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Performance-enhancing technologies in swine production

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Implications

- Market pigs require 4% less feed today to produce a 17% heavier carcass than they did 25 yr ago.
- Animal pharmaceuticals like ractopamine, immunocastration products, and porcine somatotropin are commonly thought of as performance-enhancing technologies; other technological changes that now encompass "modern swine production" are perhaps even more critical.
- Advancements in record-keeping, benchmarking, refinements in nutrient requirements, biosecurity, and increased sizes of meat-processing facilities have also contributed to increased productivity.

Key words: history, performance, swine, technology

Introduction

Technology adoption has allowed for dramatic improvements in sow productivity, wean-to-finish growth performance, and carcass composition over the last 35 yr. In 1980, the average sow farm in the US marketed 9.2 pigs per sow per year (Table 1). The average market weight was 242 lb with pigs having more than 1 inch of fat at the 10th rib, a loin eye under 5 in^2, and a carcass that produced less than 80 lb of lean meats (National Pork Board, 2016). Growth performance records from 1980 are scarce; however, in 1990, pigs grew at 1.27 lb/day and required 3.2 lb of feed per pound of gain from weaning to market (PigChamp, 1990).

By comparison, today's average sow weans 22 pigs per year and its pigs have a wean-to-finish average daily gain of 1.61 lb/day and use 2.6 lb of feed per pound of gain (National Pork Board, 2016). The average market weight is now 283 lb with 0.72 inches of back fat and a loin eye over 8 in^2 (National Pork Board, 2016). Thus, the actual feed required per pig has decreased by 4% while market weight has increased by 17% (41 lb) in the last 25 yr. Of the 41-lb increase in live weight, 38 lb (93% of the increase) has been added to the amount of lean muscle provided by each carcass, with today's pigs producing more than 118 lb of lean meat per animal. This has allowed for a 38% increase in pork production with only a 10% increase in the annual number of animals harvested over the same time period (USDA-NASS, 2015).

These values obviously represent significant improvement in swine productivity. Combining increases in sow productivity and market weight, the average US pig farms are producing more than 4,000 lb of live weight per sow per year compared with approximately 1,770 lb in 1980 (Figure 1). Without these improvements in productivity, it would take another 9 million sows (approximately 15 million in total) compared with today's 6 million sows to achieve the current level of pork produced (Patience, 2015; Figure 2).

With global food demands expected to increase by 100% in 2050, technology must continue to be applied to commercial swine production (Tilman et al., 2011). As demonstrated by the swine industry's record of rapid adoption and embracing new technology, production of safe, wholesome, and nutritious pork will continue to improve and increase while, at the same time, using fewer resources and reducing its impact on the environment. Therefore, our objective is to review the history of technology development and its application in shaping today's swine industry (Table 2).

Record Systems

One of the key drivers improving pork production and efficiency has been the adoption of sophisticated record-keeping programs and benchmarking. Some of the first such programs were developed in the late 1980s at the University of Minnesota (PigChamp) to monitor sow productivity. Not only did these record-keeping programs provide individual farm production standards, they also standardized production criteria that allowed comparisons across multiple farms. As a result, large databases could be developed for benchmarking purposes and to help producers identify opportunities for improvement within their herds (Koketsu et al., 1996; Ketchem and Rix, 2013). Record-keeping programs and benchmarks for nursery and finishing pigs soon followed. With the vast amount of production data available, key drivers of profitability began to be identified, and adoption of new technology could be monitored and evaluated (Baas, 1996). Today, production data is now coupled with financial analysis and profit projections to help control costs, manage risk, and increase revenue.

Table 1. Swine productivity improvements over time.

Production trait	1980	2015
Pigs marketed per sow per year	9.2	22
Average market weight, lb	242	283
Average daily gain, lb	1.27	1.61
Feed conversion (lb feed/lb gain)	3.20	2.60
Carcass wt, lb	171	212
Back fat, inches (10th rib)	> 1.0	0.72
Loin area, in^2	< 5.0	> 8.0
Lean meat per carcass, lb	< 80	> 118
Pork produced, lb/sow	1770	4200

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Genetics

The improvement in health of the national herd has allowed the progress in genetic improvement to be realized on a wide-scale basis throughout the industry. Initially, grid-based marketing programs provided financial incentives to reduce back fat, which correspondingly improved feed conversion. Then in the early 1980s, the swine industry began to fully utilize cross-breeding programs where prolific breeds with strong maternal traits (e.g., large white and landrace) could be crossed to provide an F1 sow, which could then be mated with sires with strong growth and market traits (e.g., Duroc, Pietran, or Hampshire). Maximizing the benefits of heterosis has allowed the industry to increase productivity while reducing mortality (Gaugler et al., 1983).

The development of best linear unbiased predictions (**BLUP**) has allowed for selection for multiple traits at the same time. It also allowed for economic indexes to be calculated, which made genetic selection possible for traits that provided steady, continuous improvement in economic return. Growing computing power, increased offspring records, and recent developments in molecular genotyping technology (marker-assisted selection; Dekkers, 2004) has allowed for selection of traits that are not highly heritable, leading to reduction in defects (i.e., hernias, dystocia, variability, structural lameness, and disposition), which has reduced suffering in addition to increased value and efficiency. Although application of genomic technology in selection programs is still in early stages, the application has increased genetic change by as much as 50% (Knol et al., 2016).

Gene mapping, disease challenge experiments, and application of gene-editing technology (CRISPR) has allowed pigs to be produced that are protected from PRRSv, the most economically important disease in the swine industry (Whitworth et al., 2015). This breakthrough is an example of the importance of continuous technological advancement in livestock production and how research in multiple disciplines can come together to provide solutions to major real-world problems. All of the genetic advances in the commercial industry have been without the introduction of exogenous genes into pigs.

Table 2. Changes in swine production methods over time.

Technology area	1980	2015
Records	Hand written, if any	Detailed computerized production and financial data
Health	Continuous flow	All-in, all out, multiple-site production
Genetic selection	Visual or single trait	BLUP with marker assisted selection
Reproduction	Pen mating, lots of boars needed	Artificial insemination using highest indexing boars
Diet formulation	Crude protein	Digestible amino acids
Processors	Small, high labor plants	High volume, sanitary plants
Processor end product	Carcass	Boxed primals
Stunning method	Electrocution	CO^2 trolley
Production systems	Many small farms	Coordinated, specialized farms

Without record keeping and benchmarking, much of the improvement in swine productivity would likely not have been possible as it is impossible to improve what cannot be measured.

Health

Advances in diagnostic management, animal population management, biosecurity, and the production of replacement breeding stock free of many endemic pathogens has greatly elevated the “baseline” health status of individual and the national herds. Endemic diseases, such as actinobacillus pleuropneumonia, swine dysentery, progressive atrophic rhinitis, sarcoptic mange, swine brucellosis, trichinosis, and others, are now largely absent from the national herd (USDA, 2016). Steady progress has been made to eliminate or effectively control other pathogens, such as mycoplasma pneumonia and porcine circovirus. The industry is deeply invested and active in pork quality assurance programs, has long produced meat without antibiotic residues, and is participating in the worldwide effort to reduce overall antibiotic use (www.pork.org).

The reasons for the improved health status of the national herd are numerous. As farms increased in size, the number of pigs that could be produced by one sow farm increased allowing for the possibility of multiple-site production. In multiple-site production, weaned pigs can be removed from the older animals (sows) while they still have maternal immunity to many pathogens preventing these diseases from reducing performance (Harris, 2000). Separating the growing pigs from the sow population also allows for eradication of important economical diseases from the sow farm, which greatly enhances reproductive performance and performance of the offspring that are not exposed to these diseases. Vaccine breakthroughs have been instrumental in controlling diseases, like porcine circovirus, that are not easily eradicated from swine farms. Improved biosecurity and understanding of disease transmission have greatly aided in keeping pigs healthy by limiting introduction of diseases through transportation, visitors, feed, and breeding stock introduction. Challenges still exist in protecting health in the U.S. swine industry. Concentration of pig growing sites to specific areas of the country makes control or eradication of some diseases more difficult. Also, the transportation and movement of pigs across the country has provided a mode of dissemination for some diseases.

Diagnostic laboratories in the U.S. continually innovate to develop new testing methods for early identification of disease agents to prevent their introduction or spread within the swine herd. These tools have evolved from gross necropsy to ELISA, PCR, and deep sequencing of viruses and bacteria. Recently, collaborative programs for disease surveillance and monitoring have helped producers understand movement of diseases in geographic regions to further protect the health of their pigs.

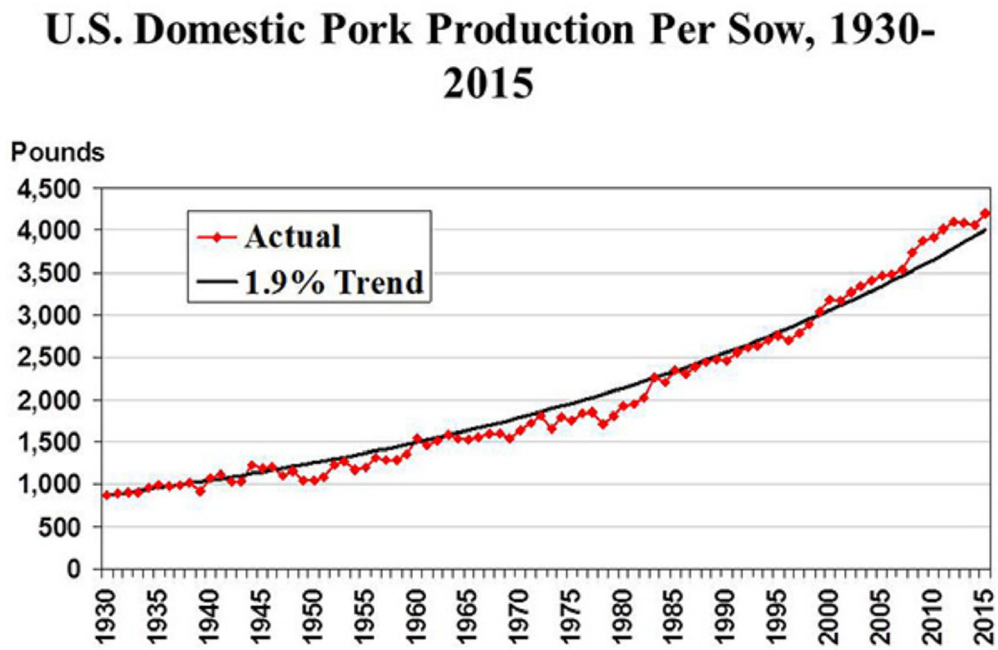

Figure 1. US domestic pork production per sow, 1930–2015. Source: Ron Plain form USDA-NASS data.

Reproduction

The advances in genetics over the last 30 yr have been facilitated by the adaptation of technology in reproductive efficiency. In the 1980s, swine farms utilized pen mating where boars were simply put out in dirt lots with a group of sows. With pen mating, it was commonly recommended that one boar was needed for every 20 sows. Pen mating resulted in wide variation of farrowing dates, and reproductive performance was severely hampered by seasonal infertility.

The technology that changed all of this was artificial insemination (**AI**), which was quickly adopted by the swine industry in the 1990s (Bortolozzo et al., 2015). Initially, individual farms collected their own boars, but with advances in specialization in the industry, boar studs were created to allow for the widespread use of high-indexing boars and better semen collection and extender technologies. Today, it is common for boar studs to produce 15 to 20 doses of semen from one collection. A 200-head boar stud provides enough semen to cover approximately 50,000 sows, or the equivalent of one boar for every 250 sows. The reduction in the number of boars required allowed increased selection and use of the highest-indexing boars driving the rapid improvement in growth performance and reproductive efficiency. Bringing the male to the farm through AI greatly reduced disease risk by eliminating the entry of live animals, which are the greatest source of disease introduction to the farm.

Historically, AI involved depositing semen into the cervix of the female, or intracervical insemination. However in the 2000s, the application of post-cervical insemination (**PCAI**), where semen is deposited directly into the body of the uterus, became available and began to be used in the industry. With PCAI, less time is required per insemination, but the huge advantage is the possibility for a reduction in sperm cells required per insemination. As reviewed by Bortolozzo et al. (2015), there are great opportunities with PCAI to lower the number of sperm cells per breeding dose from 3 billion to approximately 1.5 billion, without significant reductions in female reproductive efficiency, again allowing for fewer boars needed to satisfy the breeding demands and extending use of the higher genetically indexing boars.

In the very near future, technologies like fixed-timed insemination, use of sexed semen, and the ability to implant stem cells from elite boars to sterilized recipient boars will be a component of genetic progress.

Nutrition

At the turn of the 20th century, the role of vitamins and minerals in swine nutrition were beginning to take shape (Funk, 1914; Forbes, 1914). However, from a practical feeding management practice, swine diets were formulated with multiple ingredients because they contained "unidentified growth factors" (Morrison, 1940). Later, these "unidentified growth factors" were found to be vitamins, minerals, and other essential nutrients. As a result, the number of ingredients typically added to swine diets decreased and were replaced by corn–soybean meal diets with added vitamin and trace minerals.

Our understanding of the differences in pig requirements for individual essential amino acids vs. crude protein again followed the same trends as was observed for vitamins and minerals. As reviewed by Morrison, (1940), amino acids had been divided into essential- and non-essential, and the concept of limiting amino acids was formed. Later, Baker et al. (1975) observed that low-crude protein diets with supplemental L-lysine HCl resulted in similar growth performance in pigs as those fed high-crude protein diets containing the same total lysine concentration. Studies by Wang and Fuller (1989) elucidated the benefit to expressing the need for other amino acids as a ratio relative to lysine and the concept of "ideal protein" was developed. Establishment of the amino acid ratios led to more precisely formulated diets, minimizing crude protein levels while meeting requirement estimates of other amino acids.

After the importance of lysine as the first limiting amino acid in swine diets became apparent, it was not long until crystalline forms of lysine and other amino acids were being manufactured. Today, it is not uncommon to see diets with 3 to 5 crystalline amino acids used in formulation. This has greatly decreased nitrogen excretion in swine waste and has reduced nitrogen requirements by upward of 40%. Because of differences in digestibility of crystalline amino acids and intact protein sources, diets previously formulated on a total basis, now use standardized ileal digestible amino

Farrowing records also are used for selection purposes, as well as for farm finances (source: © 2016 National Pork Board).

acid coefficients (Stein et al., 2007). Requirement studies have helped in the development of models, both to assist in determining the amino acid requirements, but also to estimate the economic impacts of potential changes in diet formulation.

In regards to mineral nutrition, with only on average one-third of the total plant-derived phosphorus available to the pig, the development of the enzyme, phytase, has played a huge role in minimizing inorganic phosphorus additions to swine diets. One of the first instances where the phytase enzyme appears in the literature was in 1915 (Anderson, 1915). But it wasn't until the early 1970s that the significant findings of the benefits of phytase were observed in poultry and then later in swine (Nelson et al., 1971; Shurson et al., 1984; Jongbloed et al., 1992). Also the movement from expressing requirements on a total basis to available or digestible phosphorus also reduced phosphorus excretion and allowed nutritionists to better meets the pig's requirement for growth. This resulted in a 30 to 40% reduction in the phosphorus excreted in swine waste.

As for energy systems, the swine industry has evolved from digestible or metabolizable energy to use of the net energy system (Noblet et al., 1994). Now diets are formulated on a lysine-to-calorie ratio, and other amino acids are balanced accordingly as a ratio to lysine (Wang and Fuller, 1989). These changes in technology and diet formulation strategy have all benefitted pork producers through improved growth rate, feed efficiency, and carcass leanness while reducing feed costs per pound of gain and reducing environmental impact by greatly reducing excretion rates.

Feed manufacturing improvements also created efficiencies in swine production. Grinding of grain to smaller particle sizes and pelleting diets improved digestibility and feed efficiency. The changes in pig diets over the years has reduced the amount of nitrogen and phosphorus excretion by more than 40% and decreased the carbon footprint of swine production (Tokach and DeRouchey, 2013).

Meat Production

Prior to 1990, the majority of pigs sold in the US were sold via the live cash market. Today, the vast majority of market pigs are sold based on carcass merit using lean-value-based pricing grids that provide economic incentives to producers for increased leanness. This has been made possible through the use of ultrasound and optical probe technology that has allowed for packers to estimate carcass loin eye size and fat thickness and to predict lean meat yield from each carcass at chain speed prior to fabrication (Busk et al., 1999). These calculations are used to compensate producers based on the lean value of the carcass. Additionally, this information is provided to producers and offers immediate feedback on animal carcass merit to help them better manage breeding and nutrition programs to produce animals meeting industry targets.

The reduction in the fat content of pork carcasses has been driven, in part, by consumer purchasing expectations. Consumers use visual characteristics of meat products as their primary determinant for purchase. Product color and leanness are two of the largest drivers of consumer purchasing intent of pork products (Brewer et al., 2001). Consumers desire pork that is lean and without much visible fat. The industry focus on lean pork production helped meet consumer demands for visual appearance; however, this resulted in decreased eating quality of products due to a number of factors including changes in animal genotype and decreased marbling level in products (Schwab et al., 2006).

To help these lean pork products achieve an acceptable level of eating quality, moisture enhancement technology has been widely adopted across the pork industry, with close to half of fresh pork products sold at retail in the US having been enhanced (National Cattlemen's Beef Association et al., 2010). Enhancement most commonly involves the injection of a solution containing water, salt, and sodium phosphates into fresh pork to increase the amount of moisture retained by the product throughout the cooking process. Moisture enhancement results in more tender and juicy products that meet consumer eating expectations (Hayes et al., 2006). Additionally, moisture enhancement has little effect on the visual appearance of the product, allowing for enhanced products to meet consumer demands for lean pork at retail.

Multiple performance-enhancing technologies have been implemented at the packer level as well. Several factors, including pre-harvest animal stress and chilling rate, have a large impact on pork quality. To reduce pre-harvest stress, the use of CO_2-stunning methods has replaced traditional electrical stunning methods at many large packing facilities. Carbon dioxide stunning allows for the group movement of animals prior to stunning as opposed to the necessary single-file movement required for electrical or mechanical stunning. Group movement is preferred by pigs and requires less mechanical prodding. This prevents excess animal stress prior to harvest and results in pork products with improved color and water-holding capacity (Channon et al., 2002).

Chilling rate is one of the largest factors that affects pork quality. Proper muscle temperature during the post-mortem pH decline is critical to ensure acceptable product functionality and quality traits. If the muscle is too warm during the pH decline, muscle proteins will denature, and the resulting product will have an undesirable pale color, poor water-holding capacity, and reduced functionality for processed meats manufacturing. With added carcass weights and increased muscling, the use of blast chilling has become common in the pork industry to allow for more rapid chilling of carcasses. Blast chilling uses temperatures ranging from −4 to −40°F with a high wind velocity of 10 to 15 ft/s (Huff-Lonergan and Page, 2001). Carcasses are typically blast-chilled for 1 to 3 h followed by conventional chilling methods. Blast-chilling results in a reduced rate of pH decline, better meat color, enhanced water-holding capacity, and improved food safety when compared with conventional chilling methods (Huff-Lonergan and Page, 2001).

Technological advancements have also led to the increased size and efficiency of today's modern packing facilities. Market pigs were traditionally harvested in smaller, regional packing plants that often produced value-added products in the same facility. Prior to 1980, less than half of all pigs were harvested in facilities that harvested more than a million animals per year (MacDonald et al., 1999). Today, the majority of animals are harvested at fewer larger packing facilities, with the largest facilities having a daily slaughter capacity of more than 20,000 animals (National Pork Board, 2016). These facilities have the ability to process more than 1,200 animals an hour. The increase in size and efficiency of the pork packing industry is largely due to improvements in mechanical railing systems, harvest methods, carcass cooling procedures, fabrication methods, and packaging systems. Additionally, today's pork is primarily sold by packers as wholesale cuts as opposed to carcasses. These cuts are typically processed into consumer-ready products within the same harvest facility or sold to specialized processing facilities that process a single valued-added item (hams, bacon, sausage, etc.), allowing for added efficiency in the process.

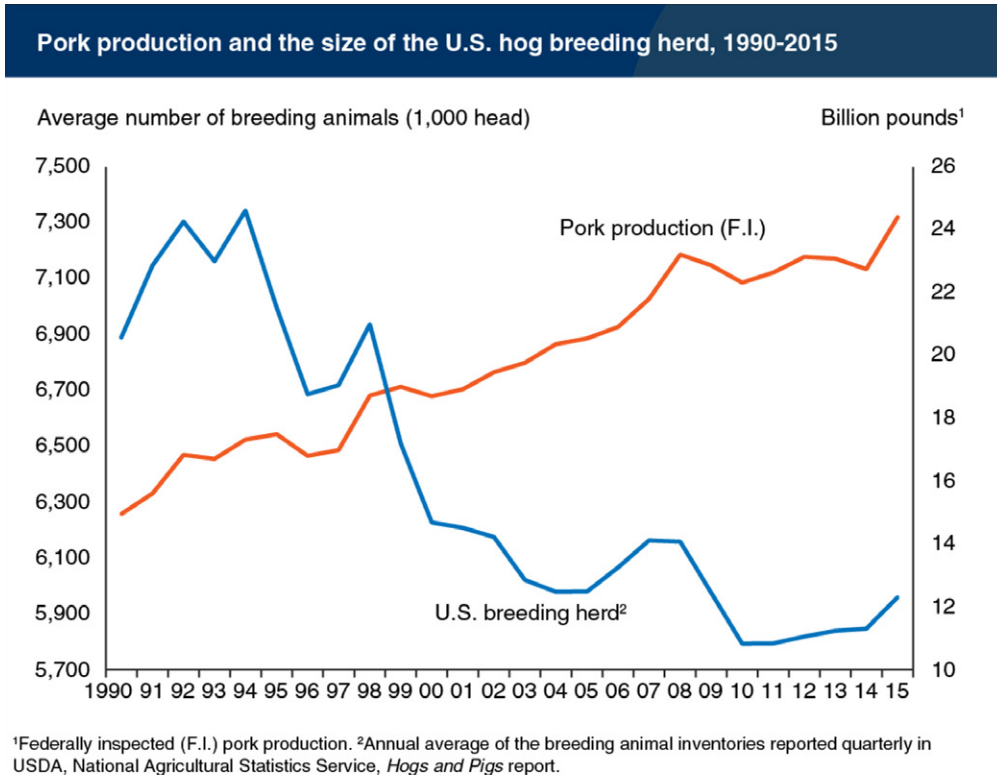

Figure 2. Pork production and the size of the US hog breeding herd, 1990–2015. Source: USDA Economic Research Service, livestock and meat domestic data.

Production Systems

Similar to other maturing industries, the number of farms with swine has declined while the size of the farms have increased (Giamalva, 2014). While this change has socio-economic impacts, increases in farm size have allowed introduction of important production methods that have helped to increase productivity of the swine herd. Farms have moved from farrow-to-finish to multiple-site production with specialized farms where the breeding herd is separated from the growing pig population. Besides greatly improving health status, this change has allowed specialization of labor and implementation of many of the health, genetic, reproductive, and nutrition breakthroughs previously discussed in this article. The move to larger sow farms also creates large numbers of pigs of the same age, health status, and body weight that can be managed as a group through the growing period. Besides the advantages in growth from these methods, group management facilitates collection of production records allowing continual production improvement.

The growth of swine farm size also has provided the scale necessary to support research facilities within production systems. The widespread application of commercial research facilities allows producers to test new technologies and validate university findings under field environments (Tokach et al., 2010). These facilities help drive the continuous improvement that further increases productivity.

Many models have evolved in the swine industry to create the scale or larger farm size, but a key component of all of these systems is coordinated production. The coordination may be through contract production, group ownership of sow farms, or through integration to gain access to other segments of the food chain. Integration is often viewed as packer ownership of pig production; however, the largest number of integration examples are through producer ownership of feed production (cropland) and pigs, which provides a means to increase value of the grain crop and the manure nutrients from the pig production.

Education System

Discovery is only one aspect of technology development. Dissemination and adoption are equally as important for the technology to truly impact swine production. In the 1970s, the United Kingdom was viewed as the leader for technology creation and adoption. The loss of most applied agriculture research and extension in the UK through lack of funding has created a knowledge and innovation vacuum (Leaver, 2010), and it has ceded pork production leadership.

Two current models are excellent examples of dissemination methods helping their countries take the place of the UK as the pork production leaders. Denmark has become a production and export leader through its cooperative system and the Danish Pig Research Centre. In the United States, two main educational and dissemination organizations have been instrumental in industry productivity growth. The Morrill Act began our long history of strong university research programs. The subsequent Smith-Lever Act formed the extension infrastructure to extend those research breakthroughs to farmers. Thus, land-grant universities have played a key role in productivity growth. Whether land-grant universities maintain this role in the future is debatable as governmental funding for applied research continues to diminish. Producers also have helped their own cause through funding of the Pork Checkoff, which funds the National Pork Board. This organization has funded production research, promoted pork, and developed quality assurance and swine care programs that have helped increase the value of pork while improving producers' knowledge.

Other Technologies

Several performance-enhancing technologies that were once commonly used across the swine industry have been eliminated from the market or are now used to a much lower degree. Ractopamine hydrocloride (**RAC**) is a β-adrenergic agonist that is approved for use as a swine feed supplement in the US. The use of RAC in the finishing diet of pigs results in increased rate of gain, improved muscling, reduced back fat, heavier carcass weights, and a greater percentage of fat-free lean (Apple et al., 2007). However, the use of RAC is banned in numerous countries. Because many of these countries, specifically China, are major export markets for US pork, the use of RAC has been removed from many US swine production systems. Additionally, the use of antibiotics for growth promotion in modern swine production has been mostly eliminated in diets for pigs greater than 20 kg. This is because with today's improved health and sanitation practices as well as multi-site production systems, antibiotics provide no improvement in the growth of finishing pigs (Dritz et al., 2002).

Exogenous porcine somatotropin as a performance-enhancing technology is approved for use in 14 countries worldwide as a performance-enhancing technology, though not in the US. Somatotropin improves feed efficiency, average daily gain, and carcass leanness but decreases meat tenderness (Dunshea et al., 2005). Similarly, the use of boars for pork production results in increased feed efficiency, growth rate, decreased back fat, and increased carcass leanness when compared with barrows due to the anabolic effect of the gonadal steroids (Xue et al., 1997). Boars also produce meat that often results in an undesirable "boar taint" off-flavor. Immunocastration of boars using vaccinations is an alternative to traditional surgical castration. Immunocastration largely reduces the boar taint flavor associated with intact males but allows the animal to retain the desirable growth performance and carcass composition traits (Batorek et al., 2012).

Conclusion

The swine industry continues to progress through the adoption of new production technologies. If the rate of improvement is as great in the future as during the last 30 yr, meeting the estimated demand for animal protein by 2050 may be possible. There are exciting new technologies to be discovered as research efforts move toward the understanding of growth and reproduction from a molecular standpoint. The challenge will be for universities to remain relevant in both basic and applied pig research and connected to the industries that they serve. Universities are needed to train the next generation of swine technologists and to remain a viable source of independent research provided in the public domain.

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