WAITER: IS THERE A GENE IN MY STEAK?

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What is genetic engineering (and how does it differ from cloning)?

Genetically engineered or "transgenic" animals carry a gene construct introduced by human intervention. Genetic engineering employs recombinant DNA, that is a DNA "construct" created in a laboratory, to confer useful novel properties. For example, these modifications may change the amount of a certain protein that an animal produces, or they may result in the production of a novel protein. The term transgenic can be applied to an organism that has been genetically engineered. Cloning, on the other hand, is the process by which an identical copy of something, either a DNA fragment, a cell, or an entire organism, is made. Genetic engineering and cloning differ in that genetic engineering seeks to make directed changes in an organism, whereas cloning seeks to make an exact copy.

Which agriculture animals have been genetically engineered and for what purpose?

Agricultural and aquacultural animals, such as cows, pigs, sheep, goats, chickens, fish and shellfish, have all been the focus of different genetic engineering projects for diverse applications ranging from agricultural improvements to biomedical and industrial applications. While there are very promising projects involving genetically engineered livestock for biomedical and industrial applications, a much anticipated use of genetic engineering research is to improve agricultural traits of food animals. Improvements ranging from enhanced growth to disease resistance to animals that produce products (milk, meat, eggs) with a beneficial effect on human health have been envisioned.

Pigs

The first genetically engineered livestock, growth-enhanced transgenic pigs, were created in 1985[1]. One-cell fertilized pig ova were microinjected with a human growth hormone (hGH) gene to demonstrate the scientific importance and potential economic value of producing transgenic livestock. Although the transgenic pigs did not increase their body weight dramatically, the experiments demonstrated the feasibility of producing transgenic livestock and paved the way for future research in improving agricultural traits in agricultural and aquacultural animals.

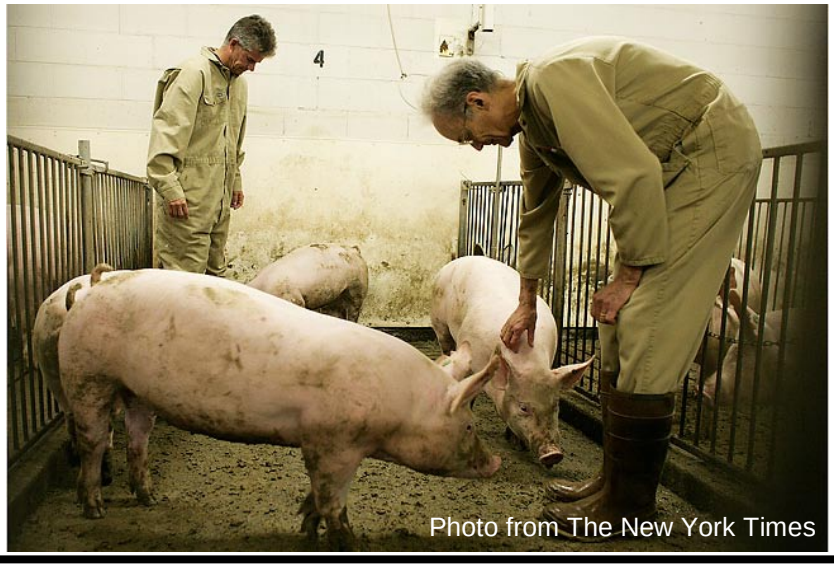

Photo from The New York Times

More recently, the Enviropig, a transgenic Yorkshire pig, (pictured left) has garnered attention for its ability to utilize phosphorus derived from phytate, a normally indigestible form of phosphorus commonly found in cereal grain diet[2]. This eliminates the need for phosphate supplementation in the diet and reduces the amount of phosphorus in pig manure by as much as 60%.

Runoff of phosphorus from manure into ponds and streams can cause algal blooms that rob oxygen from the water, killing aquatic organisms. Manure from the Enviropig has a decreased potential to result in phosphorus pollution of surface and ground water. Researchers from the University of Guelph, who created the Enviropig, emphasize that transgenic technology should be applied to solving environmental, food safety and food quality concerns before being used for economic gain[3].

Cattle

The first transgenic bull, Herman (right, top half), was produced in 1989 by Gene Pharming Europe, a Dutch biotechnology company[4,5]. Herman contained a human lactoferrin (*hLF*) gene which encodes a protein with anti-bacterial, anti-fungal, and anti-viral properties, making milk produced by Herman's female offspring (right, bottom half) potentially healthier for human infants. Cow's milk naturally contains lactoferrin, however, it is present in low levels. The addition of the *hLF* gene also benefits cows by helping to prevent mastitis, an infection or inflammation of the mammary gland.

Mastitis is the most common infectious disease of dairy cattle and costs the US dairy industry ~$2 billion dollars in lost revenue[6,7]. In addition to economic losses, mastitis also has serious negative effects on an animal's well-being and is a primary reason for the culling of death of dairy cattle[8]. Researchers continue to develop technologies to prevent mastitis by targeting the microbes that cause the disease, such as *Staphylococcus aureus*. Transgenic cows have been made that secrete lysostaphin, an enzyme from *Staphylococcus simulans*, which breaks down the cell wall of staphylococci[9]. Like lysostaphin transgenic mice[10], these transgenic cows are resistant to infection by *S. aureus*.

Another illness that affects cattle that we are all keenly aware of is bovine spongiform encephalopathy (BSE), more commonly known as mad cow disease. BSE is a fatal, neurodegenerative disease in cattle that causes a spongy deterioration of the brain and spinal cord. It is caused by a misfolded protein called a prion. The first outbreak of BSE was reported in the early 1980s in the United Kingdom. It became an epidemic in 1986 and the number of cases peaked in the early 1990s. Studies have shown that there is a relationship between BSE and a human disease, a variant of Creutzfeldt-Jakob disease (vCJD)[11-13]. Hematech, a company based in Sioux Falls, South Dakota, developed transgenic cattle lacking the protein that is responsible for BSE (pictured left at 13 months of age). Normal in every respect, *in vitro* studies showed that these cattle were resistant to propagation of the BSE prion[14].

Goats

Like transgenic cattle, transgenic goats have been made that express a human gene in their milk. Researchers at the University of California, Davis have genetically engineered the human lysozyme gene (*hLZ*) into the Alpine and Toggenberg (pictured right) breeds of dairy goats[15]. Lysozyme is an antimicrobial protein that is found in mucus, tears, saliva and milk of all mammals[16]. However, the amount of lysozyme naturally present in human milk is 1600-3000 times greater than in livestock milk[17]. With a mode of action similar to lysostaphin, lysozyme can break down bacterial cell walls leading to lysis and death of the cell. Studies have shown that transgenic dairy goats expressing *hLZ* can inhibit bacterial growth responsible for mastitis and the spoilage of milk[18]. Additional studies suggest that consumption of milk from *hLZ* transgenic dairy goats can confer the same beneficial effects of human milk[19].

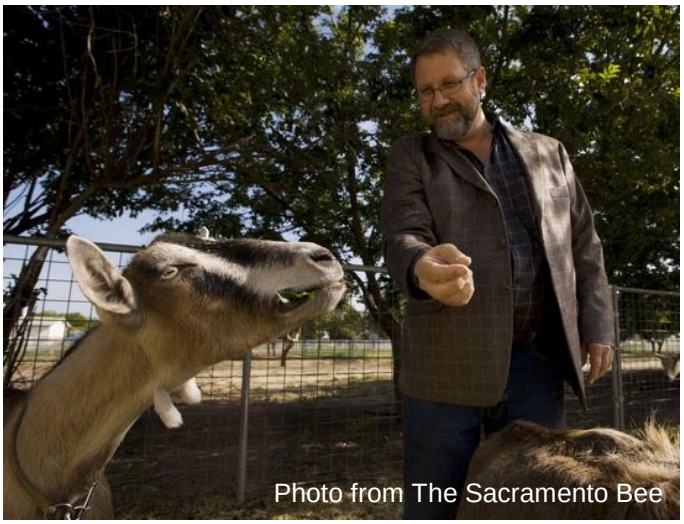
Photo from The Sacramento Bee

Fish

After the creation of the first transgenic fish in 1985, a goldfish containing a human growth hormone gene[20], many other genetically engineered fish were to follow. Since fish are not as evolutionarily advanced as mammals, they are more amenable to the techniques that are required for producing transgenic organisms. The majority of transgenic research involving fish has been focused on meeting the worldwide demand for fish-derived food products[21-23]. This has led to growth enhancement research in species ranging from tilapia to mud loach as well as increasing cold-tolerance and disease-resistance in salmon and catfish, respectively[24].

Worldwide, carp is the most important group of food fishes and research in China, Cuba, and the United States has led to transgenic growth-enhanced carp. Researchers in China have created an "all fish" construct with a common carp promoter driving a grass carp growth hormone gene inserted into yellow river carp embryos[25]. These carp were shown to attain higher growth rates and better feed conversion efficiencies than their non-transgenic counterparts[26,27]. In Cuba, scientists inserted a human growth hormone gene (*hGH*) into single-cell common carp embryos and produced transgenic fish, however they were sacrificed at 60 days for DNA analysis[28]. US researchers produced transgenic carp using a rainbow trout growth hormone gene that were 22% larger on average than their sibling controls[29].


Photo from Maclean et al., 2002

The second most important group of food fishes worldwide is tilapia. While considered a lower class food fish in Asia and Africa, it is prized as being a high value fish in Israel and the United States. Both Cuba and England have produced transgenic growth enhanced tilapia. The Cuban construct used a tilapia growth hormone gene[30] while the English construct used a Chinook salmon growth hormone gene[31]. Transgenic tilapia from Cuba were 1.8 times larger than non-transgenic fish by 7 months old[32] while transgenic tilapia from England (pictured left) were 2.5 times larger that non-transgenic fish by 7 months of age[33].

Mud loach, a commercially important food fish in Korea, has been genetically engineered with transgenic material derived only from the same species to create an "autotransgenic[34]." This autotransgenic mud loach contains a mud loach growth hormone gene driven by a mud loach β-actin promoter. As a result, these fish are able to grow 22-35 times faster than non-transgenic siblings (pictured below)[35,36].

Are there any genetically engineered food animals that are currently being commercialized for human consumption?

In the United States, there is a line of transgenic growth enhanced Atlantic salmon that is under review by the FDA for commercialization in aquaculture operations. Created by Aqua Bounty Technologies, a biotechnology company focused on improving productivity in commercial aquaculture, the *AquAdvantage* Atlantic salmon reach market size twice as fast as wild-type salmon (pictured right). Consisting of an "all fish" construct, the transgenic salmon contain an ocean pout antifreeze promoter driving a Chinook salmon growth hormone gene that allows the fish to grow up to 6 times larger than non-transgenic salmon of the same age[37]. Aqua Bounty has already completed a critical FDA requirement, characterizing the molecular "all fish" DNA construct[38]. All major studies required to gain approval for the transgenic salmon to be consumed in the US, such as food safety, allergenicity, nutrient content and genetic stability through inheritance, have been completed and are under review by the FDA. In China, transgenic lines of growth enhanced carp are under regulatory review. However, further studies will be conducted to comprehensively assess the environmental impacts and food safety of transgenic carp[39].

Are there any GE animal food products that are currently on the market?

No. In the United States, there are no genetically engineered animal food products on the market for human consumption, nor have there ever been in the past. Outside of the United States, there have been reports that a transgenic line of growth enhanced tilapia have undergone successful environmental and food safety assessments in Cuba[40]. It was determined that "under the conditions found in Cuba, little or no effect on the natural population will occur as a result of the accidental escape of transgenic fish, mainly because these natural populations do not exist and most of the fish species found now in the country have been introduced[41]." Another report suggested that these fish have already been commercialized and made available for food in local Cuban markets[42].

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Animals, like all organisms, have DNA encoding genes located in the nucleus inside each cell of their body. Therefore, when food is consumed, DNA is ingested. DNA is broken down by the digestive system[43]. The genetic code of the organism consumed is not integrated into the human genetic code.

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