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**SCIENTIFIC INNOVATIONS IN MEAT AND MEAT
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Meat production, food safety, biotechnology, precision livestock farming, cultured meat, alternative proteins, nanotechnology, automation, sustainability, genomic selection, cold chain management.

ABSTRACT

The global meat industry is undergoing profound transformation driven by rapid advances in science and technology. Increasing population growth, rising protein demand, environmental concerns, food safety challenges, and consumer expectations for high-quality products have stimulated innovation across the entire meat production chain. From precision livestock farming and genomic selection to alternative proteins and advanced processing technologies, scientific developments are reshaping traditional systems. Modern meat production is no longer limited to conventional slaughter and processing; instead, it integrates biotechnology, nanotechnology, automation, digital monitoring systems, and sustainable resource management. These innovations aim to enhance productivity, ensure safety, reduce environmental impact, and improve nutritional value.

One of the most significant innovations in modern meat production is Precision Livestock Farming (PLF). This system integrates sensors, artificial intelligence, big data analytics, and automated monitoring tools to optimize animal health, welfare, and productivity. Wearable sensors track body temperature, heart rate, movement, and feeding behavior, allowing early detection of disease and stress. Automated feeding systems adjust nutrient supply according to individual growth stages, improving feed conversion efficiency.

Digital technologies also reduce antibiotic overuse by identifying illnesses at early stages, thereby

contributing to antimicrobial resistance control. Furthermore, satellite-based pasture management and environmental monitoring improve sustainability by optimizing water and feed resource use.

Genomic technologies have revolutionized animal breeding. Through whole-genome sequencing and marker-assisted selection, producers can identify desirable traits such as disease resistance, rapid growth, improved meat quality, and reduced environmental footprint.

CRISPR-based gene editing offers precise modification of genetic traits without introducing foreign DNA. For example, gene editing has been applied to enhance resistance to viral diseases in



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pigs and to improve muscle growth efficiency. Biotechnology also supports the development of probiotic and prebiotic feed additives that enhance gut health and nutrient absorption. One of the most groundbreaking scientific innovations is the development of cultured meat, also known as cell-based or lab-grown meat. Instead of raising and slaughtering animals, muscle cells are cultivated in bioreactors under controlled conditions. This technology significantly reduces greenhouse gas emissions, land use, and water consumption compared to conventional livestock systems.

Companies such as UPSIDE Foods and Mosa Meat are pioneering commercial-scale cultured meat production. In 2023, regulatory approval in Singapore and the United States marked a milestone for the industry.

In addition, plant-based meat analogues have advanced significantly using extrusion technology to replicate muscle fiber structure and texture. These alternative proteins aim to complement conventional meat production while addressing sustainability concerns. Modern meat processing increasingly relies on non-thermal technologies to preserve quality and safety. High-Pressure Processing (HPP) inactivates pathogenic microorganisms without significant heat damage, preserving nutritional and sensory properties. Pulsed Electric Field (PEF) technology enhances microbial control and improves meat tenderness.

Cold plasma technology has emerged as a promising non-chemical method for surface decontamination. It effectively

reduces bacterial contamination while minimizing changes in texture and flavor.

Automation and robotics in slaughterhouses and processing plants improve hygiene standards, reduce human error, and enhance worker safety. Smart packaging with embedded sensors monitors freshness and detects spoilage gases, extending shelf life and reducing food waste. Blockchain technology ensures transparency and traceability throughout the supply chain. Each stage—from farm to retail—is digitally recorded, enabling rapid response in case of contamination outbreaks. Combined with Internet of Things (IoT) sensors, cold chain integrity can be monitored in real time to prevent temperature abuse.

Rapid diagnostic tools, including PCR-based pathogen detection and biosensors, allow early identification of Salmonella, Listeria, and other foodborne pathogens. These systems significantly reduce public health risks and economic losses. Sustainability is central to scientific innovation in meat production. Methane-reducing feed additives, such as algae-based supplements, lower greenhouse gas emissions from ruminants. Water recycling systems and renewable energy integration reduce environmental impact.

Life Cycle Assessment (LCA) models help evaluate carbon footprint, water use, and ecological impact, enabling evidence-based sustainability strategies. Waste valorization technologies convert by-products into bioenergy, collagen, gelatin, and high-value proteins, contributing to circular economy principles. Scientific innovation in meat and meat product production is



transforming the industry toward greater efficiency, safety, and sustainability. The integration of biotechnology, digital monitoring, advanced processing, and alternative protein development addresses global challenges such as food security, environmental impact, and public health. Future progress will depend on

interdisciplinary research, regulatory harmonization, and responsible implementation of emerging technologies. By combining scientific rigor with sustainable practices, the meat industry can meet growing global demand while minimizing ecological and ethical concerns.

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