Lesson 1:
Artificial Insemination

Animal biotechnology began when humans began selecting and pairing more desirable animals during breeding to produce offspring of higher quality. Artificial insemination (AI) is an extension of selective breeding that gives livestock managers more options for improving offspring. The advantages and disadvantages of AI must be examined if it is to be used effectively.

Artificial Insemination

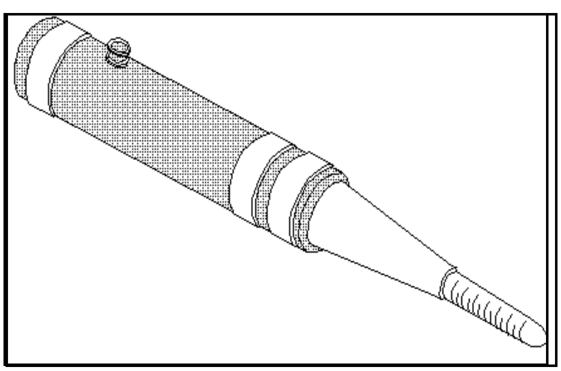
In 1780, an Italian researcher first developed a procedure for impregnating female animals without the presence of a male animal at breeding time. However, artificial insemination was not used by breeders until the late nineteenth and early twentieth centuries. Artificial insemination (AI) is the process of collecting semen from a male animal and placing it in the reproductive tract of a female animal. It is a form of biotechnology that is commonly used by livestock producers across the United States.

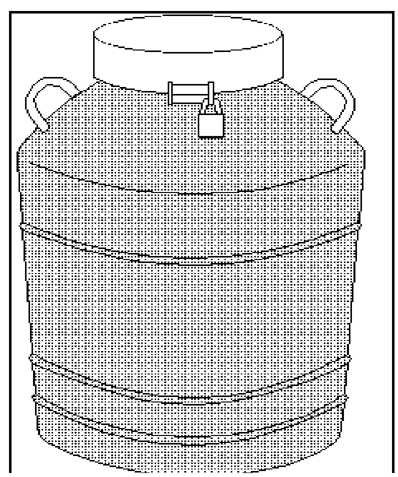
The Benefits of Artificial Insemination

Both artificial insemination and natural breeding have certain benefits. A major benefit of AI is that it allows producers to select and use male animals in their breeding programs that are proven performers, regardless of where the animals are physically located. Another benefit of AI is that reproductive or venereal diseases are not spread between breeding animals. A third benefit of AI is that it can reduce or eliminate the cost of owning and maintaining male animals for breeding purposes. The cost of the semen, the insemination process, and the hormones needed to manipulate the estrous cycle of female animals offset some of the economic benefits, but an AI system can still be more cost effective than a natural breeding system. One of the broader benefits of AI for the livestock industry as a whole is that the genetic improvement of livestock populations through the use of superior animals occurs much more quickly with AI, because of a dramatic increase in the number of offspring a male animal can produce (sire) per year. A single bull can only breed about 60 cows naturally in a year, but that same bull can be used to inseminate nearly 20,000 cows a year with AI.

Equipment for Artificial Insemination

Several different pieces of equipment are used for artificial insemination. Semen collection is most commonly done through the use of a dummy, which is a female replica. Male animals are trained to mount the dummy, and the penis is guided into an artificial vagina. The artificial vagina (see Figure 1.1) is a water-filled plastic sheath and has a collection tube in one end that holds the semen after ejaculation. A microscope is used when analyzing the collected semen. The semen is put into long, thin plastic tubes called semen straws. Each straw holds the amount of semen needed to breed one female. These straws are frozen and stored in an aluminum semen tank (Figure 1.2) containing liquid nitrogen. The straws are placed in an insemination instrument at the time of breeding. The insemination instrument is a long syringe-like tool that





holds the straw and deposits the semen into the female reproductive tract.

The Process of Artificial Insemination

Artificial insemination begins with the collection, inspection, and preparation of the semen. The collection of semen is important, since poor collection techniques will yield poor quality semen. After semen is collected using an artificial vagina, it is analyzed to examine the motility (active movement), shape, and quantity of the sperm. When the semen has been inspected, an extender is added to the semen to increase the volume. Several different types of extenders are used, but the most common are citrate, egg-yolk phosphate, and homogenized milk. These extenders protect and provide nourishment to the sperm when they are frozen. After the extenders have been added to the semen, it is placed in straws and frozen in liquid nitrogen at -320 degrees Fahrenheit.

The next part of the AI process begins when a producer decides to breed his or her animals. Producers must carefully manage the timing of insemination. Good semen and correct insemination procedures will not result in successful fertilization without proper timing. Each animal species has a different estrous cycle, which dictates the timing of insemination. Generally, insemination should occur shortly before ovulation.

When the time is right, the semen is thawed using proper thawing procedures to ensure that the sperm are not damaged. Once the semen is thawed, the straw is placed in the inseminating instrument, which is then inserted into the vagina of the animal being bred. The instrument is guided through the cervix, and the semen is placed just at the end of the cervix or the beginning of the uterus. A trained technician should perform this part of the process.

Manipulation of the Estrous Cycle

Female animals naturally produce the hormones that control the estrous cycle. However, through the injection of certain hormones, a producer can cause females to begin estrous as a group. This process, which is called estrous synchronization, simplifies the management of an artificial insemination program, because the animals in the group can all be bred within one or two days of each other.

Summary

Artificial insemination is an animal biotechnology that has a significant impact on the livestock industry. Artificial insemination is the process of collecting sperm from a male animal and placing it in the reproductive tract of a female animal. AI requires special equipment and close monitoring. The timing of insemination is critical to its success.

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Lesson 2: Embryo Transfer Technologies

Today's science is tomorrow's applied technology. Embryo transfer is a good example of this trend. Once a complicated procedure requiring surgery, it has become a technology that some livestock producers are using in their own barns. This lesson will describe how embryo transfer is done, as well as some more advanced embryo manipulation methods, such as cloning.

The Process of Embryo Transfer

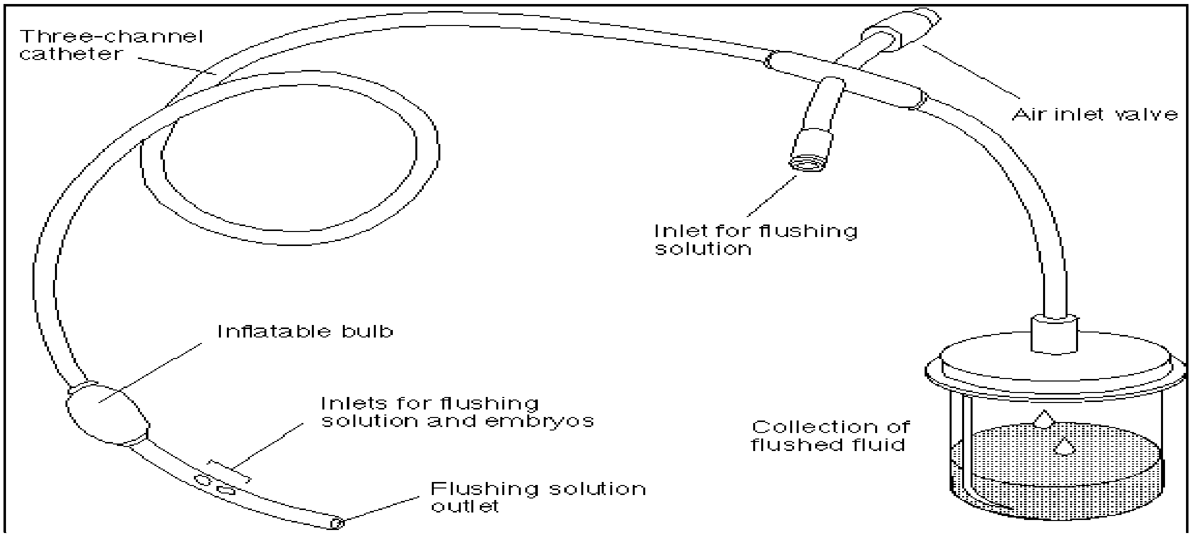
Embryo transfer (ET) is the process of transplanting embryos (fertilized eggs) from a donor female to a recipient female. Although ET is possible in several species of livestock, including sheep, goats, horses and swine, it is most common in cattle, which will be the focus of this lesson. The embryo transfer process has six steps. The first step involves the synchronization of estrous in the donor and recipient, which makes it possible for the collected embryos to be transferred to the recipient without being frozen. Next, the donor must be superovulated. Injecting the donor with a hormone like prostaglandin causes superovulation, or the release of multiple ova. The third step involves breeding the donor cow, either naturally or by artificial insemination. Next, the fertilized ova are collected from the donor through a process called embryo flushing in which fluid is used to wash the embryos out of the female reproductive tract. The fifth step in the embryo transfer process involves isolating and examining the embryos. Healthy embryos are transferred to recipients or frozen for later transfer.

Advantages of Embryo Transfer

Embryo transfer has several distinct advantages over natural breeding. It can increase the reproductive potential of superior females by allowing the female to produce multiple offspring each year. In addition, embryo transfer increases the rate of genetic improvement in a herd. The average cow can produce four to five calves per year using embryo transfer technology. With a superior cow providing four to five calves per year, high quality herd replacement heifers and bulls accumulate faster. Another advantage of ET involves progeny testing, in which offspring are evaluated for growth characteristics to determine whether an animal produces quality offspring. Using ET, female animals can be more easily and accurately progeny tested since they produce offspring more quickly; in three years, a cow should produce the ten calves needed for progeny rating. Finally, since shipping live animals internationally is a difficult and expensive process, embryo transfer has been employed as a way to use breeding stock from other countries. ET has been used to import and export rare breeds and the offspring of genetically superior animals.

Embryo Transfer Equipment

Embryo transfer requires the use of some specialized equipment. The equipment needed to flush the donor cow includes a special catheter that has three narrow tubes encased in one long tube (see Figure 2.1). One tube inflates the bulb found near the end of the catheter. Another tube injects the flushing solution into the uterine horn to flush out the embryos. The third tube collects the flushing solution and embryos from the donor's reproductive tract. The catheter is inserted into the vagina and through the cervix with a device called a stylet. A collection cylinder holds the flushing solution and embryos after they have been removed from the donor. The technician needs a shoulder-length glove and lubricant to palpate the donor and recipient. Syringes are needed to inflate the bulb in the catheter, inject hormones, and give a local anesthesia. The equipment needed to examine the embryos includes a microscope, a pipette embryo-handling tool, and a gridded search dish. Transferring the embryo to the recipient requires the use of a plastic embryo straw, which holds the embryo for transfer, and an embryo transfer gun, which is used to expel the embryo into the reproductive tract.



Management of Superovulation

When prostaglandin is used to manipulate the heat cycle, preparation of the donor cow begins ten days after she is in standing heat with an injection of the hormone FSH, or follicle stimulating hormone. The injection of large amounts of FSH causes the ovaries of the donor to release multiple ova. These injections are given once in the morning and once in the evening, until a total of seven injections have been given. On the third day of the procedure, prostaglandin is injected into the donor in the morning and evening. These two injections will cause the donor to come into estrus in 48 hours, and she can then be bred either naturally or through artificial insemination. The management of the process of superovulation is slightly different when other hormones are used.

The Embryo Flush Process

The embryo flush process is done seven days after breeding. The technician injects an epidural anesthesia into the space between two cervical vertebrae. The epidural causes the rectal muscles to relax, which aids in the insertion of the technician's hand into the rectal tract to guide the catheter. The technician uses the stylet to insert the special catheter into the vagina, through the cervix, and into the right uterine horn. He or she must palpate the donor carefully to guide the catheter into the proper location. The bulb near the end of the catheter is inflated to block off the uterine horn while it is being flushed.

A sterile flushing solution is allowed to flow into the uterine horn under the force of gravity until 500 milliliters of the solution is in the horn. The technician then starts to massage it to loosen the embryos. When the uterine horn is filled with flushing fluid, the technician opens the outlet tube of the catheter and collects the fluid and embryos in the collection cylinder. This process is repeated with the left uterine horn.

Because of their weight, the embryos settle to the bottom of the collection cylinder. The fluid above the embryos is carefully siphoned off. The embryos are ready to be counted and characterized, or examined for quality. They must be normal in appearance and of the correct size to be usable.

Transferring the Embryo into the Recipient

After the collected embryos have been washed and examined, technicians load embryos that are to be transferred to recipients into embryo straws. They are then prepared to be either transferred into recipient cows or frozen in a container of liquid nitrogen at -320 degrees Fahrenheit. The recipients have already been prepared to receive the embryos through estrous synchronization. A technician loads an embryo transfer gun with a straw and inserts it into the recipient cow's vagina. He or she guides it through the cervix and into the uterus, where the embryo is expelled.

Cloning

Cloning is the asexual reproduction of an organism in which the resulting organisms are identical. The livestock industry uses two basic methods of cloning. In the first method, the researcher physically splits the embryo into two halves as it is dividing.   Each half is transferred to a recipient and develops normally. Embryo splitting doubles the number of embryos available for transfer.

Nuclear transfer is a second method of cloning. Nuclear transfer involves removing the nucleus of an unfertilized ovum. A cell is then extracted from a parent organism and fused into the ovum without a nucleus using an electrical pulse. The new cell has a diploid number of chromosomes and will develop as if it were a natural embryo. However, it must be stimulated to act like a fertilized ova and begin dividing. Nuclear transfer technology can multiply the number of embryos by 16, 32 or even 64, depending on the number of cells available in the parent embryo.

Benefits of Cloning

Cloning has several advantages. It can increase the number of highly prized animals produced because it multiplies the number of collected embryos. Cloned animals are valuable to researchers doing live animal experiments. Fewer animals can be used in these tests because all of the animals--control animals and experimental animals--are identical. Animals genetically altered to produce pharmaceuticals could be cloned as well, which would reduce the cost of producing the animals.

In Vitro Fertilization

In vitro literally means "in glass." In vitro fertilization (IVF) is a process in which immature follicles (ova) are collected from the ovaries of a female animal, stimulated to mature, and fertilized outside the female reproductive tract in a test tube. The fertilized embryos can be transferred to recipient animals.

The process of IVF begins a few days before ovulation. A technician inserts a special probe containing an ultrasound sensor into the vagina and moves one of the ovaries to a position directly above the vaginal wall. The ultrasound equipment is then used to locate the follicles. The technician inserts a needle through the vaginal wall and into the ovary. The needle is attached to a vacuum device that sucks the follicles into a collection bottle. The follicles that are collected are stimulated to mature in the laboratory and are then fertilized.

Summary

Embryo transfer, which has only been in use since the early 1980s, is a relatively new technology in the livestock industry, but the number of dairy and beef cattle producers using it is growing rapidly. Embryo transfer is the process of transplanting embryos from a donor female to a recipient. The procedure involves superovulating a donor, flushing the embryos out of the donor, and transferring the collected embryos to a recipient. More advanced techniques such as embryo splitting, nuclear transfer, and in vitro fertilization are also beginning to be used in the livestock industry.

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Lesson 3:
Applications of Biotechnology in Animal Agriculture

The previous two lessons discussed artificial insemination and embryo transfer. These applications of biotechnology have a direct impact on the genetic makeup of the animals produced. Other forms of biotechnology, such as the use of biotechnology to produce supplemental hormones and animal health products, affect animals more indirectly.

Supplemental Hormones

Supplemental hormones are chemical messengers administered to animals that stimulate them to grow, produce more milk, or improve their performance in another way. Many of the supplemental hormones produced are growth hormones. Human beings and animals naturally produce the growth hormone somatotropin in their pituitary glands, although the somatotropin produced by two species is very different. For example, bovine somatotropin has no noticeable effect when injected into a human being.

Bovine somatotropin (BST) is one of the best known supplemental hormones. In 1993, the FDA approved BST for use as a drug. When injected into a cow, BST causes a secondary hormone to be released that increases blood flow in the mammary glands. This blood flow increases the amount of milk produced by the cow by 10 to 15 percent.

Porcine somatotropin (PST) is another growth hormone. When PST is injected into a pig, it causes the pig to grow about 15 percent faster and consume 20 percent less feed. In addition, muscle mass, including the loin eye area, increases, while backfat is reduced. Researchers are searching for a way to put PST in an implant to eliminate the need for regular injections. The FDA has not yet approved the use of PST.

Growth hormone releasing factor (GHRF) is not itself a growth hormone, but it stimulates the pituitary gland to release larger amounts of growth hormones. Researchers are looking for ways to use GHRF to improve animal production.

Supplemental hormones have shown promise for use in the poultry industry. Research has shown that the use of a chicken growth hormone shortens the time needed for broilers to reach market size by 15 percent. A chicken molting hormone has shown promise in increasing egg production levels.

Producing Supplemental Hormones and Animal Health Products

Before modern biotechnology was developed, the only way to obtain somatotropin was to collect it from the brains of slaughtered animals. However, only a small amount of the hormone could be collected from each animal. The somatotropin was therefore very expensive.

Bacteria can now be engineered to make proteins that they do not normally produce, allowing supplemental hormones like BST to be synthesized. To produce BST, researchers located and isolated the gene that stimulates the production of bovine somatotropin. They inserted it into a plasmid taken from a bacterium. Scientists opened up the plasmid ring with a restriction enzyme and spliced the gene into the opening. The plasmid was reinserted into the bacterium. Modified bacteria are placed in a fermentation tank under ideal conditions for the bacteria to grow and divide. After a substantial number of microorganisms are produced, somatotropin can be purified from the bacteria.

Poor animal health costs the U.S. livestock industry approximately $17 billion annually. Advances in biotechnology have strengthened the fight against animal disease. Biotechnology is used to improve the health of livestock in three major ways.

Monoclonal antibody technology is one way biotechnology is used to produce animal health products. When a virus, bacteria, or parasite attacks an animal, the animal's immune system responds by producing proteins called antibodies. Antibodies are very specific in their function; they are only produced in response to a particular antigen (a substance that triggers an immune response). When an animal is vaccinated with a weakened form of the disease-causing organism, the animal's body produces antibodies that continue to look for the antigen for years after the vaccination. Monoclonal antibodies are produced by fusing a tumor cell to an immune system cell

that produces antibodies against a specific antigen. This process yields a cell that divides rapidly (because of the tumor cell) and produces the desired antibody. Several tests for diseases have been developed from this technology, such as the quick sale barn test for brucellosis and the animal pregnancy test.

The second way biotechnology affects animal health is through the development of therapeutic proteins. In the past, veterinarians have not had a drug to use to fight viruses. When injected into an animal, therapeutic proteins like interferon and interleukin-2 attack viruses. They also stimulate the animal's immune system to attack the viruses. Like growth hormones, therapeutic proteins are produced by genetically modified bacteria. Preventing shipping fever, a disease found in cattle, has been a major focus of the use of therapeutic proteins. Shipping fever is the result of an attack by several viruses that the animal's immune system normally repels; this defense is weakened when an animal is under stress. Injections of therapeutic proteins may help prevent shipping fever.

The third way that biotechnology is influencing animal health is through genetically engineered vaccines. Early vaccines were made from dead or weakened disease-carrying organisms. These vaccines can take a long time to develop, must be refrigerated, and may have side effects. Vaccines developed using genetically modified bacteria contain only the antigen of the disease-causing organism. They stimulate the immune system to produce antibodies against the antigen. Genetically engineered vaccines are safer and can be produced relatively quickly. Examples of vaccines produced through biotechnology include vaccines for scours in pigs, foot-and-mouth disease, pink eye, and tapeworms in sheep.

DNA Fingerprinting in the Livestock Industry

DNA fingerprinting is the result of fragmenting DNA with a restriction enzyme and then segregating the fragments with gel electrophoresis to produce a distinctive pattern. It is being used in the livestock industry to positively identify individual animals. In the past, valuable animals like race horses have been stolen by switching an animal with a look-alike. DNA fingerprinting can accurately identify stolen animals. It can also verify that an animal is the offspring of a particular set of parents. Some breed associations require that a blood sample be submitted with the application for registration for an animal so that a DNA fingerprint can be made. DNA fingerprinting is also being used to identify transgenic animals for patenting purposes.

Emerging Applications of Biotechnology in Animal Agriculture

Research continues into the development of new and expanded applications of biotechnology in animal agriculture. Currently, genetically engineered vaccines for foot rot in cattle and strangles in horses are under development. The livestock feed industry is looking into the possibility of using genetically modified bacteria to produce protein for feeds; the bacteria containing the desired protein would be killed and the contents added to the feed. The feed industry is also researching methods of engineering rumen bacteria so that animals can better use feedstuffs that are normally hard to digest.

The cloning of adult animals is emerging as a new area of animal biotechnology. In early 1997, Dolly, a sheep cloned from a single cell taken from an adult animal, was introduced to the world. Although this type of cloning is possible, it is extremely expensive, and its applications are likely to be limited to a few highly specialized functions. For example, if animals were genetically modified to grow human organs, cloning these animals would allow their numbers to increase more quickly.

Summary

Biotechnology is playing a growing role in animal agriculture. From the use of bacteria-produced somatotropin to the development of genetically engineered vaccines, biotechnology is changing the livestock industry. As research continues, more applications of biotechnology will affect the production of livestock.

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Lesson 4:
The Impact of Biotechnology in Animal Agriculture

With more than twenty companies dedicated to the development of animal biotechnology products and many other large companies that conduct research in this field, new animal biotechnology products will likely be on the market soon. A variety of career opportunities exist in this new but rapidly growing field. A number of economic and social impacts accompany this growth in animal biotechnology. The industry will have to address these issues.

Careers in Animal Biotechnology

Careers in animal biotechnology include jobs that use the products of animal biotechnology (such as a livestock producer) and positions in the companies that develop and market these products. Biotechnology companies have a variety of job positions. Large companies usually have more specialized positions, while smaller companies have positions that include a broad range of responsibilities. However, most companies have one or more employees working in eight major areas. These major areas are research and development, quality control, clinical research, manufacturing and production, regulatory affairs, information systems, marketing and sales, and administration. The jobs in the different areas vary in the amount of education they require, ranging from a high school diploma to a doctorate in a specific scientific field.

Research and development - The area of research and development (R&D) involves the actual laboratory research needed to develop potentially useful products. Positions in this area include glass washer, laboratory assistant, research assistant, postdoctoral fellow (a term for a new scientist), and research director/principle investigator (experienced scientists).

Quality control - This area includes positions such as quality control analyst, environmental health and safety specialist, equipment validation engineer, and validation technician.

Clinical research - After some products are developed, they must be tested on live animals in a clinical research setting. Positions in this area include clinical coordinator, clinical data specialist, clinical research associate, and animal handler/technician.

Manufacturing and production - The manufacturing and production area offers a variety of positions, including product development engineer, manufacturing engineer or technician, instrument calibration technician, and packaging operator.

Regulatory affairs - Regulatory affairs offers positions for specialists who work with regulatory agencies to obtain approval for products. Examples of positions available in this area include regulatory affairs specialist and documentation specialist.

Information systems - Positions in information systems include scientific programmer analyst and literature research assistant.

Marketing and sales - Biotechnology products must be marketed, which is the responsibility of those involved in the marketing and sales area. Positions in this area include market research analyst, sales representative, and customer service representative.

Administration - In administration, positions such as human resources representative, supply buyer, and patent administrator are available.

Economic Factors Affecting Producers

One of the most important questions livestock producers face when a new technology is put on the market is whether to use it. To answer this question, producers must consider the benefit-to-cost ratio. The ratio is a comparison of the economic benefits of using the product to the costs of using the product. For example, if a new genetically engineered feed additive costs $6 per feeder calf to use but increases feed efficiency by 20 percent, which saves $18 in feed costs, then the benefit-to-cost ratio would be 3 (18 ÷ 6). If the ratio has a value of two or greater, the product is considered cost effective.

A second economic consideration that producers must take into account is the cost of not using a biotechnology product, which is not a simple task. Producers must be able to provide a competitive product. If most producers begin to adopt a new technology, the price of livestock may drop, making the use of the product necessary.

The reliability of a biotechnology product is also important. Producers must evaluate the actual effects of using the product. If a product does not perform as well as expected or is not reliable in its performance, the value of the product is not as high.

Finally, livestock producers must consider not just the cost in actual dollars but the time required for the additional management and training that is often associated with the use of new products. This economic consideration is frequently overlooked when a new product is introduced.

Consumer Health and Safety Concerns

The public, those who buy meat, dairy, and egg products, are consumers of animal biotechnology. Many people are concerned or fearful about animal biotechnology because they do not understand the technology. This lack of understanding lends itself to the acceptance of rumors as fact. Consumers have also become skeptical about research findings due in part to research reports like those about substances "shown" to cause cancer, since the quality of some cancer research studies has come into question.

The effect of these factors on biotechnology is that when research is published that suggests that new biotechnology products are safe, many consumers are not convinced. Consumers of fresh vegetables have recently turned to higher-priced "natural" or "organic" foods because they see them as healthier than nonorganic foods. This consumer perspective may be transferred to animal products, producing a new market for "natural" meat, milk, and eggs.

Is there a justification for these consumer concerns? The answer to this question is both yes and no. Yes, because consumers should always be concerned about the safety and wholesomeness of the foods they buy. They should also be informed about the methods used to produce those foods. No, because animal biotechnology products must be shown to be safe before regulatory agencies approve them.

Global Social Impacts of Animal Biotechnology

Agriculture has historically had a worldwide social impact. As the world population grows, the need for animal products will increase as well. Biotechnology has the potential to increase the global supply of meat, dairy products, and eggs. The real question, which cannot be conclusively answered, is whether animal biotechnology can increase the production of animal products without an equal increase in production inputs. BST, for example, causes cows to produce more milk, but these cows require more feed. Unless those extra inputs are available, production cannot increase.

The mid-1990s has also seen a considerable amount of debate take place in Europe over the use of biotechnology by the developed world. For example, Europeans have debated the development of transgenic animals, such as genetically modified species of fish. Scientists have developed thirteen genetically modified species of fish that grow 20 to 100 percent faster than unmodified fish. If these modified fish are accidentally or intentionally released into some of the world's oceans, will the unmodified fish be able to compete for food?

Will the fish spawn differently? What would be the result of a cross between a modified and an unmodified fish? Could one country release modified fish without the approval of other countries? These types of international concerns must be addressed. The international political environment will determine the extent of the use of animal biotechnology.

A third impact of animal biotechnology is that it may change the number of livestock producers needed in the United States and the world. If animal products can be produced more quickly and with fewer losses due to disease, will fewer producers be able to supply the meat, milk, and egg demands of the national and worldwide markets? The answer to this question is unclear. On one hand, if population growth causes demand to increase faster than production, the need for producers will grow. On the other hand, if the production of animal products increases faster than the demand, fewer producers will be needed.

Summary

Livestock producers demand biotechnology products that make economic sense. Consumers demand food products that are safe and healthy. The world needs answers concerning the social impact of animal biotechnology. The field of animal biotechnology faces several challenges but promises many rewards. As animal biotechnology continues to advance, the number of career positions available in this field will increase.

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