at reducing the risk of sarcopenia.

Keywords: Pesticides, Muscle mass; Muscle strength, Sarcopenia; Environmental exposure

1. INTRODUCTION

Pesticides are chemical agents employed to inhibit or manage populations of pests, including insects, rodents, fungi, weeds, and other undesirable organisms. Although they confer advantages in enhancing crop yields and controlling plant and animal diseases, the application of pesticides presents considerable risks to environmental integrity and public health. These chemical compounds have become persistent contaminants, infiltrating various environmental media such as air, water, soil, and food supplies, thereby posing health hazards that range from

immediate to long-term effects. (Barros & Augusto, 2025) Acute toxicity resulting from pesticide exposure can occur through inhalation, ingestion, or dermal or ocular contact with high doses, whereas chronic toxicity is associated with sustained or repeated exposure. Pesticides are associated with multiple toxicological effects, including neurotoxicity, mutagenicity, carcinogenicity, teratogenic effects, and endocrine disruption. (Ahmad et al., 2024) Several studies have also found that pesticides can affect physiological changes in muscles and decrease contractile strength. (Jauregui-zunzunegui et al., 2024)

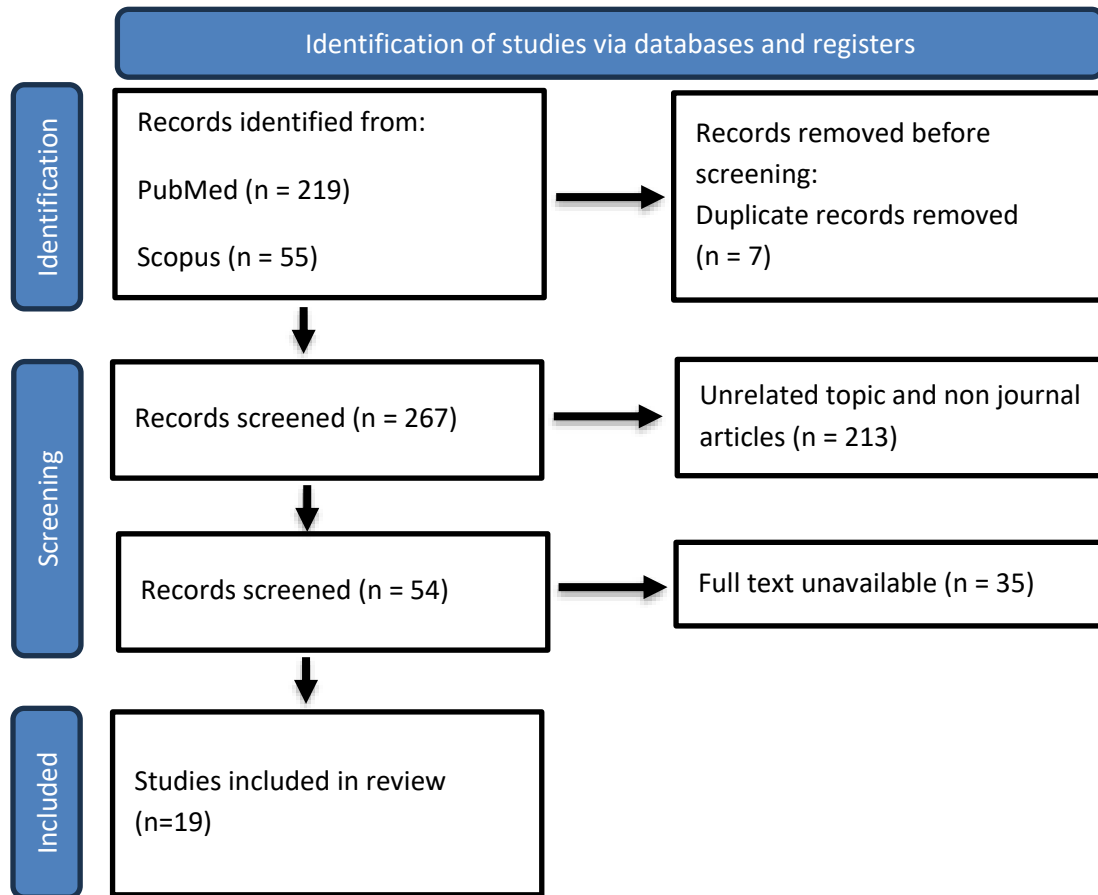
The human musculoskeletal system, encompassing bones, cartilage, ligaments, tendons, joints, muscles, connective tissues, and related structures, is essential for maintaining the normal functioning of physiological processes, facilitating movement, and supporting various bodily activities. (Mao et al., 2025) As individuals age, degenerative lesions—both localized and systemic—frequently develop within the musculoskeletal system, often as a consequence of mechanical trauma and metabolic disturbances. These degenerative changes substantially affect the quality of life among older adults and elevate the risk of adverse health outcomes in this population. (Chua et al., 2022; Lin et al., 2022)

Sarcopenia is a condition that happens as people get older, where their muscles become weaker and smaller faster than normal. This makes it harder for them to do things like walk or carry things. It can also lead to more accidents, like falling and getting hurt, and can even make it more likely for them to become very sick or pass away. Many older people, depending on where they live, might have this problem, and it can cause both health issues and worries for families and communities. (J., 2019; Rabaan et al., 2020) Therefore, this study aims to determine how pesticides affect muscle mass, resulting in sarcopenia.

2. METHODS

This study is a literature review using databases from PubMed and Scopus. The keywords used in this study are: for PubMed: ("pesticides"[MeSH] OR pesticide* OR herbicide* OR insecticide* OR "organophosphate" OR 'carbamate' OR pyrethroid* OR neonicotinoid*) AND ("muscle, skeletal"[MeSH] OR "muscle mass" OR "lean mass" OR "sarcopenia" OR "muscle atrophy" OR "muscle strength" OR "cross sectional area" OR 'DEXA' OR "bioelectrical impedance" OR "grip strength") and for (pesticide* OR insecticide* OR herbicide* OR fungicide*) AND ("muscle mass" OR "muscle strength" OR "muscle loss").

The inclusion and exclusion criteria are as follows: Inclusion (1) Studies reporting muscle mass measurements or relevant measures/indicators. (2) Studies with measurable pesticide exposure (biomarkers, exposure questionnaires, environment, occupational history). (3) Peer-reviewed publications; technical reports/dissertations (optional) if of high quality. (4) Language: English and Indonesian. Exclusions (1) Studies reporting only non-muscle outcomes without relevant data (e.g., only liver enzyme levels without muscle data). (2) Single case studies (case reports) unless highly informative for mechanisms. (3) Publications without full text available.



The search results found 274 journals based on keywords. Then, elimination was carried out based on similar journals from two databases, and 7 similar journals were found, so 7 were eliminated, leaving 267 journals. Then, elimination was carried out based on relevant titles, and 37 journals were found. After that, by reading the abstracts and contents of the journals, 19 relevant journals were found.

3. RESULTS AND DISCUSSION

No.	Author (Year)	Study Title	Study Design	Population / Sample	Pesticide / Exposure Type	Muscle Outcome Measure	Main Findings	Citation
1	Novaes et al. (2016)	<i>Acute paraquat exposure determines dose-dependent oxidative injury of multiple organs and metabolic dysfunction in rats: impact on exercise tolerance</i>	Experimental animal study	32 Wistar rats randomized into 4 groups (Control, PQ10, PQ20, PQ30)	Paraquat (10–30 mg/kg, intraperitoneal)	Skeletal muscle glycogen levels, oxidative stress markers, organ morphology	Paraquat exposure produced dose-dependent oxidative stress , reduced glycogen levels in skeletal muscle, and impaired energy metabolism. These changes contributed to reduced exercise tolerance , indicating altered muscle function.	(Novaes & Gonc, 2016)
2	Sarker et al., (2021)	<i>Arsenic secondary methylation capacity is inversely associated with arsenic exposure-related muscle mass reduction</i>	Observational human study	Adults with documented arsenic exposure	Arsenic exposure (urinary arsenic metabolites)	Muscle mass (likely DXA or anthropometric indicators)	Higher arsenic exposure and poorer arsenic methylation capacity were associated with lower muscle mass , suggesting arsenic-related metabolic toxicity affecting muscle tissue.	(Sarker et al., 2021)
3	Erkudov et al., (2023)	<i>Assessment of youth fitness under long-term exposure to toxic ...</i>	Observational cohort/cross-sectional	Children / adolescents exposed to environmental toxins	Multiple environmental toxicants (including pesticides, inferred from snippet)	Physical fitness parameters, muscle performance	Long-term exposure to toxic environmental compounds was associated with reduced youth fitness , suggesting	(Erkudov et al., 2023)

							possible adverse effects on muscle performance and growth.	
4	Nan et al. (2024)	<i>Association between exposure to organophosphate esters metabolites and sarcopenia prevalence: NHANES 2011–2018</i>	Cross-sectional study using national survey data (NHANES)	2,592 adults ≥18 years	Organophosphate ester metabolites (DBUP, BCEP, others)	Sarcopenia defined via ASM/BMI; inflammatory markers	Higher levels of urinary OPE metabolites DBUP and BCEP were strongly associated with higher prevalence of sarcopenia , partly mediated by inflammation .	(Nan et al., 2024)
5	Wang et al. (2024)	<i>Association between urinary glyphosate levels and hand grip strength in US adults (NHANES 2013–2014)</i>	Cross-sectional study	1,466 adults ≥18 years	Glyphosate exposure (urinary biomarker)	Hand grip strength, lean muscle mass (DXA)	Glyphosate exposure was negatively associated with combined grip strength , suggesting impaired muscle strength. No significant relationship with lean muscle mass.	(Wang et al., 2024)

6	Liu & Chien (2024)	<i>Associations between DEET, Organophosphorus Insecticides, and Handgrip Strength in Diabetes: An NHANES Analysis</i>	Cross-sectional analysis (NHANES 2011–2014)	412 adults ≥20 years with diabetes; weighted to represent 6.7 million U.S. adults. Mean age 58.8 years.	Urinary DEET metabolites (DEET, DHMB, DCBA); Organophosphorus metabolites (para-nitrophenol, 2-isopropyl-4-methyl-pyrimidinol); pyrethroids; herbicide 2,4-D.	Handgrip strength using digital dynamometer (combined highest values from both hands).	Higher para-nitrophenol linked to significantly lower handgrip strength in both sexes; DEET metabolite inversely associated with strength in men ≥60 years; 2-isopropyl-4-methyl-pyrimidinol associated with reduced strength in women.	(C. Liu & Chien, 2024)
7	Li & Wang, et al. (2025)	<i>Associations between Exposure to Heavy Metals and Sarcopenia Prevalence</i>	Cross-sectional AI/ML predictive modeling (NHANES 2011–2018)	3,741 adults ≥18 years with valid metal and DXA sarcopenia indicators.	Nine urinary heavy metals (e.g., Tl, Sn, Cs, Cd). Feature importance identified via SHAP values.	Sarcopenia defined via DXA-based ASMI (men <7.0 kg/m ² ; women <5.4 kg/m ²).	Heavy metals (Tl, Sn, Cs, Cd) significantly predicted sarcopenia. Age and BMI were major modifying variables. Heavy metal exposure substantially contributed to model performance.	(Li & Wang, 2025)
8	Godbole et al. (2023)	<i>Exploratory Analysis of the Associations Between Neonicotinoids and Adiposity</i>	Cross-sectional (NHANES 2015–2016)	1,675 U.S. adults ≥19 years with neonicotinoid measurements; pregnant women excluded.	Urinary neonicotinoids: imidacloprid, acetamiprid, clothianidin, thiacloprid, 5-hydroxy-imidacloprid, N-	No direct muscle mass metric; lean mass used as an adiposity-related covariate (DXA).	Acetamiprid inversely associated with adiposity; 5-hydroxy-imidacloprid positively associated with overweight/obesity	(Godbole et al., 2023)

					desmethyl-acetamiprid.		y; sex modifies associations. Low detection frequencies for several compounds.	
9	Tao, Zhai, et al., (2025)	<i>Exposure to Persistent Organic Pollutants and Sarcopenia</i>	Cross-sectional population analysis	Sample details not fully shown in extracted text.	Persistent Organic Pollutants (POPs): PCBs, PCDDs, PCDFs, OCPs, PBDEs (based on POP categories).	Sarcopenia indicators (muscle mass/strength), exact criteria not visible in snippet.	POPs significantly associated with higher sarcopenia prevalence. Mixed-exposure methods (WQS, BKMR) showed cumulative effects; pathway analysis suggested mechanistic links.	(Tao, Zhai, et al., 2025)
10	Qu et al. (2025)	Exposure to volatile organic compounds and sarcopenia risk in US adults based on NHANES	Cross-sectional (NHANES 2011–2018)	3,391 U.S. adults aged 20–59 years	Volatile Organic Compounds (urinary VOC metabolites)	Sarcopenia assessed by ALM/BMI using DXA	Higher urinary metabolites of VOCs (CEMA, CYMA, ATCA, 3,4-MHA) were significantly associated with increased sarcopenia risk. HDL partially mediated the association.	(Qu et al., 2025)
11	Blaauwendraad et al. (2023)	Fetal organophosphate pesticide exposure and child adiposity measures at 10 years of age	Prospective cohort (Generation R Study)	642 mother–child pairs (Netherlands)	Organophosphate pesticides (maternal urinary DAP metabolites during pregnancy)	Lean mass and fat mass measured by DXA	No significant associations were observed between prenatal OP exposure and childhood BMI, lean mass, or	(Blaauwendraad et al., 2023)

							adiposity at age 10.	
12	Jauregui-Zunzunegui et al. (2024)	Glyphosate exposure, muscular health and functional limitations in middle-aged and older adults	Cross-sectional (NHANES 2013–2016)	2,132 U.S. adults aged ≥20 years	Glyphosate (urinary concentration)	Hand grip strength (HGS), relative HGS (HGS/ALMBMI), self-reported functional limitations	Higher glyphosate exposure was associated with reduced grip strength, lower relative muscle strength, and higher odds of physical functional limitations.	(Jauregui-zunzunegui et al., 2024)
13	Liu et al. (2025)	Independent and combined effects of volatile organic compounds on sarcopenia	Cross-sectional with mixture analysis (NHANES 2011–2018)	2,544 U.S. adults aged ≥20 years	Volatile Organic Compounds (multiple urinary metabolites)	Sarcopenia defined by ALM/BMI (DXA)	Both individual and combined VOC exposures were associated with increased sarcopenia risk. Inflammation, oxidative stress, and renal function partially mediated the associations.	(H. Liu et al., 2025)
14	Chen et al. (2023)	Long-term exposure to air pollution and risk of sarcopenia in adult residents of Taiwan	Nationwide retrospective cohort study	286,044 Taiwanese adults aged ≥18 years	Air pollutants (PM2.5, PM10, SO ₂ , CO, NO, NO ₂)	Incident sarcopenia diagnosed clinically	Long-term exposure to higher levels of air pollutants significantly increased the risk of sarcopenia in both men and women.	(S. Chen et al., 2023)

15	Tao et al. (2025)	<i>Atrazine exposure induces skeletal muscle atrophy: Multi-omics insights into mechanisms and therapeutic targets</i>	Experimental study (in vitro C2C12 cells + in vivo mouse model)	C2C12 myoblasts; Male C57BL/6 mice	Atrazine (ATZ)	Myotube formation, muscle fiber CSA, transcriptomic analysis, ROS, inflammation markers	ATZ reduced myotube formation, decreased body weight and muscle fiber CSA, shifted fibers toward fast-glycolytic IIB type, increased inflammation, oxidative stress, and protein degradation.	(Tao, Gu, et al., 2025)
16	Coelho et al. (2024)	<i>Physical function as a marker to assess the effects of occupational long-term pesticide exposure</i>	Cross-sectional human study	127 agricultural workers	Various occupational pesticides (mainly organophosphates)	Handgrip strength (HGS), Timed Up and Go (TUG), Sit-to-Stand (STS), PChE	Long-term pesticide exposure negatively affected physical performance (HGS, STS, TUG), independent of cholinesterase levels.	(Coelho et al., 2024)
17	Barbosa et al. (2021)	<i>Study of muscle fibers of the extensor digitorum longus and soleus muscles of C57BL/6 females exposed to glyphosate during pregnancy and lactation</i>	Experimental animal study	12 C57BL/6 female mice	Glyphosate (0.5%)	Muscle weight, length, histological morphology & morphometry	Glyphosate exposure reduced maternal body weight and length but did not alter skeletal muscle morphology or fiber characteristics.	(Barbosa et al., 2021)

18	Yang et al. (2024)	<i>Urinary neonicotinoids and metabolites are associated with obesity risk in Chinese school children</i>	Cross-sectional human study	442 school children aged 7–11	Urinary neonicotinoids & metabolites	BMI z-score, waist circumference, overweight/obesity risk	Mixed associations: some metabolites increased obesity risk, others decreased BMI. Indicates neonicotinoids may act as obesogens.	(Yang et al., 2025)vvur
19	Wang et al. (2025)	<i>Volatile organic compounds exposure associated with sarcopenia in US adults from NHANES 2011–2018</i>	Cross-sectional population-based study	2,898 US adults (NHANES)	Volatile organic compounds (VOCs) via urinary metabolites	Sarcopenia index (ASM/BMI), logistic regression, WQS, BKMR	VOC metabolites were positively associated with sarcopenia risk; mediated by inflammation, endocrine disruption, and reduced vitamin D.	(W. Chen et al., n.d.)

4. CONCLUSION

Based on a review of the literature, it can be concluded that exposure to pesticides and environmental chemicals has a significant relationship with decreased muscle mass and function, as well as an increased risk of sarcopenia. Various types of pesticides, such as organophosphates, glyphosate, atrazine, and other environmental chemicals, show potential negative effects on muscle health in both experimental animals and humans.

The mechanisms underlying this relationship involve oxidative stress, chronic inflammation, energy metabolism disorders, and increased muscle protein degradation. The effects of pesticide exposure are more pronounced with long-term exposure and in adults and the elderly, who are physiologically more susceptible to muscle mass and strength decline. Meanwhile, research results in children and prenatal exposure groups show varying findings, indicating differences in biological responses based on life stage and exposure levels.

Overall, this literature review confirms that pesticide exposure is an environmental risk factor that needs to be considered in sarcopenia prevention efforts. Therefore, there is a need to raise awareness of the dangers of pesticide exposure, strengthen environmental health policies, and conduct further research with longitudinal designs to strengthen causal evidence and identify effective prevention strategies.

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