The Effects of Gene Editing and Digital Monitoring Tools on Cattle Health and Productivity

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Abstract

Gene editing and digital monitoring tools are current advancements that are enhancing cattle health and productivity. Gene editing is a scientific process in which genes are manipulated to alter genetic traits, with the intention of preventing diseases and other harmful factors. CRISPR-Cas9 is the most successful form of modern-day gene editing. The first successful example of its use was on pigs. In this experiment, it was found that CRISPR-Cas9 boosted nutritional quality and increased the rate of production. This justified continuing research and the use of this technology for livestock. However, there is controversy and concerns regarding gene editing, questioning the morality of altering livestock for human benefits. Gene editing leads to improved quality of life and longevity in livestock. Over time, gene editing has become a valuable technique in enhancing cattle health. With the use of modern technology and practices, livestock agriculture continues to develop. Digital monitoring devices used for cattle care and health surveillance are crucial as production in cattle has continued to rise with these tools. An example of these devices is wearable sensors, such as RFID tags, used to monitor cattle behaviors, that ultimately gather data that aligns with visual observations. Another example is the use of automatic feeding and milking systems for cattle to optimize their nutritional health needs daily, which increases overall production and has been implemented on many farms. Gene editing aligns with some of the United Nations (UN) Sustainable Development Goals (SDGs), which focus on global hunger, innovation, and building sustainable food systems. Like gene editing, these digital monitoring tools also address the UN SDG of sustainable consumption and production patterns, since faster production is necessary to keep up with the increase in the human population. These two advancements in veterinary medicine and animal husbandry improve cattle health, which in turn maintains strong production while benefiting humans.

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Introduction

Technological advancements in the agricultural sectors have enhanced cattle health and productivity, which supports the “one health” of agriculture: the connection and relativity between different species, where an individual species’ health affects other species. These developments also align with several United Nations (UN) Sustainable Development Goals (SDGs), specifically those focused on ending world hunger, fostering innovation, and promoting sustainable consumption and production. The developments also function within the Sustainable Agriculture systems of the USDA AFRI. These advancements would maintain these current healthy links, prevent zoonoses (diseases transmitted between animals and humans), and prevent species endangerment. Among the various agricultural sectors, veterinary medicine and animal husbandry both prioritize the welfare of animals. Veterinary medicine describes the technological and medical aspects of animal care in agriculture, while animal husbandry refers to the science of raising livestock while upholding their health. The developments, gene editing and digital monitoring tools, are two methods used in both fields to fulfill the agricultural goal of sustainability. Gene editing is a scientific process in which genes are removed, transitioned, or added to other genes to change an individual's characteristics. This helps enhance cattle’s health as it disposes of undesirable traits within their genes. Digital monitoring tools are devices that are used on cattle by scientists and producers in order to observe and optimize their health. As these fields receive more funding, there will be a decrease in the number of unhealthy cattle, facilitating the growth of beneficial products that people get from them. Gene editing and digital monitoring tools have improved cattle health and productivity, from both veterinary medicine and animal husbandry stakeholder perspectives.

Gene Editing

Gene editing is a new approach to breeding that allows scientists to alter specific DNA sequences to improve traits that can increase production in products such as dairy and beef. Unlike traditional breeding, which could take multiple generations, gene editing offers a faster, more precise alternative that can benefit farmers worldwide by providing the best genetic makeup for their cattle. Clustered Regularly Interspaced Short Palindromic Repeats, or CRISPR-Cas9, is the most efficient form of gene editing (Aboelhassan & Abozaid, 2024). It has a 50-80% success rate compared to other earlier alternatives, such as Zinc Finger Nuclease, or ZFN (10-30%), and Transcriptor Activator-Like Effector Nuclease, or TALEN (20-60%) (Jiang & Shen, 2019). In CRISPR-Cas9, scientists can cut and modify DNA at exact nucleotides, allowing them to alter the traits within the DNA sequence. This opens the door to creating cattle that are healthier, more productive, and better adapted to meet the demands of the beef and dairy market.

In the lab, scientists first begin the process of gene editing by identifying the specific gene they wish to alter. Using CRISPR-Cas9, scientists can precisely cut the genetic sequence they intend to change. CRISPR helps guide the protein Cas9 to the specific sequence that needs to be cut (Research Outreach, 2020). This forms a DNA double-strand break, which activates the cell’s regeneration, ensuring the completion of CRISPR-Cas9. Once deemed successful, the edited embryo goes through a testing process and is implanted into a surrogate cow to develop naturally.

However, this process raises ethical and financial concerns from an average farmer's standpoint. The cost of the CRISPR-Cas9 process is high, and it is not guaranteed to work 100% of the time. It also requires a specialized team that will, in turn, require some salary. Due to these challenges, gene editing in cattle is not as widespread in commercial farming.

The United Nations (UN) Sustainable Development Goals (SDGs) 2 and 9 directly align with gene editing as they address global hunger and the need for innovation. SDG 2 aims to end hunger worldwide, achieve food security, and promote sustainable agriculture (United Nations, 2015). Gene editing improves livestock health, reducing deaths from disease by strengthening the animals' immune systems, increasing the productivity of meat and dairy cattle, and making food more accessible and affordable. At the same time, SDG 9 fosters innovation and builds sustainable food systems. Gene editing aligns with this goal by advancing biotechnology in agriculture and driving technological progress in the community. Together, SDGs highlight how gene editing is not only a solution for food production challenges but also helps advance scientific and sustainable economic development.

In 1985, gene editing began impacting the livestock industry in pigs to increase growth and obtain more product (Fischer & Schnieke, 2023). This method, called Pronuclear DNA micro-injections, has been proven to be inefficient and, because of the high number of animals necessary for it, was deemed unethical to the animals being tested on. In 2012, CRISPR-Cas9—although present since the 1980s—created a breakthrough in the gene editing world, allowing scientists to cut and modify DNA at specific nucleotides to increase animal productivity (Gostimskaya, 2022). In cattle, CRISPR-Cas9 boosts nutritional quality and increases the rate of production, specifically in beef and dairy. Because of CRISPR-Cas9, scientists are able to make genetic changes at an embryonic level, inseminate the altered embryo into a female cow, and raise the cows as if they were unaltered.

Gene editing in cattle raises important ethical questions and global controversy. Some people argue that gene editing increases animal husbandry and welfare by reducing disease, while others argue that gene editing crosses a moral line because it alters animals for human benefit. Many people have also raised concerns about consumer rights regarding gene-edited product labeling, believing that consumers should be informed when animal products have undergone modifications (Lee, 2025).

Gene editing refers to the precise modification of an organism's DNA using advanced biotechnology tools, which specifically include CRISPR-Cas9. This method of gene editing allows scientists to target and alter specific genes with high accuracy, without altering foreign DNA; unlike other, more commonly used forms of gene editing. In cattle, gene editing is used to influence desirable traits such as disease resistance, improved growth rates, and better tolerance to environmental stressors. The process involves first identifying a specific DNA sequence, then using a guide RNA to direct the Cas9 enzyme to that sequence, and then finally either disabling a gene or inserting a beneficial mutation (Gim et al., 2021). This form of veterinary medicine is revolutionizing animal agriculture by providing breeders with a more efficient and ethical way to improve livestock genetics (Liu et al., 2022).

From a veterinary perspective, gene editing offers significant advantages in disease prevention and overall cattle health. By editing genes linked to disease immunity, cattle can be more resistant to viruses and bacteria that previously required extreme medical intervention. Veterinarians also benefit from fewer cases requiring antibiotic treatments, which supports efforts to combat antibiotic resistance in livestock. Additionally, gene editing can help address congenital issues in cattle, like genetic disorders that may affect fertility, digestion, or skeletal structure. Overall, gene editing may lead to improved quality of life and longevity in livestock herds (Xu et al., 2025).

Historically, cattle have been more vulnerable to both environmental and genetic stressors. Before the introduction of gene editing, farmers and veterinarians relied heavily on reactive measures like antibiotics, vaccines, or euthanizing very sick animals. In the past, livestock tended to live shorter and lead less healthy lives due to disease outbreaks, harsh climates, or hereditary conditions that could not be easily addressed (Hein, 2023). Now with gene editing, the welfare of cattle has significantly improved. Animals can be bred to withstand higher temperatures, resist many different diseases, and even avoid painful procedures. These procedures may include dehorning, which can be avoided through the genetic removal of a horned trait (Schuster et al., 2020). Gene editing not only reduces suffering but also minimizes the need for invasive interventions, further supporting a more humane and sustainable approach to animal agriculture (Mattia Pozzebon et al., 2024).

As time moves forward, animal producers are increasingly valuing gene editing as a tool to boost both productivity and efficiency in cattle farming (Unlocking Genetic Heat Tolerance in Cattle, 2024). Farmers and producers can select traits like faster growth, increased muscle mass, and improved feed conversion ratios. By doing this, gene-edited cattle represent a more profitable and sustainable option for meat and dairy production. Additionally, traits that reduce disease risk and improve fertility result in fewer losses and lower costs overall. For example, editing genes linked to heat tolerance allows cattle to thrive in warmer climates. This will expand where they can be raised and reduce the rate of heat-related deaths (Camargo et al., 2023).

Digital Monitoring Tools

Humans have been practicing animal husbandry and monitoring animal health for centuries. Fortunately, as technology started to develop, so did cattle management strategies. The technologies used today, called digital monitoring tools (and automated systems), stem from long-standing issues. Another example of innovations used to monitor and care for cattle within a large group is digital technology. Over time, the makeup of the dairy industry has changed significantly; by 2021, less than 1.3% of total US employment was on farms (White, 2023). Dairy farming has generally shifted from smaller farms to large-scale operations. High market volatility of dairy products causes prices to be unstable, and smaller farmers are increasingly unable to financially compensate for investments and losses that occur. This has caused many smaller farms to consolidate into large companies. Although there are many fewer farms, overall production has continued to rise as cows become more efficient due to better breeding, management, and milking practices. These larger farms can afford investment in new technologies, such as automated

milking, feeding, and tracking systems, which not only make it possible to manage the labor shortage in the industry but also increase productivity in the individual cows by tailoring to each one's needs.

Technology that has become common technology among dairy cattle is an ear tag that monitors the cows' behavior. Depending on the farm, some monitoring systems connect with automated milking and feeding systems to track the intake and productivity of each cow. Depending on the tag, farmers can track the cows' behavioral patterns, including movement, using a built-in accelerometer and GPS, Radio Frequency Identification (RFID), and food and water intake. A study from Pereira in 2018 validates that the sensors can accurately monitor behaviors such as rumination, eating, drinking, and movement. By showing that the data gathered by the tags align closely with a farmer's visual observation of the cows, the data from the technology is becoming more widely accepted and lowers the stress of the shortage of workers in the industry (Pereira et al., 2018). Using technology to track individual cows' behavior, workers can efficiently monitor hundreds of animals. RFID is a technology that is often used to identify animals and keep track of individual animals throughout their lives as they are bought, sold, and reside within a large herd of cattle. A tag or other device goes on the cow and emits radio waves that are read by a sensor to identify the animal (Simanungkalit et al., 2021). They are also used by many automated feeding and milking systems to track the feed and supplement consumption, as well as the milk production of each animal, sorting and recording information to ensure each cow is given optimal nutrition and care.

The data gathered by these wearable technologies or sensors is used to monitor an animal's behavioral patterns, and an algorithm can be used to assess a range of normal behavior; if there is a significant change, the system will alert the workers. A study from Schupbach 2025 found that digital monitoring technology is even more efficient at detecting illness in cows than traditional human monitoring. Technology records data more accurately than visual observation, and the computer can identify outliers and trends better than a farmer would. It should be noted that this technology is intended for detection, not diagnosis. This technology is not used in place of a veterinarian, but to help farmers better monitor large herds of cattle and quickly identify individuals who need to receive care. Without this technology, it is unrealistic to properly monitor large herds on consolidated farms with a shrinking labor force. Using a tracking system along with mechanized milking and feeding has greatly increased productivity in dairy cattle.

Automatic feeding systems optimize individual cattle consumption of energy and nutrients using total mixed rations (TMR), feed that supplements cattle nutritional needs beyond forage. Mechanized feeding systems make it possible to customize feed to a group of cattle depending on their nutritional needs, which differs between heifers, dry cows, and milking cows. Research has shown that cows receiving adequate nutrition—often through supplement concentrates—will increase milk productivity (Schingoethe, 2017). The benefits of the system eventually overcome initial investment costs on large-scale operations by allowing farmers to reduce management and labor costs, but most importantly by increasing production when each cow has their nutritional needs met.

Another important branch of new technology used to care for and monitor cattle is automated milking systems (AMS). The process of milking has gone through significant changes since the early days of hand milking cows. From there, simple milking devices developed into fully automated robots that have now been integrated into most commercial farming operations. AMS' growth and advancement have been steadily increasing throughout the 20th century, contributing to enhanced quality and cultivation of animal husbandry in farms and pastures.

AMS first identifies which cow has entered the milking box through the RFID chip attached to their collar, ear, or leg tag. The milking box is a structure specifically designed to create an efficient yet stress-free environment for milking cows, which offers the animals the choice to wander in as they please. The cows often receive a feed incentive in the milking stall that further optimizes nutrition for each cow. Once the cow is standing in its allotted stall, a robotic arm uses sensors, lasers, or 3D cameras to find each teat. Then it preps the teat to stimulate milk let-down and thoroughly cleans and disinfects the teat. Most importantly, this automated system monitors the flow of milk from each teat and any abnormalities (Khutan et al., 2018). If abnormalities such as blood or clots are detected, the milk is rerouted to a waste bin. Then, the robotic arm disinfects the udder and opens the gates for the cow to roam freely (Morales-Piñeyrúa et al., 2023). Data on milk production per cow, as well as the quality of the milk, is uploaded into a software system that informs farmers so they can take action when needed. With the introduction of Artificial Intelligence, AMS technologies outside of robotic milkers have been in the making. These systems utilize Artificial Intelligence to calculate the amount of feed a cow should receive based on its performance (Tse et al., 2018). The computer can also monitor behavioral patterns in cows, such as kicking or stepping, or a dramatic change in output, to identify anything alarming and out of the ordinary that the farmer should investigate.

This technology was first put into practice by Lely Industries N.V., a Dutch company, through the support of its founder, Cornelis van der Lely, in 1992. Since then, AMS has benefited from countless dairy operations internationally and fostered animal husbandry. The average time spent milking cows went from five to two hours per day, reducing the reliance on manual labor (Sharipov et al., 2021). Additionally, milk yield increased to seven pounds of milk per cow every day, compared to the average of two pounds before, reflecting the crucial role of AMS in the prosperity of American dairy businesses. Beyond the benefits of reducing labor costs, the AMS is beneficial to the cows by allowing them to pick their milking schedule and reduce the discomfort of waiting long hours between milkings.

SDG 12 addresses sustainable consumption and production patterns. Because the planet has limited resources and the human population continues to grow, people will likely need to change their consumption habits to be more sustainable over time; however, production will still need to increase to meet the needs of more people (United Nations, 2015). Within agriculture, there are many limited resources, including land, labor, and water, which must be managed carefully to be practiced sustainably. These circumstances have driven the dairy industry to make animal care sustainable with fewer labor resources. Many of the new technologies developed—particularly automated feeding, milking, and digital tracking—are designed to help meet this goal of increased production using fewer resources. Overall advancements in technology have made

dairy production more efficient than ever, which will be necessary if current consumption patterns continue.

Conclusion

Gene editing and digital monitoring tools enhance cattle health and productivity. Gene editing alters cattle characteristics by modifying their genetic sequences during the embryonic stage. This cuts undesirable traits, reduces the risk of cattle diseases, and improves production efficiency (Gim et al., 2021). However, gene editing is very expensive, making it difficult to implement a large scale. Moreover, gene editing is a very controversial topic as it was created to benefit humans at the expense of animals, which raises questions regarding the morality of gene editing. New digital and mechanized technologies continue to improve animal care and health. These tools are put on cattle to track data, informing algorithms that can detect illnesses and alert veterinarians if the cattle need assistance, increasing effectiveness and productivity (Schupbach et al., 2025). Unlike gene editing, mechanized technologies have a lot of support from the people with minimal controversy. While implementing gene editing is a financial challenge, some mechanized technologies (mainly digital monitoring tools) are widely used. It is a fact that both advancements support overall cattle health and well-being, as they improve the production and efficiency in utilization (Peterson, 2017). This would support several United Nations (UN) Sustainable Development Goals (SDGs), as they aim to increase production with the goals of ending world hunger, encouraging innovation, and responsible production. With these goals in mind, technologies such as gene editing, digital monitoring tools, and automated systems will continue to influence the future of cattle production.

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