# Role of Biotechnology in Animal Production Systems in Hot Climates

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خلاصة : مكنت التطورات في العلوم البيولوجية في العقود الثلاثة الأخيرة من إحداث ثورة في القدرات البشرية لمعالجة الوراثة وبيولوجيةالخلية و فسيولوجية الأحياء. تعرف هذه التقنيات مجتمعة بالتقنية الحيوية. وتوفر الفرصة لتحوير الحيوانات الأليفة بأساليب تزيد من كفاءة الإنتاج. تتضمن الطرق التي يتم تطويرها للاستخدام في أنظمة الإنتاج الحيواني انتخاب جينات عابرة، والتبويض المتفوق، ونقل الأجنة والتلقيح خارج الرحم وتحديد جنس الأجنة وإنتاج كميات كبيرة من البروتينات النادرة باستخدام بكتيريا أو خلايا تعرضت لهندسة وراثية وتحديد جزئيات جديدة ذات حيوية فعالة كمنظمات محتملة لوظائف الحيوان. تركزت معظم استخدامات التقنية الحيوية حتى الآن على مشاكل لها علاقة عامة بالحيوان الزراعي بدلاً من مشاكل محددة ذات علاقة بالانتاج الحيواني في الأجواء الحارة. لكن من المحتمل أن يتم استخدام التقنية الحيوية لهذا الهدف الأخير أيضاً. ستثبت المخططات التي ترمي إلى زيادة مقاومة الأمراض باستخدام الانتخاب عن طريق المعلمات المساعدة وانتاج حيوانات ذات جينات عابرة تنتج بروتينات فيروسية سايتوكاينات متحدة لدفع الوظائف المناعية تسهم في تقليل حدوث وتخفيف درجة فاعلية مختلف الأمراض في المناطق الحارة. بالإضافة إلى ذلك فإنه توجد طرق أخرى لتخفيف أثر الاجهاد الحراري على عمليات التعرف على دورة الشبق وتثبيت الحمل تشمل التعرف على البعد وسيل موائمة التبويض ونقل الأجنة. هناك حاجة أكبر للبحوث في مجال العمليات الفسيولوجية التي تتحكم في مقاومة الحرارة والطرق التي يبدل بواسطتها الاجهاد الحراري وظائف الجسم وذلك قبل استخدام تقنيات البيولوجيا الجزيئية لتخفيف الآثار الضارة للاجهاد والحرارة في مجال الإنتاج الحيواني.

ABSTRACT: Developments in the biological sciences in the last three decades have revolutionized mankind's ability to manipulate the genetics, cell biology and physiology of biological organisms. These techniques, collectively termed biotechnology, create the opportunity for modifying domestic animals in ways that markedly increase the efficiency of production. Among the procedures being developed for animal production systems are marker-assisted selection of specific alleles of a gene that are associated with high production, production of transgenic animals, superovulation and embryo transfer, in vitro fertilization, embryo sexing and cloning, production of large amounts of previously-rare proteins through use of genetically-engineered bacteria or other cells, and identification of new biologically-active molecules as potential regulators of animal function. To date, most uses of biotechnology have concentrated on problems of general relevance to animal agriculture rather than specific problems related to livestock production in hot climates. However, it is likely that biotechnology will be used for this latter purpose also. Strategies to increase disease resistance using marker-assisted selection, production of transgenic animals expressing viral proteins, and recombinant cytokines to enhance immune function should prove useful in reducing the incidence and severity of various tropical diseases. Additionally, there are methods to reduce effects of heat stress on oestrus detection and establishment of pregnancy. These include remote sensing of oestrus, ovulation synchronization systems and embryo transfer. More research regarding the physiological processes determining heat tolerance and of the pathways through which heat stress alters physiological function will be required before molecular biology techniques can be used to reduce the adverse effects of heat stress on animal production.

Mankind has long been interested in effects of the environment on biological processes. Indeed, these effects were discussed as early as the 5th century B.C. by Hippocrates in his treatise on *Air, Waters, Places*. One reason environmental biology has been of great interest is because of the important effects that environment can have on the output and efficiency of animal production systems. For most of history, attempts to alleviate effects of adverse environments on domestic animals have involved 1) natural and artificial selection for genetic traits that confer resistance to adverse environments and 2) alteration of the environment to reduce the severity of environmental stress. These approaches have been partially successful as witnessed by the successful use of animals for production of food, work and fibre throughout most of the world and by the often high levels of production that can be achieved in environments not conducive to production. Nonetheless, significant effects of environmental stress remain. This is particularly true in hot climates because the combined effects of heat stress, low water availability, parasites and pathogenic microorganisms can limit or prohibit animal production.

In the coming years, it is likely that the breadth of approaches for alleviating deleterious effects of the environment on animal production will expand greatly. This will occur because developments in the biological sciences in the last three decades have revolutionized our ability to manipulate the genetics, cell biology and physiology of biological organisms. These techniques, often referred to collectively as biotechnology, create the opportunity for modifying organisms in ways hitherto impossible. The sentiment expressed in the quotation from the developmental biologist, Ryuzo Yanagimachi, is indicative of the thinking that these techniques have engendered. To date, the application

of biotechnology to animal production is only beginning and few specific uses of biotechnology to improve animal performance in hot climates have been developed. The purpose of this review will be to outline some of the more important techniques of biotechnology and give appropriate examples of ways in which the technology could be used to modify livestock production in hot climates.

## Marker-Assisted Selection

Most genetically-controlled traits of importance in animal production systems are controlled by multiple genes. Consequently, quantitative genetics has dominated the field of animal breeding since its development in the early part of this century. Nonetheless, all genetic variation is mediated through polymorphisms in the structure of individual genes and the proteins encoded for by those genes. It may be possible to improve genetic potential for production by identifying particular genetic variants (or alleles) of a gene that are associated with a high level of production. Before the explosion of molecular biology, various attempts were made to relate productive traits with genetic polymorphisms in specific proteins, particularly milk proteins and blood group markers, as well as genetic variation in amounts of particular metabolites and hormones. The tools to identify genetic variation in protein structure are relatively inefficient, however, and metabolite and other quantitative measures are affected by environment as well as genetics. Advances in molecular genetics have greatly simplified the task of identifying allelic variants of specific genes. The techniques most commonly used are determination of restriction fragment length polymorphisms (RFLP) and the polymerase chain reaction (PCR). The technique of RFLP is based on the discovery of specific enzymes called restriction endonucleases that cleave double-stranded DNA at specific sequence motifs. For example, the endonuclease *Hpa I* recognizes the sequence GTTAAC and its complementary sequence and cuts the DNA between the T and A. Cuts in DNA can be evaluated by examining the size of DNA fragments on an agarose gel. A genetic mutation in the above sequence to GTTCAC would prevent cutting by *Hpa I* and lead to a different pattern of fragments on an agarose gel. The technique of PCR allows large-scale amplification of DNA segments bounded by specific DNA sequences. This technique can be used to type animals for known alleles as well as for identification of new allelic variants.

Using molecular techniques such as these as well as more conventional serotyping, there is an active search for allelic variants of specific genes that are linked to production traits. Among the more promising findings are those in chickens that genetic resistance to the virus-mediated lymphoproliferative disease, Marek's disease, is conferred by the $B^{21}$ haplotype of the type I major histocompatibility complex (MHC) (Lamont, 1989). There is also evidence that certain haplotypes of the bovine MHC complex are related to resistance to mastitis (Weigel et al., 1991) and ticks (Lewin, 1989) as well as production traits such as milk yield and meat production (Mejdell et al., 1993).

Nonetheless, the number of marker genes closely tied to animal production traits is small. In part, this reflects the fact that use of molecular techniques for identifying genetic markers is still a new field. There are other limits to progress, however. First, not all variants in nucleotide sequence will give rise to amino acid mutations, and not all amino acid substitutions give rise to alterations in protein function. Secondly, the multigenic nature of most production traits may make it unlikely that genetic polymorphisms in any single gene are highly correlated with some productive traits. As pointed out by Shook (1989), a genetic marker will be most useful when the marker has a high genetic correlation with the productive trait and has a higher heritability than the productive trait. Shook (1989) has given mathematical relationships to demonstrate that marker assisted selection becomes most useful when heritability of the productive trait is low or selection is on individual performance rather than progeny testing. The success of marker-assisted selection will also depend upon the correlative responses of other production traits to selection for the marker gene. Many gene products such as hormones, enzymes and transcription factors play roles in several physiological systems. Reduced heterozygosity of the MHC loci as a result of marker-assisted selection for resistance to a particular disease could lead to increased susceptibility to other diseases (Lewin, 1989).

The ease of conducting RFLP and related techniques means that it is easier to identify allelic variants than it is to relate these to productive function. There are two possible approaches for identifying relationships between gene markers and production traits (Freeman and Lindberg, 1993). The first is to correlate allelic variation in a large number of genetic loci with production traits. The second approach is to use knowledge of biology to identify genes that are likely to be involved in the production trait of interest and then relate allelic variation in these genes to the production trait. Both of these approaches are feasible for selection for increased production for animals in hot climates. For the first approach, genotype x environmental interactions may affect the genetic correlation between gene markers and production traits and it is important that marker genes be identified or verified in populations of animals used in that

environment. Use of the second approach for selection of genes that are specifically useful in hot climates is limited by the lack of knowledge about physiological factors determining adaptation to hot climates. It is clear that thermotolerance is genetically controlled. For example, clear differences exist in thermoregulation between *Bos indicus* and *Bos taurus* cattle (Finch, 1986) and rectal temperature is moderately heritable (Finch, 1986). Moreover, selection for thermotolerance has been demonstrated in chickens (Wilson et al., 1975). In cattle, selection for growth rate in a hot environment also leads to increased thermotolerance (Frisch, 1981). The physiological basis for increased heat tolerance involves changes in tissue resistance to heat flow, alterations in water metabolism and evaporative cooling, and characteristics of hair coat (Finch, 1986). There are also breed differences in resistance of cultured bovine reproductive tract tissues (Malayer and Hansen, 1990) and lymphocytes (Kamwanja et al., 1994) to elevated temperature that could affect the degree to which hyperthermia alters reproductive or immune function. Identification of the gene products involved in physiological regulation of body temperature and cellular resistance to elevated temperature could lead to new genetic markers specifically related to heat tolerance.

## Transgenic Animals

A more revolutionary technology that has arisen from advances in molecular biology is the production of transgenic animals in which a foreign gene (i.e., transgene) is introduced into an animal's genotype. A typical strategy for producing a transgenic animal is illustrated in Figure 1. As of 1992, over 30 gene constructs had been integrated into the genome of pigs, cattle, sheep and goats (Pursel and Rexroad, 1993). Transgenes have been transferred to increase growth rate or muscle development, enhance disease resistance, increase cysteine synthesis for wool production and to produce recombinant proteins of value to the pharmaceutical industry (Pursel and Rexroad, 1993).

Research is still in the early stages and no transgenic animal of value to animal agriculture has yet been developed. There are several obstacles that prevent rapid development of transgenic farm animals. The procedure is expensive since large numbers of embryo transfer recipients are necessary. Depending upon the species, only about 0.03-4.5% of microinjected embryos transferred to recipients develop into transgenic animals (Pursel and Rexroad, 1993; Seidel, 1993). This efficiency may be enhanced somewhat by incorporating screening procedures to identify the transgene in embryos using PCR before transfer. The long generation intervals of domestic

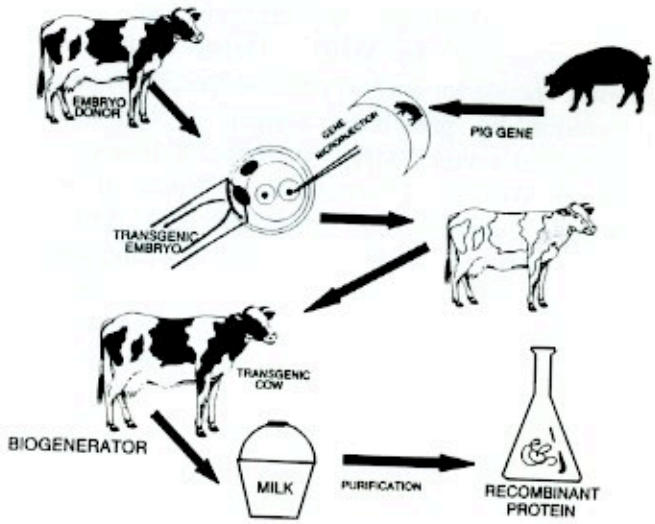


**Figure 1.** Typical strategy for producing a transgenic animal. In the case illustrated, the goal is to produce a transgenic cow that secretes a pig protein into milk. After a gene has been isolated, it is placed in an appropriate vector (typically a plasmid) and, when appropriate, is engineered to contain regulatory elements that direct tissue-specific expression. The plasmid is usually microinjected into oocytes. Other methods of gene insertion (use of retroviruses or stem cells) have also been used but not in domestic animals. Injected embryos that develop in culture are transferred into recipients animals, sometimes after screening by PCR for presence of the transgene. A fraction of cows that develop from the microinjected embryos will express the transgene. In the example given, the transgene has been constructed to be expressed specifically in mammary tissue. Therefore, the recombinant protein will be secreted into milk where it can be subsequently purified for pharmacological purposes. This figure was reproduced with permission from Simmen (1992).

animals also delays development of transgenic animals. It has been estimated that the time to produce a transgenic animal homozygous for the transgene is 50 mo in sheep and 78 mo in cattle (Seidel, 1993). The development of transgenic offspring from the original transgenic founder animal is also slowed by mosaicism in germ cells (i.e., only some germ cells contain the transgene). In pigs, Pursel et al. (1990) found that 20% of transgenic animals did not transmit the transgene to offspring.

Progress has been made in using transgenic animals to increase disease resistance and such an approach may prove useful in reducing the incidence of specific tropical diseases. Clements et al. (1994) produced transgenic sheep that express the gene encoding for the envelope glycoprotein of visna virus, a lentivirus that causes ovine progress pneumonia. Expression of the protein in transgenic lambs occurred in the target cell where natural virus replicates, the macrophage. Two of three transgenic sheep produced antibodies to the transgenic protein. Thus, it is possible that expression of the envelope glycoprotein will make lambs resistant to the virus. Another possible use of

transgenic technology is manipulation of the heterozygosity of the MHC. Genes of the MHC complex encode for surface proteins that allow antigen recognition by presenting antigen to cytotoxic T lymphocytes (class I MHC) or helper T lymphocytes (class II MHC). Diversity in structure of MHC molecules enhances the probability that cells will express at least one MHC variant that can bind antigen and present it to the appropriate lymphocyte. Since the number of MHC proteins expressed increases with number of gene copies, it has been suggested that disease resistance could be enhanced by using transgenic technology to increase the copy number and heterozygosity of MHC genes (Lamont, 1989). One could also use transgenic technology to create animals with MHC haplotypes that confer resistance to a particular disease (Lewin, 1989) but marker-assisted selection would be a more feasible way to achieve this goal in most cases.

At present, there are few candidates for transgenes that increase heat resistance because the genes controlling thermoregulation have not been well characterized.

Critical to development of agriculturally-useful transgenic animals will be evaluation of the genetic value of the transgene for improved production. Many transgenic animals may not have the desired improvement in productivity because of deleterious effects of the gene product on other physiological systems, because the gene was inserted into another gene, rendering it inactive, or because assumptions regarding the role of the gene product in animal function were incorrect. Each transgenic founder animal is unique because of differences in the number and sites of transgene integration into chromosomal DNA. Assuming 50% transmission of the transgene, the number of animals required to demonstrate a beneficial effect of the transgene is large: 36 offspring are required to show a significant effect if the transgene increases the mean of the population by one standard deviation and 198 if the transgene increases the mean by 0.4 standard deviation units (Smith et al., 1987). Homeotherms (mammals and birds) maintain body temperature by matching heat production with heat lost to the environment via radiation, conduction and convection (Figure 2). Successful thermoregulation becomes difficult when environmental conditions limit heat flow from the animal (i.e., high air temperatures, high humidity and low wind speed) or cause a net flow of heat from the environment to the animal (intense solar radiation; air temperatures higher than skin temperature). Under such heat stress, metabolic heat production is greater than net heat flow from the animal and body temperature rises. Homeotherms can engage a variety of adaptive physiological mechanisms to

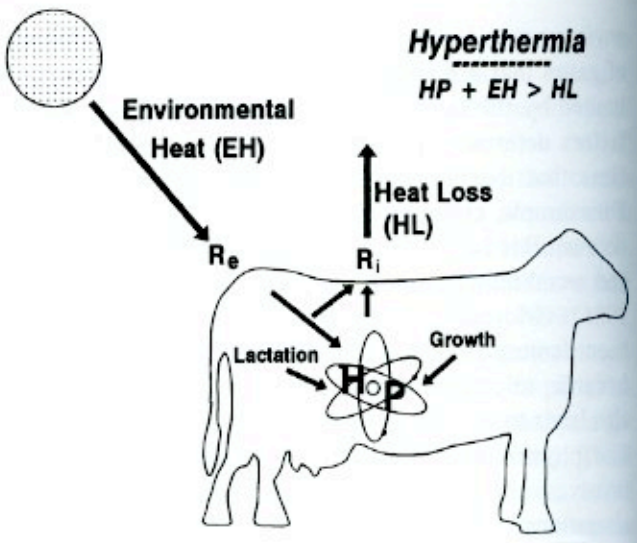


**Figure 2.** Maintenance of body temperature in homeotherms. A constant body temperature is maintained when the amount of heat produced by the animal (HP) and the amount of heat gained from the environment (EH) is matched by the amount of heat lost by the animal (HL). Heat exchange occurs via conduction, convection, radiation and evaporation. The amount of heat lost via these modes depends upon internal resistance to heat flow ($R_i$) as well as environmental factors (air temperature, win speed, humidity). Internal resistance to heat flow is determined by factors such as blood flow to the skin and rate of sweating. $R_e$ refers to resistance to heat flow from the environment and is determined by factors such as properties of the hair coat. Hyperthermia, which results when HP + EH > HL, causes a decrease in productive function because of 1) disruptive effects of elevated body temperatures and 2) deleterious consequences of the physiological changes hyperthermic animals undergo to reduce HP and increase HL. Use of transgenic technology or marker-assisted selection to improve heat tolerance will be dependent upon identifying the genes that control $R_i$ and $R_e$ (Taken from Hansen, 1994).

reduce the magnitude of hyperthermia. These include decreasing internal heat production, increasing the resistance of heat flow from the environment to the animal and reducing the resistance of heat flow from the animal to the environment. There are genetic differences in ability of animals to undergo thermoregulation (Finch, 1986) but little is known about the molecular basis for these differences. Most deleterious effects of elevated temperature on animal production occur as a result of the physiological changes animals undergo to maintain body temperature. Thus, the decrease in milk yield in heat-stressed dairy cows is in large part a reflection of the decrease in feed intake accompanying heat stress (Beede and Collier, 1986). Similarly, much of the heat-stress associated changes in fetal weight can be ascribed to the redistribution of blood flow away from the placenta during heat stress (Reynolds et al., 1985). Transgenic approaches to increase heat tolerance should not do so by using genes that cause physiological effects that reduce production.

While most effects of heat stress are caused by

## Alteration of Reproductive Function to Alleviate Effects of Heat Stress

The major reproductive disorder caused by heat stress is an increase in the interval from calving to conception. This phenomenon is partly caused by a decrease in fertility of males (Meyerhoefer et al., 1985) but artificial insemination can bypass this effect by allowing collection of semen in cool months. Heat stress also increases embryonic mortality and pregnancy rates in warm months can be less than a third of what is achieved in cool months even when artificial insemination is used (Thatcher and Collier, 1986). Embryo transfer may be one way to bypass effects of heat stress on embryo survival because pregnancy is relatively resistant to disruption by heat stress after d 1-2 of pregnancy (Dutt, 1963; Tompkins et al., 1967; Ealy et al., 1993). Thus, embryos transferred into recipients after this time would be more likely to survive maternal hyperthermia than embryos produced as a result of natural or artificial insemination.

Data from cattle support this idea. During the summer, pregnancy rates of lactating embryo transfer recipients on a commercial dairy in North Florida were 29.2% vs 13.5% for cows bred by artificial insemination (Putney et al., 1989). In another study, there was no relationship between daily maximum air temperature and pregnancy rate of lactating embryo transfer recipients in a commercial embryo transfer company operating in the Southwest United States (Table 1). Embryo transfer is likely to increase pregnancy rates even if cows serving as donors are exposed to heat stress because, generally, the only embryos transferred are those having developmental and morphological characteristics deemed suitable to be used for transfer. Development of embryo freezing technology and in vitro fertilization could further the utility of embryo transfer for improving fertility in heat-stressed cows by allowing for production of embryos without the possibility of heat stress and by reducing the costs of embryo transfer.

Table 1

**Pregnancy rates in embryo transfer recipients as related to maximum dry bulb temperature on d 0-10 *after transfer*[a]**

| Recipient type | n | < 27 | 27-32 | 32-40 | >40 |
|---|---|---|---|---|---|
| Lactating beef cow | 4,618 | 57.9 | 55.3 | 54.8 | 65.8 |
| Lactating dairy cow | 199 | 58.9 | 60.9 | 63.1 | 66.7 |

[a] Data are from Putney et al. (1988)

Table 2

***Effect of recombinant bovine somatotropin on milk yield in dairy cattle exposed to heat stress.***

| | Milk yield (kg/d) | | |
|---|---|---|---|
| Location | Control | BST | Reference |
| Florida[a] | 22.7 ± .4 | 24.8 ± .4 | Zoa-Mboe et al., 1989 |
| Georgia | 20.9 ± .7 | 24.9 ± .7 | West et al., 1990 |
| Missouri | 28.8 ± .5 | 34.9 ± .7 | Johnson et al., 1991 |
| Environmental chambers | 21.0 ± .4 | 28.3 ± .4 | Johnson et al., 1991 |
| Florida | 18.8 | 21.3 | Elvinger et al., 1992 |
| Arizona[b] | 26.0 | 31.2 | Sullivan et al., 1992 |
| Israel | 0.8 ± .1 | 35.2 ± .1 | Lotan et al., 1993 |

[a] Fat-corrected milk yield; effects on milk yield were not significant (24.4 vs 25.5 kg/d).
[b] Fat-corrected milk yield

Effects of heat stress on oestrus detection also become a limitation to establishment of pregnancy when artificial insemination is used. In one study on a commercial Florida dairy, 18-24% of oestrus periods were detected by dairy managers during the summer as compared to rates of 34-56% at other times of the year (Thatcher and Collier, 1986). The decreased rate of oestrus detection in heat-stressed cows occurs because of a reduction in the duration of oestrus. Duration of oestrus in one experiment averaged 17.0 h in heifers maintained at 18.2 C and only 12.5 h in heifers maintained at 33.5 C (Abilay et al., 1975). There are two general approaches being developed for reducing effects of heat stress on oestrus detection in cattle. First, there is intensive work devoted to developing remote sensing devices for oestrus detection based on changes in locomotory activity, electrical resistance of reproductive tract tissues, or pressure applied to the tailhead region of the oestrus cow during mounting behaviour (Senger, 1994). Commercial systems for remote oestrus detection have been developed (Afikim-USA, Visalia, CA and ABS, De Forest, WI) but these systems have not been tested for ability to improve oestrus detection in periods of heat stress. There is also much interest in developing ovulation synchronization schemes that allow fixed-time breeding without oestrus detection. In one such scheme, cows received 100 $\mu$g gonadotropin releasing hormone (**GnRH**) on day 0, 35mg prostaglandin-$F_{2\alpha}$ on day 7, and 100 $\mu$g GnRH on day 9 and artificial insemination on day 10 (Pursley et al., 1994). All cows ovulated 24-32 h after the second GnRH injection and pregnancy rates were 55%. The usefulness of these schemes will be improved if schemes for encapsulation of semen to allow continuous release of sperm becomes practical (Nebel et al., 1993).

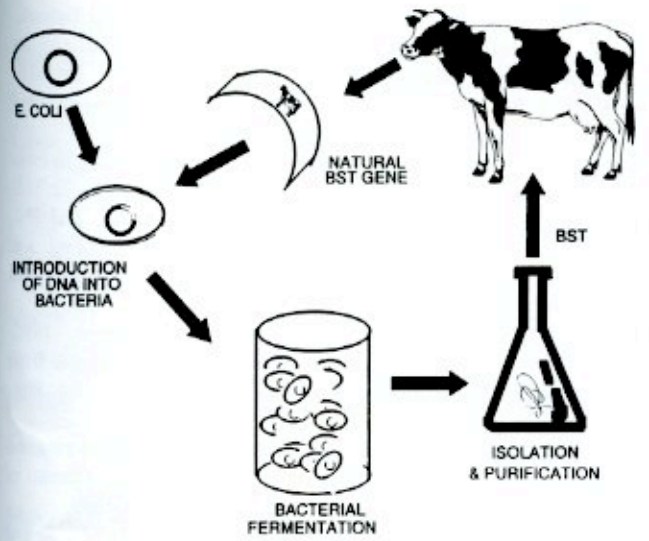


**Figure 3.** Example of genetic engineering to produce a recombinant mammalian protein. In this case, the gene encoding for bovine somatotropin (BST) is placed in an appropriate plasmid designed to promote transcription of the gene, and then transfected into *E. coli*. The bacteria are screened for the presence of the foreign gene and colonies positive for the gene are grown up in large quantity (bacterial fermentation). The gene product (BST) is then isolated from the bacteria and used to modify the function of species of interest (in this case, dairy cattle). The figure was reproduced with permission from Simmen (1992).

### Production of Recombinant Proteins

It is become routine to produce large amounts of previously-rare proteins through utilization of genetically-engineered bacteria, yeast, or mammalian cells. A schematic representation of these procedures is illustrated in Figure 3. Several recombinant mammalian proteins have been developed for modifying animal function, including hormones involved in growth processes (Dunshea, 1993) and cytokines used to reduce the incidence or severity of infectious disease (Blecha, 1991; Kehrli et al., 1991; Campos et al., 1994). One recombinant molecule, bovine somatotropin (BST), is now being marketed in several countries as a lactational promoter.

In some cases, the effectiveness of recombinant molecules may differ somewhat for heat-stressed animals than for animals in thermoneutral environments, particularly if the molecule alters physiological systems that are involved in thermoregulation. Extensive research shows that BST increases milk yield in cattle under heat stress conditions (Table 2). However, BST can also increase body temperature of heat-stressed cows (Zoa-Mboe et al., 1989; West et al., 1990; Elvinger et al., 1992; Sullivan et al., 1992; Cole and Hansen, 1993) and therefore careful attention should be given to limiting exposure of BST-treated cows to heat stress.

### Applications of Other Biologically-Active Molecules

The use of recombinant proteins to modify animal function is only one aspect of a broader development in animal science in which pharmacological approaches are being used to manipulate animal physiology and increase production. The molecules that are under exploration come from a variety of sources. Some, such as the β agonists, used to modify carcass composition (Dunshea, 1993), and GnRH, used for regulation of reproductive function (Thatcher et al., 1993), are either molecules that occur naturally in mammalian systems or more potent agonists. Others are molecules derived from microorganisms. One example is phytase derived from *Aspergillus niger* which has been used to increase phosphorus availability from corn-soyabean pig diets (Cromwell et al., 1993). Live microbial cultures are also being used to increase feed intake and alter ruminal metabolism (Wallace, 1994). There is evidence that feeding *A. oryzae* to increase milk yield or enhance milk composition can have beneficial effects that are particular to heat-stressed cows. Specifically, some studies (Gomez-Alarcon et al., 1991; Higginbotham et al., 1994), although not all (Denigan et al., 1992), found that rectal temperatures of lactating cows fed cultures of *A. oryzae* were reduced as compared to control cows. The mechanism for this effect is unknown.

Another possible use of biologically-active molecules to reduce effects of heat stress relates to antioxidants and embryonic survival. Many adverse effects of exposure to elevated temperature on cells are caused by increased production of free radicals and other reactive oxygen products (Loven, 1988). Addition of antioxidants taurine (Malayer et al., 1992; Ealy et al., 1992), glutathione (Ealy et al., 1992; Aréchiga et al., 1994) and vitamin E (Aréchiga et al., 1994) to culture medium improved survival of heat-shocked preimplantation mouse and bovine embryos. Presumably, these molecules worked by scavenging free radicals within the embryo. Whether antioxidant treatments will prove effective in increasing pregnancy rates of heat-stressed females is unknown. Injection of 3000 IU of vitamin E at the time of breeding (Ealy et al., 1994) did not improve pregnancy rate of heat-stressed lactating Holsteins. Furthermore, Ealy et al. (1995) found that 2-cell bovine embryos could not be protected from elevated culture temperature by either glutathione or taurine, even though both of these molecules can protect bovine morulae (Ealy et al., 1992).

### What is Necessary to Realize the Gains of Biotechnology in Hot Climates?

It is obvious that many of the advances in

biotechnology will have broad applications throughout the world livestock industry. Nevertheless, there are unique problems associated with animal production systems in hot climates that could in some cases be alleviated by utilization of biotechnology. To do so will require a more complete understanding of the basic physiological processes involved in animal productive functions and heat tolerance and the pathways through which environmental stress alters physiological function. Acquisition of this knowledge will require interdisciplinary research between physiologists, animal management specialists and molecular biologists. Development of biotechnology is an expensive undertaking that requires long-term commitment of personnel and resources. It is unlikely that rapid progress will be made in implementing biotechnological approaches to enhancing animal production in hot climates without that commitment.

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