Review Article

The future of warfare: Arthropods as blueprints for military innovation

Asmaa M Ammar, Noha A Elleboudy, Shimaa E Mohammed

Medical Parasitology Department, Faculty of Medicine, Ain Shams University, Abbasia, Cairo 1181, Egypt

ABSTRACT

Arthropoda is the largest and most diverse group of organisms on earth. Their association with warfare provides a different perspective that links entomology and military studies. This review explores the different aspects of arthropods' applications in warfare by emphasizing their roles in biological and psychological warfare, applications in surveillance, logistics, medical support, and their contributions to forensic science. As technology advances, the potential military applications of arthropods in warfare continue to develop, presenting new challenges and possibilities. Consideration of ethical standards, legal aspects, *e.g.*, failure of biological weapon convention to address technology advances, banning weapons without specifying, and lacking transparency protocols, and promotion of expertise collaboration, endorses the efficacy of arthropods while protecting global security and ecological stability. This review highlights the vital roles of arthropods that necessitates coordination across scientific, military and environmental sectors.

Keywords: arboweapons; arthropods; cybersecurity; cyborg insects; forensic entomology; warfare.

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Corresponding Author: Asmaa M. Ammar, **Tel.:** +20 10 27280087, **E-mail:** asmaa.mostafa273@gmail.com

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INTRODUCTION

Arthropods are invertebrates characterized by their jointed limbs, segmented bodies, and exoskeletons. This diverse group includes insects, arachnids, crustaceans, and myriapods, representing a significant part of the Earth's biomass[1]. With an estimated 5-10 million species, arthropods are predominant in terrestrial and aquatic ecosystems, playing a vital role in pollination, decomposition, and disease transmission[2]. Their unique biological traits, behaviors, and low cost of breeding have attracted interest for military applications throughout history. Hence insects have been a part of the military arsenal[3].

The history of arthropods' association with warfare is massive, extending from ancient to modern times. Arthropods' weaponization dates to ancient times, as in throwing beehives into enemy camps. Other examples include using scorpion grenades in Hatra city and using assassin bugs in Uzbekistan. One of the most well-known examples is Japan's Unit 731 in World War II, which weaponized plague-carrying fleas[3,4]. Lice transmit typhus, and mosquitoes spread yellow fever and malaria. More recently, during the Cold War, the U.S. utilized insects in Korea, the Soviet Union employed ticks, and the U.S. experimented with mosquitoes[5]. Arthropods have been devastating weapons of war, debilitating armies, and impacting civilian populations[6]. The different and often missed roles of arthropods in modern warfare, extend beyond their common roles as disease vectors and nuisance pests. We explore emerging applications of arthropods in entomological warfare, agroterrorism, psychological operations (PSYOPS), forensic entomology, bio-sensing, and in the development of bio-inspired robotic systems. This review aims to provide a comprehensive understanding of the potential benefits, risks, and ethical considerations associated with the military use of arthropods. It will offer a valuable resource for military strategists, policymakers, and researchers investigating arthropod-related warfare.

Weaponizing arthropods: From disease to disruption

Entomological warfare; a deliberate use of arthropods: Entomological warfare refers to the weaponization of arthropod vectors, utilizing their capabilities to disrupt operations, damage economies, cause long-term environmental damage, transmit diseases, spread chemical or radiological substances, and evade detection[7]. A related concept is arboterrorism which involves the intentional spread of arthropods as agents of terror or warfare. This represents a category of bioterrorism that uses living organisms as delivery systems to amplify the complexity and unpredictability of attacks, making vectors act as living dirty bombs[8]. Preferred bioterrorism vectors exhibit dual characteristics: high pathogenicity for maximum harm and wide host specificity to permit greater ecological disruption.

An ideal agent should be easy to propagate, ensuring rapid and extensive outbreaks, and capable of efficient transmission to required sites[7]. Both short and long-life cycles can be advantageous. Short cycles are suitable for immediate impact, and long ones for sustaining infections over time. Ease and cost-effectiveness of production, along with the feasibility

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of large-scale manufacturing, make the agent more accessible for malicious use. Moreover, resistance of vectors to control measures increases the likelihood of prolonged outbreaks, while stability during storage and transport preserves their effectiveness. Lastly, ecological adaptability enables the agent to thrive in diverse environments, supporting its persistence and continued threat[9].

Arboweapons (mosquitoes, ticks, fleas, lice, flies) are typically classified under Class A and B agents due to their ability to cause significant morbidity and general disruption. Additionally, the emergence of diseases such as Zika and Chikungunya, both transmitted by mosquitoes, suggests that specific vectors may also fall under Class C agents, given their evolving epidemiological significance and outbreak potential[8]. Genetic engineering advances could enable the creation of modified insects as covert biological weapons, potentially spread diseases or disrupt ecosystems while appearing natural. Advances in genetic engineering such as CRISPR-edited mosquitoes designed to suppress malaria could be weaponized to spread deadly pathogens. This dual-use dilemma challenges international treaties, as well-intentioned field research could be stolen to weaponize insect vectors for anonymous biological attacks by malicious actors[10].

Apart from the contribution of arthropods as vectors, venomous arthropods can produce toxins and venoms that could theoretically be harvested and weaponized for warfare[11]. Neurotoxic venoms from scorpions and spiders have the potential to injure or kill enemies. as low-tech but potent weapons. Large swarms of stinging insects, such as bees and wasps, can be directed at enemy troops to cause pain, panic, or even anaphylactic shock in allergic individuals[12].

Agroterrorism; targeting food systems and economic stability: Agroterrorism involves the intentional release of harmful agents into agriculture, affecting food production, and related supply chains to inflict economic damage, undermine food security, destabilize governments, and provoke social panic[13]. Targeting agricultural resources is a potent form of warfare. Invasive pests, including insects such as locusts, aphids, and beetles, can destroy crops and spread plant diseases resulting in widespread famine and economic devastation. Their capacity to cause mass starvation and widespread economic damage in unrest areas[14], together with the relatively inexpensive and ease of deployment, makes invasive pests' available agents for induction of widespread fear of economic disruption through starvation war[13]. The "insect allies" program proposed using insects to deliver environmental genetic alteration agents involving viral manipulation, insect vector optimization, and selective gene therapy[15]. The stated intention of this program is to save humanity from starvation by using insects to deliver protective genes to plants. Scientists and experts argue the program normalizes ecological weapons development, as insect vectors are inherently uncontrollable and could be repurposed to bypass bioweapon detection systems, a violation of the Biological Weapons Convention's prohibition on unidentifiable agents[16]. The lack of international governance for insect-vectored genetic tools creates alarming gaps for agroterrorism.

Disrupting ecosystems; a less visible form of warfare: In addition to causing direct harm to humans and agriculture, arthropods can disrupt ecosystems by preying on native species or modifying ecological processes. This disruption can trigger a cascading effect on food chains, nutrient cycling, and other essential functions, resulting in prolonged environmental damage and economic instability[17].

The human factor: Exploiting fear and shaping perceptions

Arthropods as tools of fear; psychological operations: Of note, PSYOPS refers to psychological strategies that weaken an enemy's morale and cohesion, through targeting the mind, exploiting cognitive biases, cultural fears, and emotional vulnerabilities[18]. Arthropods can relay entomophobia creating psychological disruption and panic among enemy populations. Their use as biological agents enables the spread of fear and chaos while weakening morale and operational effectiveness[19]. Efforts to reclaim areas affected by such tactics are often ineffective in alleviating the long-term psychological effects, which can lead to considering those areas unsafe even long after repossession takes place[3]. Modern PSYOPS have evolved with new technologies from using drones to acoustic warfare. Drones mimicking insects are frightening tools, and the deployment of insect cyborgs can create disturbing combat scenarios. In addition, mimicking of insect sounds enhances psychological distress *e.g.*, using buzzing sounds that resemble swarms of bees or wasps[20]. In the era of social media, arthropods can be used to spread misinformation. The diverse uses of these applications in creating threats or heightening public anxiety have the potential to manipulate information models.

Fake news stories and social media posts about swarms of deadly insects can trigger panic and anxiety among the population. This causes people to fear the outdoors, store insecticides, and demand action from their governments[21]. Artificial Intelligence (AI) can be used to analyze public reactions to arthropod-related stimuli, to tailor propaganda campaigns and to predict swarm behavior, thus aiding in maximizing psychological effects. AI amplifies misinformation campaigns and enhances their psychological effects[22].

Arthropods as living radiological dispersal devices; psychological impacts: Arthropods can serve as biological radiological dispersal devices (RDDs), spreading radioactive contamination in a more concealed and psychologically distressing way than conventional bombs. If these insects die or excrete radioisotopes, the radiation level remains relatively constant[23].

Emerging technologies: Arthropods as advanced platforms

Cyborg insects; bridging biology and robotics: Cyborg insects represent novel military technology, integrating living organisms with micro-electron-mechanical systems (MEMS). This fusion aims to control the natural capabilities of insects in sensing, communication, and movement control while enhancing them with human-controlled functions[24]. In 2008, the Defense Advanced Research Projects Agency (DARPA) called for an HI-MEMS (Hybrid Insect Micro-Electro-Mechanical Systems) program to serve as a channel for cyborg insect research. This initiative required the development of remotely controlled insect drones for military applications. DARPA's focus is on interdisciplinary research that enables the development of these insect-cyborgs, which can perform tasks such as surveillance and data collection[7].

Rather than designing robots from scratch, the HI-MEMS depend on existing insects' nervous systems and integrated MEMS devices for control and communication[25]. This approach offers several advantages. Firstly, insects are naturally self-powered, which means that cyborgs can operate for longer periods without needing constant control. Additionally, insects have evolved to survive in harsh conditions and environments, possessing natural abilities that may be difficult to replicate in mechanical drones. Furthermore, they are relatively less expensive compared to purely mechanical technologies that serve similar functions, making the mass production of cyborg insects commercially feasible. Examples of cyborg insects are beetles, cockroaches, moths, dragonflies, locusts, and bees. The control of these cyborgs is achieved through electrical stimulation, light, or tattoos attached to the wings. The cyborg is equipped with a backpack that contains a battery, a mini-computer, and an antenna for communication, all secured with beeswax[26,27].

Insect drones have military applications in surveillance, chemical and explosive detection, and search and rescue missions. They can access dangerous environments, detect hazardous agents, and locate survivors using heat or CO_2 sensors. Additionally, they serve as mobile communication relays in compromised infrastructure zones[24].

Arthropod-inspired robotics; mimicking nature's designs: The remarkable adaptation of arthropods has long served as a source of inspiration for robotic design. Biomimicry, by imitating natural designs and processes, is being used to develop robots that mimic arthropods behavior[28]. The diverse range of arthropods' locomotion strategies is adapted to specific environments and tasks, inspiring the development of multiple-legged robots designs that can navigate rough topography, climb walls, and navigate obstacles with greater agility and stability. The advantages of such robots include being small and flexible, making their mass production achievable at a lower cost. Integrating AI in autonomous robotic swarms for military applications, has promising potential in space, underwater, and counterinsurgency operations[29]. These operations include military and political actions taken against a local social revolt while minimizing harm to the civilian population. While still in the research phase, these technologies are expected to soon become a matter of fact. Additionally, the locomotion and sensory adaptations of aquatic arthropods have guided the development of underwater robots and autonomous vehicles. These bio-inspired systems can navigate complex underwater environments, conduct survey missions, and detect mines by mimicking the efficient movement and perception mechanisms of marine arthropods[30,31].

Arthropods as living sensors: The biosensing capabilities of arthropods can be utilized in military applications since they possess highly developed sensory systems that allow them to detect a wide range of environmental stimuli, including chemical compounds, vibrations, and electromagnetic fields. Certain arthropods, such as locusts and bees, can detect explosives and chemical agents. By training these insects to respond to specific target compounds, they can be used as mobile detectors[28,32]. Arthropods can also be used as bioindicators to assess the health of ecosystems and monitor the presence of pollutants through studying the abundance, diversity, and physiological condition of arthropod populations[33].

Forensic entomology in conflict zones

Where traditional forensic methods may be unavailable or unreliable, entomological evidence can provide critical insights into the circumstances surrounding war crime investigations[34]. Warfare often results in widespread loss of life, including civilian casualties, prisoners of war, and victims of genocide or ethnic cleansing. In such scenarios, arthropods drive the discovery and investigation of war crimes and mass graves through their involvement in the decomposition process[35]. Forensic entomology can aid in identifying victims of war crimes by estimating the post-mortem interval (PMI) and providing clues about the geographic origin of the remains. The stage of development, species composition, and insect succession can provide valuable information about the timing and circumstances of death. Entomo-toxicology, the analysis of toxins and other substances in insects, can provide evidence of poisoning, drug use, or exposure to chemical weapons. Additionally, insects feeding on human remains can contain DNA, allowing for victim identification even in advanced stages of decomposition[36]. In cases of torture, the presence of conditions like scabies, myiasis, and insect bite marks on a corpse can suggest injuries that occurred ante-mortem[37].

The role of arthropods in combat support; sustaining operational success: Combat support includes the logistical, medical, environmental, and technological systems that enable military forces to operate effectively during warfare[38].

Arthropods in field medicine: Arthropods have a dual role in field medicine during war. While they present significant risks as disease vectors and venomous predators that compromise troop health, they also provide innovative solutions in field medicine, such as maggot debridement therapy in wound care. This can be very beneficial in cases from areas where it may be difficult to secure transport[39]. Pharmaceuticals derived from venom are utilized to create antidotes and investigate their therapeutic potential in apitherapy for pain relief, anti-inflammatory medications, and cancer treatment[40,41].

Arthropods in logistics: Logistics is a critical component of military operations, ensuring the on-time delivery of resources such as food, water, medicine, and equipment to troops. Arthropods impact logistics efficiency and sustainability both directly and indirectly[38-42]. Arthropods successfully address food security challenges during warfare, offering innovative solutions to maintain sustainable, high-nutritional values with low environmental impact. Arthropods provide rich sources of protein, essential amino acids, omega-3 fatty acids, vitamins, fiber (from chitin found in their exoskeletons), and important minerals like iron, zinc, magnesium, and B vitamins[43,44]. Arthropods contribute to biodegradation and waste management during warfare, offering sustainable sanitation and environmental restoration by their natural behaviors and adaptability, making them invaluable in maintaining hygiene, conserving resources, and pollution mitigation during conflict[45]. Arthropods take part in the ecological recovery of damaged environments during and after conflicts, contributing to the restoration of all forms of life[46].

Operational roles of arthropods in future military and security contexts

Arthropods as bio-inspired tools for cybersecurity: Biomimicry of arthropods has emerged as a promising approach in advancing digital defense systems, offering innovative strategies for cybersecurity. One such concept is swarm intelligence, inspired by the decentralized and self-organizing behaviors of ants, bees, and fireflies that efficiently solve complex tasks such as search and rescue, environmental monitoring, and coordinated attacks[47,48]. In cybersecurity, this principle is applied to distributed threat detection and rapid response. Digital agents, modeled after ants, autonomously navigate networks, detect anomalies, and leave behind digital trails that alert others, enabling a swarm-based response to emerging cyber threats[59-50]. Another arthropod-inspired tactic is camouflage and deception. Many arthropods rely on these survival strategies to evade predators, blending into their environments or mimicking other organisms. Similarly, cybersecurity systems can utilize deception techniques, such as honeypots and misleading data paths, to confuse attackers and protect sensitive information, reducing the risk of successful breaches[51-52]. Furthermore, immune system comparisons drawn from arthropods facilitate the design of adaptive cyber defense systems. Arthropods possess innate immune mechanisms capable of detecting and neutralizing pathogens. These biological principles inspire interference detection systems that use different detection procedures to identify and respond to cyber threats dynamically[53].

Arthropods in autonomous supply chains: Arthropod-inspired algorithms that mimic ant colonies behavior through decentralized and adaptive decision-making can enhance autonomous supply chains by improving logistics, resource allocation, and distribution. This approach boosts the efficiency and flexibility of military supply chains, particularly in challenging, rapidly changing military operations[54].

Arthropods in multi-domain operations: Multi-domain operations (MDO) involve coordinated actions across land, sea, air, space, and cyberspace. The behaviors of arthropod swarms serve as a model for autonomous systems that can operate hand in hand across multiple domains. Inspired by insects, swarm robotics have been applied in aerial, marine, and ground-based scenarios, with potential for integration into MDO contexts[55].

Arthropods as models for military infrastructure: Arthropods' remarkable traits of abundance, adaptability, and self-repair inspire the design of resilient military infrastructure, such as self-healing networks, adaptive supply chains, and robust communication systems[54]. Inspired from arthropod colonies, military systems can improve their ability to survive and continue operating even when facing attacks[56].

Ethical and legal considerations governing arthropod-based warfare

International efforts to prohibit the development, production, trading, and use of biological weapons established the Biological Weapons Convention (BWC) in 1975. However, with limited scope for emerging technologies such as synthetic biology and gene editing, enhancing the capabilities of arthropods for weaponization could be manipulated. Additionally, the BWC lacks a verification mechanism for compliance with its principles. Addressing these gaps requires new laws and regulations[57].

Using arthropod-based weapons raises many ethical concerns regarding animal and human rights. Manipulating insects for military purposes may cause pain, suffering, or distress, raising moral objections regarding their use. The extent to which insects should be manipulated and controlled for military purposes and whether their use could result in unintended consequences that violate international humanitarian law needs reconsideration[58].

Additionally, ecological risks that can disrupt native ecosystems, harm biodiversity, and inflict economic damage exacerbate existing challenges rather than resolving them. The weaponization of arthropods, while offering potential advantages, presents a complex web of ethical and legal challenges that demand careful consideration and proactive authorities[59].

Real-world applications of arthropods in military contexts

Mosquitoes (Culicidae): They serve as vectors in bioterrorism, by spreading diseases such as malaria and Zika virus and are being studied for their potential to target crops using engineered gene drives[60].

Flies

- Brachycera, including blowflies (Calliphoridae) and flesh flies (Sarcophagidae), contribute to forensic entomology by feeding on human remains to provide DNA evidence for victim identification and estimating the PMI, particularly in post-conflict investigations like those in Bosnia[61].
- The black soldier fly (*Hermetia illucens*, Stratiomyidae) is employed by militaries to process organic waste at forward operating bases, aiding sanitation, environmental restoration, and logistical efficiency by converting waste into fertilizer or protein-rich food[62].
- Fruit flies (*Drosophila*) have been hypothetically considered for use in radiological dispersal devices to spread radioactive particles in contaminated zones[63].
- Dragonflies (Odonata) influence biomimicry and robotics due to their wing structures, which inspire drone designs with improved maneuvering for exploration missions[64].
- Butterflies and moths within *Lepidoptera* serve as bioindicators of environmental degradation due to their sensitivity to airborne pollutants[65].
- Genetically modified Bombyx mori change color when exposed to chemical agents like sarin gas, offering a visual warning system for detecting toxic substances[66].

Honeybees: *Apis mellifera* is trained to detect explosives like landmines through olfactory sensing of nitrate residues. Their acute sense of smell inspired chemical detection technologies, such as DARPA's (Stealthy Insect Sensor Project)[67].

Fleas (*Xenopsylla cheopis*) were historically weaponized by Japan's Unit 731 during World War II to spread bubonic plague through aircraft-dispersed infected fleas[68]. Water fleas (*Daphnia*) monitor toxins in water supplies near military bases, indicating environmental contamination[69].

Cockroaches: House crickets (*Acheta domesticus*) are explored as sustainable protein sources for military rations under initiatives like DARPA's "Insects as Food" program. Cockroaches (*Blaberus discoidalis*) are developed into cyborgs under DARPA's HI-MEMS program for surveillance and reconnaissance missions, while also being used in robotics for search-and-rescue operations in collapsed buildings after bombings[70]. Conversely, locusts (*Schistocerca gregaria*) pose threats as agroterrorism tools capable of devastating food supplies through swarming behavior, potentially leading to famine and economic destabilization[71].

Beetles: Species of Coleoptera play multiple roles in warfare. They aided forensic entomology by detecting explosives at blast sites in Kosovo and Iraq[35]. They act as covert radiological dispersal devices when contaminated with radioactive isotopes, causing psychological distress[72]. Dung beetles assist in desert operations by managing animal waste and maintaining hygiene[73]. *Mecynorrhina torquata* are developed into cyborg insects through DARPA-funded research, allowing remote control via implanted electrodes for surveillance purposes[74]. Larvae of the yellow mealworm beetles (*Tenebrio molitor*) offer innovative dietary solutions while promoting sustainability by converting organic materials into protein-rich biomass[75]. Soft-bodied beetles (fireflies, Lampyridae) inspire cybersecurity systems based on swarm intelligence that patrol networks, detect anomalies, and mitigate threats collaboratively[76].

Ants: *Termites* (Termitoidae) assist in habitat rehabilitation post-conflict by recycling abandoned wooden structures, contributing to ecological recovery[77]. On the other hand, genera of Formicidae influence military algorithms inspired by colony behavior, optimizing logistics, search-and-rescue missions, reconnaissance, and swarm robotics[78].

Spiders: Genera of *Araneae* are used in psychological operations; for example, ISIS utilized spider imagery in propaganda to symbolize fear and entrapment[79]. Spider silk is explored for bulletproof vests, medical sutures, and parachute cords, while chitin from arthropod exoskeletons inspires bioplastics and wound-healing applications[80].

Scorpion venom contains peptides useful for pain relief and cancer treatment, demonstrating dual-use potentials in medicine and warfare[81].

CONCLUDING REMARKS

1. Since arthropods are easily accessible, they have unique contributions to warfare from ancient times (throwing beehives) to modern research (cyborg insects and genetic engineering).
2. Balance between advantages and risks is mandatory. Insects have the ability to heal injuries, eliminate waste, and motivate the development of life-saving technologies. Meanwhile, they have potential hazards if not utilized properly, they may transmit diseases, and disrupt ecosystems.
3. Existing laws, including the biological weapons convention, does not adequately address emerging technologies like gene-edited mosquitoes or robotic

insects. Clear regulations are essential to prohibit detrimental applications and facilitate non-threatening research.
4. Legal outline for using arthropods in conflict zones while balancing tactical military needs against potential risks to human health, food security, and environmental stability and ethical requirements are mandatory. Therefore, it is necessary to plan for risk mitigation through early identification, appropriate surveillance systems, and remediation and recovery measures.
5. Entomological experts must be included in both anti-terrorism investigations and the points of entry security teams. A strong international partnerships plan to mitigate the risks through early detection, proper surveillance systems, and plan remediation and recovery actions is needed. Finally, transparent communication with the community is necessary to align decisions with public values and security requirements. By adopting this complex approach, we can gain the potential benefits of arthropods while minimizing the risks, thereby supporting global security and ecological well-being.
6. Nowadays, arthropods are used to reduce risks in conflict zones with smart strategies, *e.g.*, monitoring arthropod populations in war zones to detect unnatural changes, and using nature's solutions to clean up after conflicts, utilizing waste-eating insects.
7. There is a need for international collaboration to revise laws to encompass emerging insect-derived technologies, allocate resources towards preventing misuse, *e.g.*, halting unauthorized insect weaponry, and educate decision-makers regarding these threats and possibilities. Through prudent management of arthropods, it will be feasible to harness their distinctive capabilities for beneficial purposes, while ensuring the safety of communities and the environment.

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REFERENCES

1. Sollai G, Giglio A, Giulianini PG, Crnjar R, Solari P. Topic: Arthropod biodiversity: Ecological and functional aspects. Insects 2024; 15(10):766.
2. Chakravarthy AK, Shashank PR. Arthropods: Evolution and ecology. In: Economic and Ecological Significance of Arthropods in Diversified Ecosystems: Sustaining Regulatory Mechanisms; Chakravarthy AK, Sridhara S (Eds), 1st ed.; Springer International Publishing, Cham, Switzerland; 2016;1-17.
3. Lockwood JA. Insects as weapons of war, terror, and torture. Annu Rev Entomol 2012; 57(1):205-227.
4. Li P. Japan's biochemical warfare and experimentation in China. In: Japanese War Crimes; Tanaka Y, McCormack T, Simpson G (Eds.) (2nd ed.); Routledge, London, UK, 2017; 289-300.
5. Biselli R, Nisini R, Lista F, Autore A, Lastilla M, De Lorenzo G, *et al*. A historical review of military medical strategies for fighting infectious diseases: From battlefields to global health. Biomedicines 2022; 10(8):2050.
6. Clark DP, Pazdernik NJ. Biological warfare: Infectious disease and bioterrorism. Biotechnology 2015; 2015:687-719.
7. Lockwood JA. Six-legged soldiers: Using insects as weapons of war. In Lockwood JA (Ed.), 1st ed., Oxford University Press; New York; 2008: 337.
8. Kwak ML. Arboterrorism: Doubtful delusion or deadly danger. J Bioterror Biodef 2016; 8(1):1-4.
9. Nchu F. Sustainable biological control of pests: The way forward. Appl Sci 2024; 14(7): 2669.
10. Ray S, Banerjee A: Genetic engineering of insects and their application. Futur Trends Biotechnol. 2022;2(19):217–232.
11. Bhaskar AS, Sant B. Toxins as biological warfare agents. In: Rai M (Editor). Handbook on Biological Warfare Preparedness. 1st ed. Cambridge (MA), Academic Press, 2020; 33–64.
12. Lüddecke T, Paas A, Harris RJ, Talmann L, Kirchhoff KN, Billion A, *et al*. Venom biotechnology: Casting light on nature's deadliest weapons using synthetic biology. Front Bioeng Biotechnol. 2023; 3(11):1166601.
13. Sharma S, Loveleen, Bhargav VB, Adhikary A. The forensic frontier: Countering agro-terrorism in the agricultural sector. Adv Biores 2024; 1:165–171.
14. Babar TK. Risks of deserts locust and its mitigation. In: Ayyappan S, Jat ML (Eds), Disaster Risk Reduction in Agriculture, 1st ed, Singapore: Springer Nature Singapore, 2023; 361–392.
15. Pfeifer K, Frieß JL, Giese B. Insect allies: Assessment of a viral approach to plant genome editing. Integr Environ Assess Manag 2022; 18(6):1488-1499.
16. Devos Y, Mumford JD, Bonsall MB, Camargo AM, Firbank LG, Glandorf DC, *et al*. Potential use of gene drive modified insects against disease vectors, agricultural pests and invasive species poses new challenges for risk assessment. Crit Rev Biotechnol 2022; 42(2):254-270.
17. Wilson RJ, Fox R. Insect responses to global change offer signposts for biodiversity and conservation. Ecol Entomol 2021; 46(4):699-717.
18. Herberger K. The role of mental health professionals in PSYOP. In: Mind warfare: Psychological operations and the inducement of psychosis in military strategy. Herberger K (Ed.), 1st ed., self- published; 2025.
19. Taylor M. Domesticity and fear: Insects and creepy crawlies. In: Taylor M, Downey G, Meade T (Eds.), Domesticity under Siege: Threatened Spaces of the Modern Home. 1st ed., Bloomsbury Publishing, London (UK): 2022:237–224.

20. Li Y, Sato H. Insect-computer hybrid robot. Mol Front J 2018; 2(01):30-42.
21. Yamamoto K, Ariyanto M, Refat CMM, Morishima K. Multi-cyborg insect-linked formation for object transportation. In: 2023 IEEE International Conference on Mechatronics and Automation (ICMA). Available online at https://ieeexplore.ieee.org/document/10215744.
22. Vinay R, Spitale G, Biller-Andorno N, Germani F. Emotional prompting amplifies disinformation generation in AI large language models. Front Artif Intell 2025; 8:1543603.
23. Goddard B, Metwally W, Ababneh A. Irradiation experiment for living insect-based radiological dispersal device. Int J Nucl Secur 2018; 4(1):3.
24. Siljak H, Nardelli PH, Moioli RC. Cyborg insects: Bug or a feature? IEEE Access 2022; Available online at https://ieeexplore.ieee.org/document/9770076
25. Uppal R. DARPA's HI-MEMS created cyborg insects for military micro air vehicles missions. International Defense, Security and Technology; 2019, Available online at https://idstch.com/technology/electronics/electronics-for-extreme-environments/ Last update: Jan 24, 2025.
26. Pimentel H Jr. Cyborg insect drones: Research, risks, and governance. UC Davis environmental law report 2017 available at https://law.ucdavis.edu/sites/g/files/dgvnsk10866/files/media/documents/Cyber-Insect-Drones-Heraclio-Pimentel-Jr.Fall-2017.pdf.
27. Bharghavi K, Madhuri B, Vinutha RK, Srija P, Supraja KVL, Satwika M, *et al*. Sting of defeat: Insect as protective cyborg: A review. Plant Arch 2024; 24(2):2265–2272.
28. Cornejo J, Sierra-Garcia JE, Gomez-Gil FJ, Weitzenfeld A, Acevedo FE, Escalante I, *et al*. Bio-inspired design of hard-bodied mobile robots based on arthropod morphologies: A 10-year systematic review and bibliometric analysis. Bioinspir Biomim 2024; 19(5):051001.
29. Zhou Z, Mei H, Li R, Wang C, Fang K, Wang W, *et al*. Progresses of animal robots: A historical review and per-spectiveness. Heliyon 2022; 8(11):e11499.
30. Hepworth AJ, Yaxley KJ, Baxter DP, Keene JC. Report on applied research directions and future opportunities for swarm systems in defense. Canberra (AU): Australian Army Research Centre; 2022. Available at https://researchcentre.army.gov.au/library/occasional-papers/swarming-and-counter-swarming.
31. Foster KL, Petty MD. Estimating the tactical impact of robot swarms using a semi-automated forces system and design of experiments methods. J Def Model Simul 2021; 18(3):247-269.
32. Nemiroski A, Shevchenko YY, Stokes AA, Unal B, Ainla A, Albert S, *et al*. Arthrobots. Soft Robot 2017; 4(3):183-190.
33. Gruss I, Twardowski J, Nebeská D, Trögl J, Stefanovska T, Pidlisnyuk V, *et al*. Microarthropods and vegetation as biological indicators of soil quality studied in poor sandy sites at former military facilities. Land Degrad Dev 2022; 33(2):358-367.
34. Deps PD, Aborghetti HP, Zambon TL, Costa VC, Dos Santos JD, Collin SM, *et al*. Assessing signs of torture: A review of clinical forensic dermatology. J Am Acad Dermatol 2022;87(2):375-380.
35. Viero A, Montisci M, Pelletti G, Vanin S. Crime scene and body alterations caused by arthropods: Implications in death investigation. Int J Legal Med 2019; 133:307–316.
36. Haxhiaj S. Among the dead: Forensic scientists recall horror of Kosovo's mass graves. Balkan Insight. Pristina. 2023. Available online at: https://balkaninsight.com/2023/08/30/among-the-dead-forensic-scientists-recall-horror-of-kosovos-mass-graves/
37. Hanson I. Mass graves: The forensic investigation of the deaths, destruction and deletion of communities and their heritage. Hist Environ Policy Pract 2023; 14(3):359-401.
38. Sander M. Medical logistics sustainment in multidomain operations. U.S. Army 2023. Available online at https://www.army.mil/article/267687/medical_logistics_sustainment_in_multidomain_operations.
39. Nnachi IA, Okeanya BC, Ezinwa HC. Maggot debridement therapy and innovation from myiasis: A review. Bio-Research 2022; 20(3):1721-1729.
40. Freuville L, Matthys C, Quinton L, Gillet JP. Venom-derived peptides for breaking through the glass ceiling of drug development. Front Chem 2024; 12:1465459.
41. Zona Rubio DC, Aragón DM, Almeida Alves I. Innovations in snake venom-derived therapeutics: A systematic review of global patents and their pharmacological applications. Toxins 2025; 17(3):136.
42. Shehzad K, Tu S, Majeed MZ, Lei B, Zhang J. Arthropods in soil reclamation and bioremediation: Functional roles, mechanisms and future perspective. J Environ Manage 2024; 370:122820.
43. Lange KW, Nakamura Y. Edible insects as future food: chances and challenges. J Future Foods 2021; 1(1):38-46.
44. van Huis A. Progress and challenges of insects as food and feed. In: Purslow PP (Ed.), New aspects of meat quality, 2nd ed. Elsevier; Cambridge (MA); 2022; 533-549.
45. Yang XG, Wen PP, Yang YF, Jia PP, Li WG, Pei DS. Plastic biodegradation by *in vitro* environmental microorganisms and i*n vivo* gut microorganisms of insects. Front Microbiol 2023; 13:1001750.
46. Schapheer C, Pellens R, Scherson R. Arthropod-microbiota integration: Its importance for ecosystem conservation. Front Microbiol 2021; 12:702763.
47. Di Fiore C, Nuzzo A, Torino V, De Cristofaro A, Notardonato I, Passarella S, *et al*. Honeybees as bioindicators of heavy metal pollution in urban and rural areas in the South of Italy. Atmosphere 2022; 13(4):624.
48. Chowdhury S, Dubey VK, Choudhury S, Das A, Jeengar D, Sujatha B, *et al*. Insects as bioindicator: A hidden gem for environmental monitoring. Front Environ Sci 2023; 11:1146052.
49. Vashisht S. Tactical training using augmented reality/virtual reality and haptics. In: The 4th International Conference on Technological Advancements in Computational Sciences (ICTACS); 2024; 646-651. Available at https://ieeexplore.ieee.org/abstract/document/10840957.
50. Chui KT, Liu RW, Zhao M, Zhang X. Bio-inspired algorithms for cybersecurity: A review of the state-of-the-art and challenges. Int J Bio-Inspir Comput 2024; 23(1):1-15.
51. Truong TC, Huynh TP, Zelinka I. Applications of swarm intelligence algorithms countering the cyber threats. In: Proceedings of the 2020 Genetic and Evolutionary Computation Conference Companion. 2020; 1476-1485. Available online at https://doi.org/10.1145/3377929.3398119.

52. Almeshekah MH, Spafford EH. Cyber security deception. In: Jajodia S, Subrahmanian VS, Swarup V, Wang C (Eds), Cyber Deception: Building the Scientific Foundation. 1st ed.; Springer; Cham, Switzerland; 2016; 23–50.
53. Schrom E, Kinzig A, Forrest S, Graham AL, Levin SA, Bergstrom CT, *et al*. Challenges in cybersecurity: Lessons from biological defense systems. Math Biosci 2023; 362:109024.
54. Phonekeo S, Dave T, Kern M, Franklin SV, Hu DL. Ant aggregations self-heal to compensate for the Ringelmann effect. Soft Matter 2016; 12(18):4214-4220.
55. Chamanbaz M, Mateo D, Zoss BM, Tokić G, Wilhelm E, Bouffanais R, *et al*. Swarm-enabling technology for multi-robot systems. Front Robot AI 2017; 4:12.
56. Xin Q, Zhang J, Han Z, Zhao H, Hou T, Liu Y, *et al*. Advanced bio-inspired mechanical sensing technology: learning from nature but going beyond nature. Adv Mater Technol 2023; 8(1):2200756.
57. National Academies of Sciences, Engineering, and Medicine. Gene drives on the horizon: Advancing science, navigating uncertainty, and aligning research with public values. Washington (DC): National Academies Press; 2016. Available online at https://doi.org/10.17226/23405.
58. Reeves RG, Voeneky S, Caetano-Anollés D, Beck F, Boëte C. Agricultural research, or a new bioweapon system? Science 2018; 362(6410):35-37.
59. Pelegrín-Borondo J, Arias-Oliva M, Murata K, Souto-Romero M. Does ethical judgment determine the decision to become a cyborg? Influence of Ethical Judgment on the Cyborg Market. J Bus Ethics 2020; 161(1):5-17.
60. Moreno RD, Valera L, Borgoño C, Castilla JC, Riveros JL. Gene drives, mosquitoes, and ecosystems: An interdisciplinary approach to emerging ethical concerns. Front Environ Sci 2024; 11:1254219.
61. Dias R, Viana T, Santos-Mallet JR, Alencar J, Queiroz MM. Development and intrapuparial characterization of Peckia (Euboettcheria) collusor (Curran and Walley, 1934) (Diptera: Sarcophagidae) for application in forensic entomology. Sci Rep 2024;14(1):15824.
62. Hu X, Zhang H, Pang Y, Cang S, Wu G, Fan B, *et al*. Performance of feeding black soldier fly (*Hermetia illucens*) larvae on shrimp carcasses: A green technology for aquaculture waste management and circular economy. Sci Total Environ 2024; 928:172491.
63. Komel S. Technology in scientific practice: How HJ Muller used the fruit fly to investigate the X-ray machine. Hist Philos Life Sci 2023; 45(2):22.
64. Santos LR, Rodrigues ME. Dragonflies (*Odonata*) in cocoa growing areas in the Atlantic Forest: Taxonomic diversity and relationships with environmental and spatial variables. Diversity 2022; 14(11):919.
65. Malireddi P, Jarpla M, Rajesh DP, Bandhavi HL, Desai HR. Safe-guarding insects as bio-indicators of environmental changes and pollution: A review. Plant Archives Plant Arch 2025; 25(1):1018-1032.
66. Abou-Donia MB, Siracuse B, Gupta N, Sokol AS. Sarin (GB, O-isopropyl methylphosphonofluoridate) neurotoxicity: Critical review. Crit Rev Toxicol 2016; 46(10):845-875.
67. Papa G, Maier R, Durazzo A, Lucarini M, Karabagias IK, Plutino M, *et al*. The honey bee *Apis mellifera*: An insect at the interface between human and ecosystem health. Biology 2022; 11(2):233.
68. Wilson JM, Daniel M. Historical reconstruction of the community response, and related epidemiology, of a suspected biological weapon attack in Ningbo, China (1940). Intell Natl Secur 2019; 34(2):278-288.
69. Hamilton JW. Contamination at U.S. Military Bases: Profiles and Responses. Stan Envtl Law J, 2017; 35:223–249. Available online at https://law.stanford.edu/wp-content/uploads/2017/01/hamilton_0.pdf
70. Murphy RR. Unmanned ground vehicle. In: Disaster Robotics, Murphy RR (Ed.), 1st ed., MIT Press, Cambridge (MA), 2017; 63–111.
71. Maeno KO, Ould ES, Ould MS, Jaavar MEH, Ould BEMA. Adult desert locust swarms, *Schistocerca gregaria*, preferentially roost in the tallest plants at any given site in the Sahara Desert. Agronomy 2020; 10(12):1923.
72. Goddard B, Metwally W, Ababneh A. Irradiation experiment for living insect-based radiological dispersal device. Int J Nucl Secur 2018; 4(1):3.
73. Fowler F, Denning S, Hu S, Watson W. Carbon neutral: The failure of dung beetles (*Coleoptera*: Scarabaeidae) to affect dung-generated greenhouse gases in the pasture. Environ Entomol 2020; 49(5):1105-1116.
74. Doan TT, Sato H. Insect-machine hybrid system: remote radio control of a freely flying beetle (*Mercynorrhina torquata*). J Vis Exp 2016; 115:54260.
75. Bosch G, Van Zanten HHE, Zamprogna A, Veenenbos M, Meijer NP, Van der Fels-Klerx HJ, *et al*. Conversion of organic resources by black soldier fly larvae: Legislation, efficiency and environmental impact. J Clean Prod 2019; 222:355-363.
76. Irfan M. Nature-inspired techniques in cybersecurity: Evolving approaches to domain detection and threat mitigation. DOI: https://doi.org/10.13140/RG.2.2.14573.81124, 2024.
77. Rodríguez-León CH, Peña-Venegas CP, Sterling A, Castro D, Mahecha-Virguez LK, Virguez-Díaz YR, *et al*. Soil quality restoration during the natural succession of abandoned cattle pastures in deforested landscapes in the Colombian Amazon. Agronomy 2021; 11(12):2484.
78. Ghelis D. Towards an efficient multi-robots search and rescue strategy. Master’s Thesis, Department of Computer Science, Faculty of Mathematics, Computer Science and Science of Matter, University of 8 May 1945, Guelma, Algeria, 2023. Available online at http://dspace.univ-guelma.dz/jspui/handle/123456789/14986.
79. Venkatesh V, Podoshen JS, Wallin J, Rabah J, Glass D. Promoting extreme violence: Visual and narrative analysis of select ultraviolent terror propaganda videos produced by the Islamic State of Iraq and Syria (ISIS) in 2015 and 2016. Terror Polit Violenc 2020; 32(8):1753-1775.
80. Branković M, Zivic F, Grujovic N, Stojadinovic I, Milenkovic S, Kotorcevic N. Review of spider silk applications in biomedical and tissue engineering. Biomimetics 2024; 9(3):169.
81. Rapôso C. Scorpion and spider venoms in cancer treatment: State of the art, challenges, and perspectives. J Clin Transl Res 2017; 3(2):233.