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Animal Sciences in Academia: What Does the Future Hold?

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Introduction

The enactment of the Morrill Land-Grant Act by the U.S. Congress in 1862 catalyzed the establishment of public universities mandated to give particular attention to the "agricultural and engineering" arts. In the post-Civil War era the nation was in rapid transition to an industrial economy characterized by large factories that employed large numbers of people in non-agricultural pursuits. There was a pressing need to significantly improve the efficiency with which a dwindling rural population could produce food and fiber to provision the growing urban population. The U.S. Department of Agriculture established an in-house research capacity and with the passage of the Hatch Act in 1887 individual states were encouraged to establish Agricultural Experiment Stations in partnership with the federal government.

Establishment of Animal Sciences

Early efforts in instruction and research were devoted largely to "farming" and "animal husbandry." Many departments of animal, dairy and/or poultry science trace their origins to the first decade of the 20th Century. The National Association of Dairy Instructors and Investigators (now the American Dairy Science Association) was formed in 1906. The American Society of Animal Nutrition, the antecedent organization to the present American Society of Animal Science, was constituted in 1908. The Poultry Science Association will celebrate its centennial in 2008.

During the past century academic programs in the animal sciences have quite literally changed the world through research, classroom instruction and extension education. And, in the process, scholars have contributed very substantially to fundamental understanding in the disciplines of nutrition, reproductive biology, endocrinology, breeding and genetics, animal physiology and environmental management, animal behavior, and genomics. Additionally, new fields of study, such as veterinary medicine, food science, dairy manufacturing, meat and meat science, have emerged from animal sciences programs.

Recipients of degrees in animal sciences have enjoyed successful careers in private industry, government and academia. Many used their technical background to lead in on-farm innovations that were the basis for what has become the most efficient and safe system for producing, processing and marketing meat, milk and eggs in the world. Academic programs in the animal sciences have a rich history of accomplishment BUT, past success is no guarantee of the future.

Emerging Issues

Students: Undergraduate enrollment should be a good indicator of the interest and by extension the "health" of the field. Each year colleges are asked to submit enrollment data to the U.S. Department of Agriculture and that data is published through the Food and Agricultural Education Information System on the USDA website: www.csrees.usda.gov/nea/education/part/education_part_faeis.html Enrollments in "Animal Sciences, General" were 10,062, 14,620, 15,380, 15,786 and 16,208 in 2002, 2003, 2004, 2005 and 2006, respectively.

With an acknowledgement that data submitted voluntarily will never be complete, the figures seem to indicate student interest is not only strong, but growing. What these data do not indicate is the areas of student interest within the rather broad field of animal science. Many are undoubtedly interested in companion animals, some in wildlife biology and a significant number are enrolled in animal science as a point of entry into veterinary medicine.

Fortunately, there are more specific data available in some areas of animal science. The U.S. National Pork Center of Excellence (NPCE) http://www.us-porkcenter.org/ was established in 2005 at Iowa State University. It is a joint venture between the National Pork Board, USDA and about 20 Land-Grant Universities. The goal is to address the growing lack of local extension and educational programs in swine science across the country.

The NPCE has carefully collected data on enrollments in "swine production" courses at four-year universities. In the academic year defined as fall 1998-Spring 1999 there were 914 students enrolled in 37 swine production courses nationally. By fall 2004-Spring 2005 that number had dropped to 663 students in 30 courses. These figures are somewhat misleading because of large enrollments at the California Polytechnic University at San Luis Obispo; Iowa State University and North Carolina State University. Thirteen courses were taught to fewer than 10 students. In Fall 2004-Spring 2005 a total of 66 students enrolled in swine production at Purdue, The Ohio State University, Michigan State University and the University of Illinois.

Why are students not pursuing education in swine production science today? There are many reasons—image of the industry, lack of understanding of the opportunity and a general lack of enthusiasm by young Americans today in fields that require in-depth understanding of math, chemistry and biology.

Will there be enough technically-prepared graduates to meet the staffing needs of a swine industry producing in excess of 100 million head per annum? It is doubtful, and these trends are evident in other applied areas of animal science—beef cattle, dairy and poultry production as well as meat science.

Faculty: There was a time when animal sciences department heads could look at the needs of the state's livestock industry and fill vacant or new faculty positions with individuals whose teaching and research activities would specifically address the needs of the industry. That is often not the case today. In the face of very significant erosions of state funding for agricultural research and educational programs, the administrator has little choice but to first define the areas where there will be significant federal or private funding available to support the individual's program. The consequence over the past decade has been to shift faculty capacity into areas of fundamental biology and biomedical research and away from the type of production animal research that defined the field of animal science for more than 100 years. Fundamental research is both appropriate and essential to a strong department of animal science. The issue is the lack of support for the research that translates fundamental discoveries into practical application. In sum, this is the type of research that is reported at conferences of this nature.

But, it is more than just the kind of research that is done. The next generation of extension specialists, swine production teachers and translational researchers are being trained in laboratories where application research is being done today. As those laboratories decline in number there will inevitably be fewer graduates prepared in the next generation.

Facilities: Historically, animal teaching and research "farms" were constructed with state funds and staff, maintenance and utility needs were provided for by an annual appropriation to the university. Income from livestock sales were generally used to cover feed costs and other incidental expenses. That is changing rapidly as many universities move to a full cost-recovery model. The livestock unit is viewed as a research lab and all costs for operating that lab must come from grants that fund the research that is done.

This reality is leading to a growing level of realization that each university cannot be "all things to all people" and with that comes quiet acknowledgement that a likely outcome will be increasing regionalization of programs.

Animal Sciences Whither?

In the 1960's balladeer Tom T. Hall wrote a song titled, "Who's gonna feed them hogs?" that reflected the worries of an elderly, hospitalized hog farmer. He anguished over who would rise up to the challenge-family, neighbors, friends? Who will be the next generation of technical experts in livestock production science? Clearly, someone will. With the global demand for meat growing at a steady three percent per annum, there will be a robust livestock industry well into the foreseeable future.

A few animal science departments will see great opportunity to be centers of excellence in livestock production science and will emerge as regional, perhaps global, leaders. Other departments will lose focus and over time disappear as their faculty becomes indistinguishable from their colleagues in other areas of biology. A few will find opportunities to specialize in the companion animal science and the emerging field of pet-assisted therapies.

It is critical for the livestock industry leaders to understand the challenges facing academic programs in the animal sciences and step forward to articulate the research and educational needs of the industry both to university leaders as well as those who craft appropriations that ultimately set the agenda for university programs.

Managing Grouped Sows

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Summary

A negative public perception of the use of gestation stalls (crates) is a continual problem for the pork industry. Researchers and producers must continue to seek a solution this problem which, first and foremost, engenders and enhances the well-being of the sow. However, those solutions should not create a negative economic impact for the American pork industry. We must scientifically develop, validate, and implement alternative sow-keeping systems and sow-management strategies and tactics that are both practical and economically feasible but that effectively sustain sow well-being and preserve or increase the efficiency of producing pork. A well-defined, science-based assessment of the welfare of the pregnant sow is essential to the future of the entire livestock industry.

Unfortunately, there is a lack of data to establish welfare-friendly guidelines on how to effectively manage sows in groups during gestation. It is not as simple as removing individual stalls and forming group pens. Despite the notion held by some that keeping sows in groups is a relatively welfare-friendly practice because sows in groups can turn around and interact socially, keeping sows in groups can lead to its own welfare problems. These problems importantly include increased aggression at mixing and feeding, increased injuries and lesions, increased variability in body-condition score, among others. All of these factors can be influenced by feeding method, social status, floor space per animal, group size, genetics, and management procedures.

Despite the choices of group-keeping systems that are being tried, many of these have not been shown to improve the dry sow's state of being. Thus, some of the many factors that should be considered when designing, implementing, and managing sows in groups during gestation are: group size, floor-space allowance, group composition (static vs. dynamic), diet type, method of feed delivery, genetics, sow temperament, and so forth. Most importantly, existing group-keeping systems differ in terms of feeding, group management, and floor type, but group keeping systems are more complex than these few factors.

Introduction

Farm-animal welfare is a major public issue for US agriculture today. Finding and using scientifically sound approaches to assess the state of being of farm animals is crucial to the long-term sustainability of American agriculture. State and federal lawmakers are continually bombarded by humane activists who offer proposed legislation on animal welfare. Unfortunately, there is a dearth of scientific information as to how to defend several contemporary farm-animal husbandry practices.

Today's typical sow-keeping system—the individual 0.61m wide × 2.12 m long stall (or crate)—is perhaps the most controversial welfare concern now facing the US pork industry. Following the European trend, which are based on public intuition as much as scientific evidence, the use of individual gestation stalls has been banned via public referenda in Florida and Arizona. New bills and referenda are set to be introduced and held in several other states, including California. Also, there have been recent announcements of intent to abandon sow stalls by Smithfield Foods, Maple Leaf Farms, McDonalds, and Burger King, among others. The national mass media have given much space and time to the goodness and rightness of abandoning the individual dry-sow stall in favor of keeping pregnant sows is groups. As a consequence, US pork producers face a dilemma: They now must decide how they will keep their sows in the future.

The term "sow keeping" refers to the accommodating and caring for breeding, gestating, and lactating sows. But the *sow-keeping issue* refers for the most part to "should pregnant sows be kept individually or in groups?" As for keeping dry sows in groups a variety of system alternatives have been proposed and are being tried. But neither a set of acceptable group systems nor an ideal group system has been identified. So far, results of industry and experiment-station research from around the world indicate that alternative keeping systems do not necessarily result in improving sow state of being. In fact, sows in individual stalls as compared to group pens have similar values across measurement perspectives (McGlone et al., 2004). No one system has been identified as being better than others based on current notions of sow welfare (Barnett et al., 2001; McGlone et al., 2004; Rhodes et al., 2005).

Group Sow-keeping Systems are not Jigsaw Puzzles

Group keeping systems are extremely complex, and difficult with which to come to grips, simply because there are so many factors that must be considered and integrated. Animal accommodations are not jigsaw puzzles (Curtis, 1995). Jigsaw puzzles once were a whole picture that was, in its original form, jig-sawed into integral pieces. The pieces fit together perfectly because at one time they *were* together. Not so with the contemporary group sow-keeping systems we are in the process of contriving, sometimes in Rube Goldberg fashion (http://en.wikipedia.org/wki/Rube_Goldberg_machine). The pieces, we are finding, as expected, do not always fit together perfectly or even acceptably, simply because they were not designed in the first place to fit together in the present arrangements. In the case of group-housing systems, the pieces include, among others:

- indoors or outdoors, drylot or pasture, and insulated, mechanically ventilated frame structure or hoop structure;
- floor type—slots, solid, or bedding;
- group size and floor-space allowance (will vary with group size);
- group management-static or dynamic (will vary with group size and floor-space allowance);
- group feeding systems-drop, trickle, or electronic or individual feeding stalls;
- sow-handling-labor requirement; herder safety while handling and managing manure;
- manure-handling system—suspension, scrape semi-solids to auger or belt, or Bobcat®; labor requirement;
- capital costs, maintenance costs, and operating costs;
- behavioral management, disease management, and disease-preventive and treatment management; and
- sow state of being, sow productivity, and sow productive lifetime.

As empirical observations and experimental results accumulate, it is clear that each piece has advantages and each piece has disadvantages in terms of productivity, profitability, and, yes, animal welfare. All of the current group-system alternatives allow sows, some freedom of movement, opportunity for social interaction, and individual choice among (available) microenvironments. But there are greater or lesser welfare problems associated with each of these Rube Goldberg group-keeping systems, too, including, stress due to aggression early on and social tension for the duration, variable body-condition score, and injury.

Moreover, clearly, more highly skilled and more attentive stockmanship is required to successfully manage sows in groups. And, even more importantly, when a group-keeping system fails to work well, some sows inevitably experience a poor state of being. The sow-welfare problems in a group system can be horrendous (McGlone, 2006; Curtis, 2007).

Keeping Sows Individually versus in Groups

Based on scientific evidence and empirical observations there are positive and negative aspects of all systems of sow accommodation that have been tried. The sow is a creature that is difficult to keep. As for reproduction, few studies have shown reproductive impairment in pregnant sows kept in stalls as against sows in groups. Although some studies have shown greater reproductive performance for sows in groups than in stalls (Bates et al., 2003; Lammers et al., 2007), some findings have been that reproductive performance is similar for sows either in groups or in stalls (Langendijk et al., 200; Harris et al., 2006; Salak-Johnson et al., 2007). Whereas others have found greater reproductive performance for sows that gestated in stalls as compared with those that gestated in groups (Barbari, 2000; Bates et al., 2003; Karlen et al., 2006).

How might the differences in results and conclusions have arisen?

Phase of Reproduction

It recently has been documented that welfare challenges to the sow change over time. Sows in groups during *early gestation* have increased incidence of scratches, higher estrus return, and higher cortisol concentration, whereas, sows in stalls have increased lameness during late gestation (Karlen et al., 2006). These findings are similar to those reported by Salak-Johnson et al. (2007), wherein lesion scores for group-housed sows were high at group-formation (mixing) time, plateau during mid-gestation, but increased again during late-gestation. Even the European Union regulations already recognize this as they provide for sows to be kept in individual accommodation during breeding and the first few weeks of gestation, when reproductive functions are most sensitive to deleterious effects of social strife and other stresses. This, of course, further complicates the rational design of the ideal sow-keeping system. Thus, we probably should accommodate sows differently during different stages of reproduction.

Stereotypies

Stereotypic behavior patterns (e. g., repetitive, invariant, apparently functionless and purposeless bar- and trough-biting, sham-chewing, drinker-pressing, floor-nosing, head-weaving) often are used as a measure of sow welfare. Differences in stereotypic behaviors between sows in stalls and those in groups have been found (Vieuille-Thomas et al., 1995). Specifically, sows in groups spend less time interacting with bars and troughs (Karlen et al., 2006). Others, however, have reported no differences in stereotypic snout behaviors between sows kept in indoor stalls and those kept in outdoor groups (Dailey and McGlone, 1997).

Although sow behavior in this regard may differ among housing systems, often it seems some component such as direction of bars or other design feature that is responsible for the behavior displayed by the sow (Dailey and McGlone, 1997; McGlone et al., 2004). In other words, sow repetitive behavior patterns seem to be partly driven by external stimuli and opportunities, and therefore can be designed out of a system. Only if it has been established that a behavior is internally driven and clearly associated with reduced welfare need we have ethical concerns about its display.

Also, conclusions that these behavior patterns are a bad sign in terms of sow welfare may have been premature and erroneous. Pregnant gilts either on pasture or on drylot or in stalls showed similar amounts of snout behaviors (Daily and McGlone, 1997). These behaviors did not start with the gestation stall, and they apparently are at least partly triggered internally. So, if anything, they ought to be accommodated and encouraged not neutralized and discouraged. Most stereotypic snout behaviors in sows come around the time of once-daily feeding of a restricted ration. So there also seems to be an external component in the motivation for such snout behaviors. So it now seems that the sow's motivation to display repetitive snout behaviors is mixed—internal and external—and therefore it is complex and will not be easy to come to understand. Finally, there is good evidence that restricting a small ration of high-concentrate diet to a once-daily feeding causes hyperacidic indigestion in the sow. Those repetitive snout behaviors result in increasing saliva secretion, the buffering capacity of which neutralizes the heartburn. Thus, the bottom line is that the sow's so-called snout stereotypies might not be functionless or purposeless after all.

Plusses and Drawbacks Around

There are both advantages and disadvantages associated with dry sows being kept either individually or in groups during gestation. No keeping system in either category has been identified, developed, or optimized such that it ultimately and invariably sustains the well-being of the pregnant sow.

Possible explanations are that

- most studies have not taken a holistic approach by assessing multiple measures of state of being,
- most studies have compared so-called "systems" but have not considered all of the features of those respective systems that can influence how a sow responds to and interacts with her environment, or
- both of the above.

It is crucial that producers realize that there is more than the several approaches for each of the several design features, and thus many permutations of design features. Numerous feature combinations are possible, and not all of them work.

Management of Sows in Groups

How should we manage sows in groups? This is a million dollar question for which we do not yet have a definitive answer.

According to the AVMA website, sow keeping systems should attempt to

- minimize aggression and competition among sows;
- protect sows from detrimental effects associated with environmental extremes, particularly temperature'
- reduce exposure to hazards that result in injury, pain, or disease;
- provide every animal with daily access to appropriate feed and water;
- facilitate observation of individual sow feed intake, respiratory rate, urination and defecation, and
- allow sows to express most normal patterns of behavior.

Additional management strategies that should be considered are:

- once a small group (4 or 6) of sows has been established, no more sows should be added to the group;
- mix sows only if they are being kept in larger groups (20+);
- if sows are mixed, mix in a new pen not a home-territory pen; and
- if an individual feeding system is not being used, sort and establish sow groups according to sow eating speed to reduce fighting and undernourishment (Temple Grandin, http://www.grandin.com/welfare/tips.sow.housing.html).

Group Housing Systems: Factors to Consider

Keeping sows in groups during gestation is not as simple as removing individual stalls, forming group pens. Despite the perception that keeping sows in groups is a relatively welfare-friendly practice as compared to using individual stalls simply because sows in groups can turn-around and interact socially, keeping sows in groups can lead to its own welfare problems. These mainly include increased aggression at mixing and feeding, increased injuries and lesions, increased variability in body-condition score, and so forth. All of these factors can be influenced by feeding method, social status, floor space per animal, group size, genetics, and management procedures. Thus, some of the many factors that should be considered when designing and implementing group keeping systems are group size, floor space allowance, group composition (static vs. dynamic), diet type and method of feed delivery, genetics, sow temperament, and so forth (Levis, 2007). Most importantly, group-keeping systems differ in terms of feeding, group management and floor type.

Feeding Systems and Management

What are our feeding options? Feeding systems can be first categorized as individual or group systems. Feeding grouped sows individually can be accomplished by using individual feeding stalls of some sort or electronic sow feeders (ESF).

Individual stalls. Individual feeding stalls will minimize aggression at feeding time, but some aggression still occurs. Also, it is not possible to feed individual rations because sows enter stalls somewhat at random at feeding time.

Electronic sow feeders. With ESF, each sow wears a transponder and eats by entering a feeding station, and each sow has her own daily feed allotment. Each feeding station can accommodate ~40 sows. A sow can consume her entire daily ration in one meal during a single daily visit or in several smaller meals spaced throughout the day.

Aggressive physical acts can occur while sows are waiting to enter the feeding station (Jensen et al., 2000; Anil et al., 2006). Vulva-biting is a welfare concern associated with ESF, but attempts have been made to reduce vulva biting. Appropriate feeder design and placement have reduced the incidence and severity of vulva biting (Levis, 2007).

Group-feeding options. There are three general approaches to group feeding: trough feeding, single-drop feeding, and floor feeding. These feeding systems have been used for small groups of ~6 as well groups of ≥100 sows.

Floor feeding, where the feed is simply dumped on the solid floor, engenders the most feeding-time aggression because sows compete for feed. Dominant sows overeat and become fat, submissive sows become thin. However, Salak-Johnson et al. (2007) found that floor feeding sows in groups of 5 at floor-space allowances of 2.3 and 3.3 m^2 had greater body weight and backfat depth than did sows in groups of 5 at 1.4 m^2 per sow or individual stalls.

Single-drop feeding, in which a single drop of dry feed across a wide area is made once a day, also has been tried. This system leads to increased aggression because some sows eat faster than others and will consume their own allotment and then go looking for more, stealing the feed of others. Threats, attacks, and fights were evident in a study by Jansen et al. (2007) that involved 32 drop-feeders depositing feed into 3 troughs across the width of a pen for 50 sows.

A modification of single drop feeding is the *trickle-feeding system* wherein feed is continuously delivered at a slower rate over a period of time. There seems to be less aggression expressed in this system. Both the drop-feed and trickle–feed systems operate well with a wide range of group sizes, the most common group size being 5 to 6 sows.

Hulbert and McGlone (2006) reported that neither pen type (individual or group) and nor feeding system (drop or trickle) was associated with physiological stress responses in sows. Feeding system had no affect on social interaction or overall activity, although gilts in group pens equipped with drop feeding did show more snout behavior at 1200 h than did those in trickle-feeding pens. Over a 24-h period, however, snout behavior did not differ with feeding system. Neither did time spent feeding differ between drop- or trickle-fed sows. Treatment differences in behavior were due to available floor space not feeding system.

Despite the general perception that sow aggression is reduced with trickle feeding, it still is not perfect in this regard. Aggressive behavior and poor and variable body-condition score are still apparent in group systems with trickle feeding (personal observation, November, 2006).

Static versus Dynamic Group Management

The question remains: How can we minimize aggression and competition among group-kept sows? The most serious and injurious aggression and competition among group-kept sows occurs upon introduction of new sows to a group (mixing) and at feeding-time. Upon mixing, sows will fight with a high level of aggression, part of their natural attempt to form a new dominance hierarchy. The aim of sow management must be to enable the formation of the social order with as little stress and physical injury as possible.

Still, in many layouts, a sow's inability to retreat and protect itself is limited. As already mentioned, a great number of excessively fat sows may occur due to over-eating by dominant sows, as well as a great number of very thin sows due to reduced feed intake by low-ranking, submissive sows. Moreover, this increased fighting can result in vulva biting' skin lesions and wounds on rump, shoulders and other regions of the body' as well as lameness.

In loose accommodations—with relatively large space allowances and few places for sows to get "cornered" by an aggressive groupmate--there are the options of

- large groups with sows entering and leaving the group each week (*dynamic* group management);
- weekly service groups which stay together throughout pregnancy (*static* group management);
- smaller groups with each weeks sows broken up into a number of subgroups; and/or
- a combination of these, each used at different stages of pregnancy.

In many cases, feeding system dictates group size.

Dietary Strategies

Attempts to develop diets and feeding strategies for grouped sows have been aimed at reducing the motivation to eat (hunger) as well as stereotyped behaviors associated with restricted access to feed.

Adding fiber to diets can increase eating time and decrease stereotyped behaviors (7 to 50 %) and aggression, but it also may decrease voluntary intake of the actual nutritious diet (Meunier-Salaun et al., 2001). One Danish producer reported that his gestating sows, given free access, some sows would consume up to 18 kg/day of citrus pulp if given the opportunity. Consequently, one must stop offering such highly palatable feedstuffs ≥2 wk prior to farrowing so sows will be more motivated to take in the increased amounts of feed needed for lactation after parturition (personal communication, November, 2006). Some have reported less stereotyped and manipulative behaviors in sows fed high-fibrous diets (Whittaker et al., 1998; Van der Peet-Schwering et al., 2003; Zonderland et al., 2004), but others have reported that sows raised outdoors and fed a high-fiber diet show more sham-chewing and less standing at gestation day 30 (McGlone and Fullwood, 2001). Self-directed behavior and total oral behavior were reduced by feeding a diet rich in fermentable non-starch polysaccharide to gestating sows (de Leeuw et al., 2005), but others have found no such effect (McGlone and Fullwood, 2001).

Feeding wet rations and *lengthening the partitions* of feeding stalls have been used as means for reducing aggression during feeding (Andersen and Bøe, 2001). They found that, as partition length increased at feeding time, there was a reduction in number of bites and total agonistic encounters and displacements. Lower-ranked sows less likely to be subjected to aggression and displacement as partition length increased. Contrary to this, some producers have reported less injury to low-ranking, slow-eating sows when they have more opportunity to maneuver their bodies in feeding stalls with "short" or "quarter" partitions (typically 18" long) (personal communication, 2007). Andersen and Bøe (2001) also reported that feeding wet feed reduced aggression. This may be related to eating time because wetting facilities ingestion, so the time required to eat a daily ration is more uniform across sows.

Although some success has been achieved by feeding high-fiber diets to reduce stereotyped behavior and hunger, this approach has not been refined and optimized.

Conclusion

Acceptability of housing systems for the pregnant sow is a major public issue in the USA nowadays. It is being driven primarily by public perceptions and regulations promulgated in Europe, not by science. Innovative approaches are needed to satisfy the valid concerns of special-interest groups and to minimize the economic disadvantages that would be incurred if gestation stalls were to be immediately banned. Factors that actually do enhance the success of group sow-keeping systems in terms of welfare still must be identified, characterized, and optimized before any such system should be implemented. Otherwise, the industry risks seriously compromising the well being of dry sows.

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Are Antioxidants associated with pig and sow mortalities?

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Summary

Several vitamins and trace minerals have been associated with the antioxidant system in the body. It has been shown that a deficiency of Se or vitamin E can result in an increased mortality in young pigs. Because sow mortality has risen during the past decade, a study was conducted to evaluate the serum constituents of sows over their reproductive life. The evaluation of various nutritional, environmental and physiological conditions and the resulting effects on the serum concentrations of several nutrients associated with the antioxidant system was conducted with a total of 480 gilts and sows. In general, ascorbic acid (ascorbate and dehydroascorbic acid), α-tocopherol, Se and glutathione peroxidase activity were each relatively constant during the first 60 to 80 days postcoitum, but the latter part of gestation and lactation showed a decline in each of these antioxidants. Most of the antioxidants but particularly ascorbic acid and α-tocopherol were influenced by parity and seasonal effects. The results imply that although sow mortality was not directly linked to the decline found in the sow herd of this experiment, the data suggest that the sow is vulnerable to the stresses of late gestation and lactation, which can be exacerbated with season and parity could affect sow mortalities.

Introduction

Swine producers, veterinarians, technical specialists in the feed industry, and scientists are concerned about the increasing mortality of pigs, particularly in sow herds where mortalities in some herds averages 15% (Irwin et al., 2007). On a national scale, Pig Champ (2007) has demonstrated that the rate of sow mortality has risen during this past decade from 5% in 1996 to almost 9% in 2005 (Figure 1). In addition, there are several reports from veterinarians and swine producers that pig mortality postweaning is higher than desirable, and that those pigs affected appear to be the largest and faster growing pigs. These observations lead one to believe that nutrition, management, or environmental problems are not the sole culprit here and other reasons may account for the increasing incidence of the problem. In the case of sow herds, some genetic lines reportedly have greater mortalities than others, and that warmer weather increases the mortality rate, whereas in the weanling and grow finish pig it appears to be closely associated with pigs of high lean gain potential. Although the stress gene is considered responsible for the greater occurrence of sudden deaths several years ago, the problem still persists even after the stress gene has been removed or its affect diminished in many swine breeding programs. Several nutrients are, however, involved in reducing metabolic and physiological stresses, but no one has investigated the changes of several stress indicators that occur during the life cycle of the pig, particularly in the reproducing sow. An additional concern is that nutritional excesses, particularly the micro nutrients (vitamins and minerals) are often increased with the expectation that the modern pig has greater dietary requirements. These dietary micro nutrients are often times increased without supporting research documenting that they are beneficial. In other cases these micro nutrients are withdrawn from the diet, in an attempt to reduce feed costs, but their affect on the biological responses under stress conditions have not been examined. In fact, evidence is becoming more prevalent that such excesses or withdrawals may be detrimental rather than beneficial to the pig.

Can certain nutrients affect weanling pig mortality?

From 1960-1970"s, weanling pig mortality approached and even exceeded 10% in some swine herds. This was later identified to be largely attributed to a Se deficiency that prevailed at high mortality rates until FDA approved its use in 1973 at 0.10 ppm, and later (1984) increased the supplemental Se level to 0.30 ppm. Although mortalities are not as great today in weanling pig as during this previous era, postweaning mortalities and the presence of Se and vitamin E deficiencies are still reported in the herds of many swine producers. It is clear, however, from the early studies that Se and Vitamin E reduced or prevented the high number of pig deaths. The research presented in Table 1, where Se and Vitamin E was one of the first reports, where young pigs at weaning were injected with each or both of these nutrients. The results show that both nutrients reduced pig mortality quite substantially. This gives clear evidence that these two nutrients when administered to deficient swine can influence pig mortality. The reasons for this lowered mortality were not identified, except that the report did demonstrate that tissue damage did occurred and serum enzymes (i.e., SGOT) reflecting tissue damage were greatly increased. Upon administration of vitamin E and Se, these serum enzymes were lower. These two nutrients (i.e., Se and vitamin E) have been identified as antioxidants (although Se is part of the antioxidant enzyme responsible for antioxidant activity, rather than Se *per se*) and thus are critical in maintaining pig health. If these two nutrients can produce such effects in young pigs, one would speculate that these same biological phenomena can occur with older pigs.

What effect do the antioxidant nutrients have on sow mortality?

There can be several causes of sow mortality or a need to euthanize the sow. These include twisted digestive tracts, poor feet and legs, "thin sow syndrome" as well as esophagogastric ulcers and heart failure. It has been estimated that losing a sow costs the swine producer approximately $400 to 500 which results in approximately $18 added cost for each sow in the herd (Irwin et al., 2007). There are only a few studies that have been conducted to investigate sow mortality in commercial herds, and most have been surveys. We are addressing herein those factors in sows lost from sudden or spontaneous deaths at any stage of their reproductive cycle.

We recently had the opportunity to collect blood samples from the OSU sow nutrition research herd where the experiment was examining dietary mineral sources and levels over several parities during the year 2003 to 2004. We collected blood samples from all sows in that experiment on one day per month for a 12 month period regardless of stage of reproduction (breeding to weaning). The total number of observations was approximately 480 sows of which some sows were bled several times (at monthly intervals) depending on their parity and length of time remaining in the experiment, whereas other sows were bled less often. The time of bleeding each month was not fixed but rather was at 3 to 4 week intervals from the last bleeding, but bleeding did occur at the same time of day (3 to 4 hours post feeding). The blood was analyzed for vitamin C (ascorbic acid, ascorbate, and dehydroascorbic acid), α-tocopherol, Se, and glutathione peroxidase activity. These nutrients or enzymes are considered the ones most responsible for antioxidant activity and have been found to reflect tissue activity from blood analyses.

The blood data were then statistically evaluated using the variables (trace mineral level (NRC vs. Industry levels), trace mineral source (organic vs. inorganic), Ca and P levels (NRC vs. Industry levels), parity (1 vs. 2-6), season (cool vs. warm months) and the data plotted by day of reproduction for each measurement. Sow mortality was low (< 2%), but the results suggested areas where the various antioxidant nutrients were influenced by the experimental variables evaluated. Because the treatment effects of each variables are too numerous to present, their statistical probabilities comparing each at the day of reproduction are presented in Table 2. The main effect of day of reproduction with each measurement is presented graphically.

The results in Figure 2 demonstrate that the serum level of ascorbic acid is relatively constant during the initial 60 to 80 days of pregnancy, whereupon there is a decline in its concentration to farrowing and throughout lactation. The lower sow serum ascorbic acid concentration is largely attributed to the transfer of the vitamin to the fetus and to the milks, but its low level in the serum leaves the sow in a somewhat lower vitamin C status during this critical phase of the reproductive cycle. Although the same general trend occurs with different parities, the serum ascorbic acid concentration was lower in older sows ($P < 0.001$). Older sows produce larger litters and more milk thus potentially more ascorbic acid is transferred by older sows to these tissues. Because the sow synthesizes vitamin C in her liver and is therefore the vitamin is generally not added to swine diets, this data implies that the sows ascorbic acid status may be low during the period of time when sow mortality incident is highest.

Total ascorbic acid is comprised of 2 forms. Ascorbate is the active form of the vitamin in the body where it is used as an antioxidant, whereas, dehydroascorbic acid is the inactive form (where the hydrogen has been removed). Its concentration is increases when the active form is used. Dehydroascorbic acid concentration would be expected to increase during periods of stress or when the body has a greater need for ascorbate. The results in Figure 3 demonstrate that the serum level of ascorbate is relatively constant during the first 60 to 80 days of pregnancy, however, a sharp decline occurs in ascorbate to farrowing and during lactation. The lower ascorbate level in the blood may not allow adequate ascorbate to be available for biological antioxident functions thus the sow becomes more vulnerable to oxidative stress during this phase of the reproductive cycle. Although the same trend occurs with different parities, the ascorbate concentration is lower with older sows ($P < 0.001$).

Figure 3 demonstrates the serum concentration of dehydroascorbic acid during reproduction. Dehydroascorbic acid concentration follows the same general path as ascorbate during gestation and lactation where a decline occurs during late pregnancy and throughout lactation. However, the dehydroascorbic acid appears to be somewhat higher during late gestation and lactation when stress conditions are greatest. Although the differences are not significant, the data implies that the dehydroascorbic acid concentration difference between ascorbate and dehydroascorbic acid curves widens during this period. This implies that more of the active ascorbate is being used and converted to the inactive form, again leaving the sow more vulnerable to oxidative damage of tissue and possibly death. The results in table 2 indicate a significant effect of parity ($P < 0.001$), season ($P < 0.001$), and trace mineral level ($P < 0.04$) where each of these variables were lowered in older sows, in the warmer seasons and at the lower trace mineral level.

Figure 4 and 5 reflect serum α-tocopherol concentrations in two groups of sows. Each group was fed differing dietary levels of vitamin E. The group in Figure 4 was provided vitamin E at 20 IU/kg diet, while the second group as shown in Figure 5 was fed 40 IU/kg diet. In both cases the trend of serum α-tocopherol concentration were the same for both groups reflecting a decline in serum α-tocopherol from about 80 to 90 days postcoitum through farrowing but a subsequent rise in α-tocopherol occurred upon lactation. The latter is indicative of a greater feed and thus vitamin E intake during lactation. Serum α-tocopherol is also affected by trace mineral level ($P < 0.04$), dietary Ca and P levels ($P < 0.02$), parity ($P < 0.001$), and season ($P < 0.001$). This suggests that each of these variables had an impact on the sow's antioxidant activity status from vitamin E. Because the sow mobilizes and metabolizes body and dietary fat during this period as well as transferring fatty acids to the mammary tissue for milk fat synthesis both physiological conditions increases the need for this vitamin. Thus when environmental or physiological stresses occur it may further exacerbate the need for vitamin E.

Selenium and glutathione peroxidase are associated with Se as a component of the enzyme glutathione peroxidase. Serum Se begins declining in sow serum around 60 day postcoitum and decreases more rapidly as the sow approaches parturition, whereupon it increases during lactation (Figure 6). Organic mineral sources resulted in greater serum Se values ($P < 0.01$), while sows in later parities ($P < 0.01$) and younger sows ($P < 0.01$) had lower serum Se values. The Se containing enzyme glutathione peroxidase presented in Figure 7 also declines as the sow approached parturition and was lower in younger sows ($P < 0.001$) and during warmer months ($P < 0.001$) of the year.

Although many of these declines for the various nutrients appeared to be greater when sows were in late gestation and during lactation, the decline coincides with the period where sow mortality is also greatest. Although the decline in these antioxidant nutrients are undoubtedly partially attributed to their transfer to conceptus products and colostrum or milk, it leaves the sow in a physiological situation more vulnerable to oxidative stress and potentially death. Although the same general trend occurs within each reproductive cycle it is during periods of high stress where these nutrients may have their greater antioxidant need than during periods of less stress. During the warmer months, or at parturition and immediately postpartum, or periods when low feed intake is followed by higher feed intakes (i.e., parturition to lactation), the higher producing sow would likely be more 0osubjected to greater oxidative stress. It has been reported that cardiac failure constitutes > 30% of spontaneous sow mortalities (D'Allaire et al., 1993) that corresponds to poor antioxidant status and tissue damage. Once the antioxidant status is lowered it could affect the responses of their tissues and perhaps death may occur.

How do Antioxidants work

There is obviously a need to protect body tissues from oxidative damage via antioxidants. A deficiency can damage DNA, body proteins and polyunsaturated acids by forming free radicals. Such activity has been implicated in many diseases common today. Although the body has several protective systems in the category of antioxidants there are two major types of antioxidants. There are a group of antioxidants that protect the fatty tissue and another major group that are intracellular and thus water soluble. The interrelationship, and balance between these two groups of antioxidants rely on the adequacy of vitamin E (E), vitamin C (C), selenium (Se), copper (Cu), zinc (Zn), manganese (Mn) and iron (Fe) as all are essential to maximize the health of productive animals.

Typically, Fe and Cu are bound to proteins and are part of antioxidant defense, transport or storage. However when Fe and Cu become freed (not bound to proteins), they are involved in the excessive production of highly active molecules capable of damaging tissue or cellular membranes. These products are super oxide (O_{2*}) and free hydroxyl (OH_*) radicals where each are involved in causing oxidative damage. These radicals can further generate other free radicals in an escalating manner such that the peroxy radical which reacts with hydrogen ions to form hydrogen peroxide (H_2O_2).

The accumulation of H_2O_2 can produce damaging consequences to the animal unless converted to water (H_2O). The formation of the free radicals is prevented by (1) catalase, a heme Fe containing enzyme, in peroxisomes and the mitochondria and (2) glutathione peroxidase, a Se containing enzyme, in the mitochondria and in the cytoplasm of the cell. Superoxide dismutase (SOD) reacts with the superoxide radicals to form H_2O_2. The SOD in the cytosol requires Zn and Cu to function, while the SOD in the mitochondria requires Mn for its activation. Ascorbate (Vitamin C), which is the active form of the vitamin reacts with superoxide radicals, donating its hydrogen to from H_2O_2 where it forms water. Vitamin C is also important in regenerating α-tocopherol once vitamin E has been oxidized or inactivated.

While free Fe and free radicals can damage lipid membranes, α-tocopherol, located in the membranes can prevent the chain reaction that ultimately leads to lipid hydroperoxides. Lipo glutathione peroxidase, similar but not identical to the GSH-Px in the cytoplasm, contains Se, but also prevents the formation of oxidized fatty acids at the layer of the cellular membrane. Thus to maintain healthy membranes requires the dual functioning of vitamins C and E to regenerate reduced glutathione that is part of the enzymatic reaction of glutathione peroxidase.

What does this mean in application?

These antioxidants (both fat and water soluble forms) work synergistically to prevent the buildup of oxidized cellular components in the cell membrane and cytoplasm and allows normal cellular absorption and metabolism to take place. The greater the transfer of nutrients into the cell (i.e., greater feed intakes) will increase the need for the antioxidants and if these needs are not met, the cellular formation of the oxidative products is increased. If their formation is not reduced to water, cellular membranes and structure are damaged. Consequently, once damage occurs, the cellular contents are released into the circulatory body fluids, and the cell is damaged. If this damage is extensive, the animal cannot handle the accumulation of these oxidized products and upon severe stress (i.e., farrowing, heat, movement, etc.), the animal dies. The modern pig with high productivities resulting in more metabolic cellular activity thus faces a tremendous challenge in meeting their genetic potential for growth or reproduction. Thus, it is becoming recognized that functional forms and adequate quantities of certain vitamins and trace minerals must be provided to the pig and sow in the correct ratios, without excesses being supplemented, in order to maintain the health and productivity of the modern pig.

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Table 1. Effect of injected selenium and vitamin E in weanling pigs deficient in these nutrients on mortality responses.

	Experiment	No. of pigs [a]	No. of deaths	Percent mortality
Control	1	30	24	80
	2	36	12	33
+ Vitamin E (68 IU)	1	24	12	50
+ Vitamin E (200 IU)	2	28	3	11
+ Se (1 mg)	1	21	0	0
+ Se (1 mg)	2	26	0	0
+ Vitamin E/Se (68 IU + 1 mg Se)	1	24	0	0
+ Vitamin E/Se (200 IU + 1 mg Se)	2	22	0	0

[a] Pigs were 4 weeks of age at weaning and were on the above test for 42 days.

Source: Mahan et al., 1973.

Table 2. Effect of various nutritional, environmental, and physiological variables on the resulting statistical probabilities during the reproductive cycle

	Serum constituent and probabilities of each					
Measurement	Ascorbic acid (total)	Ascorbate	Dehydro ascorbic acid	α-tocopherol	Se	GSH-Px
Day of reproduction	0.01	0.01	0.01	0.01	0.01	0.01
Trace mineral source (organic vs. inorganic)	0.47	0.86	0.99	0.28	0.01	0.98
Trace mineral level (NRC vs. Industry.)	0.44	0.97	0.39	0.04	0.29	.68
Ca/P level (gest. & lact.) (0.75/0.60% vs.1.80/1.20%)	0.31	0.81	0.68	0.02	0.25	.81
Parity (1 vs. 2-6)	0.001	0.40	0.001	0.001	0.001	.001
Season (Cool vs. warm months)	0.46	0.001	0.001	0.001	0.001	.001

Figure 1. Sow mortality trends in the United States

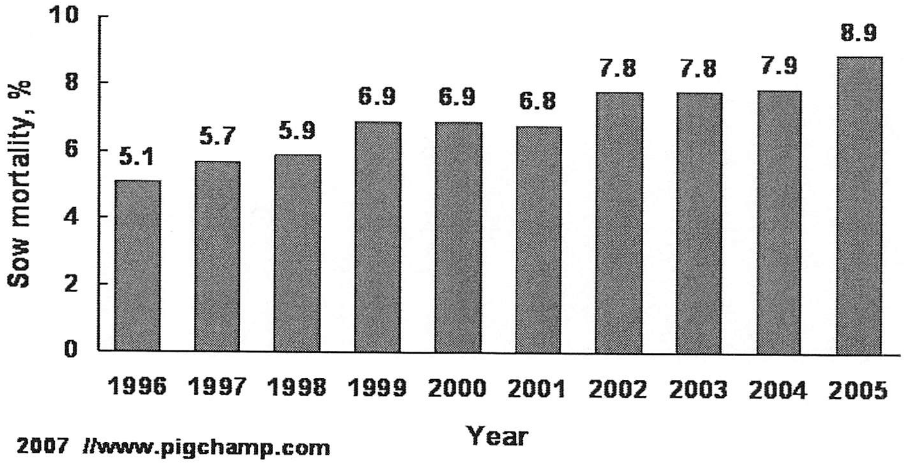


Figure 2. Serum ascorbic acid in adult sows over their reproductive cycle

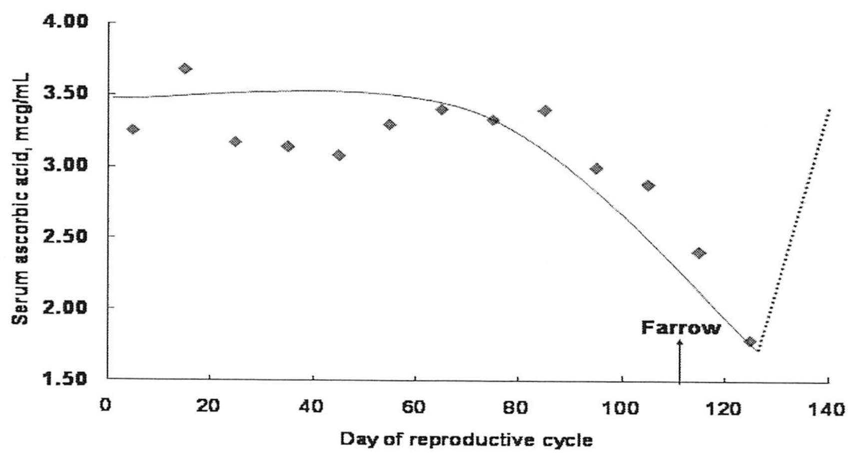


Figure 3. Serum ascorbate and dehydroascorbic acid in adult sows over their reproductive cycle

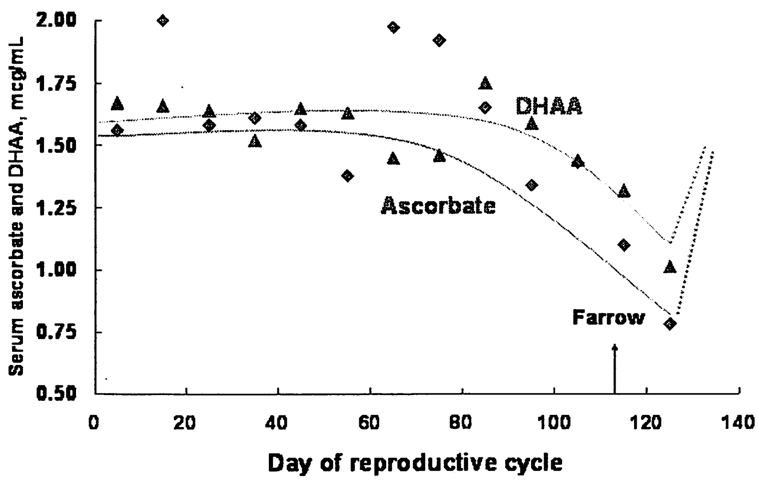


Figure 4. Serum α-tocopherol in adult sows 20 days prepartum to 20 days postpartum (20 IU vitamin E/kg diet)

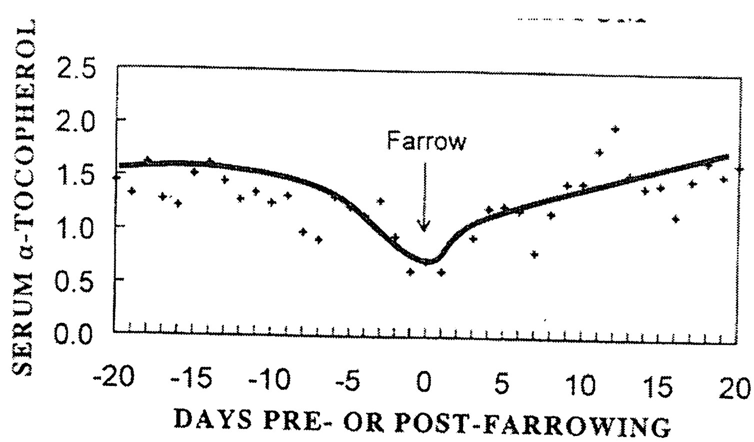


Figure 5. Serum α-tocopherol in adult sows over their reproductive cycle (40 IU vitamin E/kg diet)

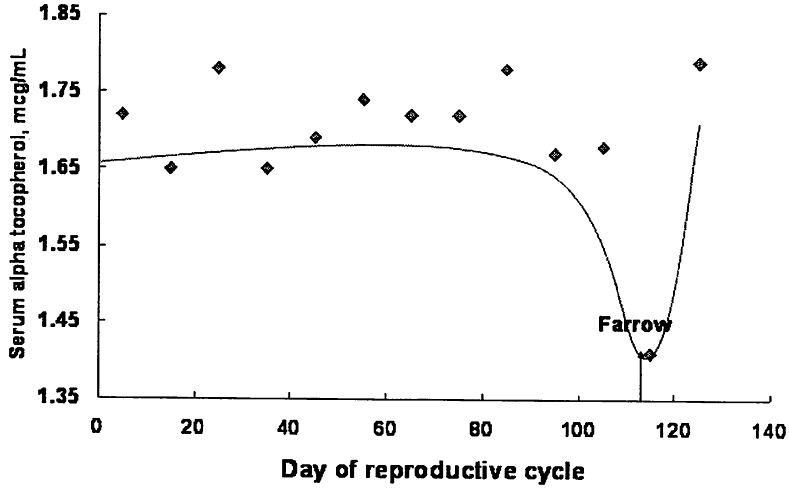


Figure 6. Serum Se in adult sows over their reproductive cycle

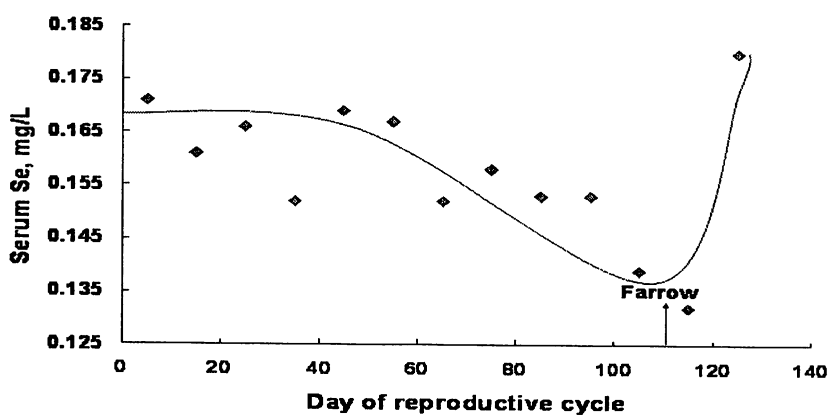


Figure 7. Serum glutathione peroxidase activity in adult sows over their reproductive cycle

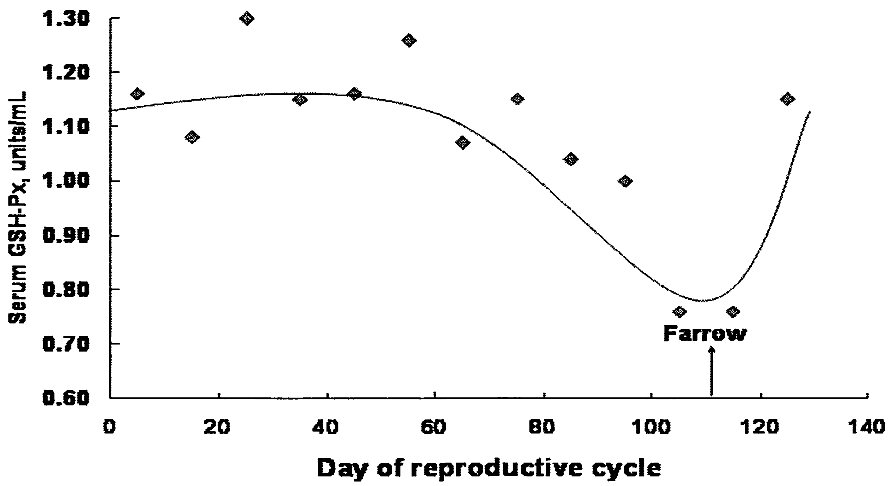
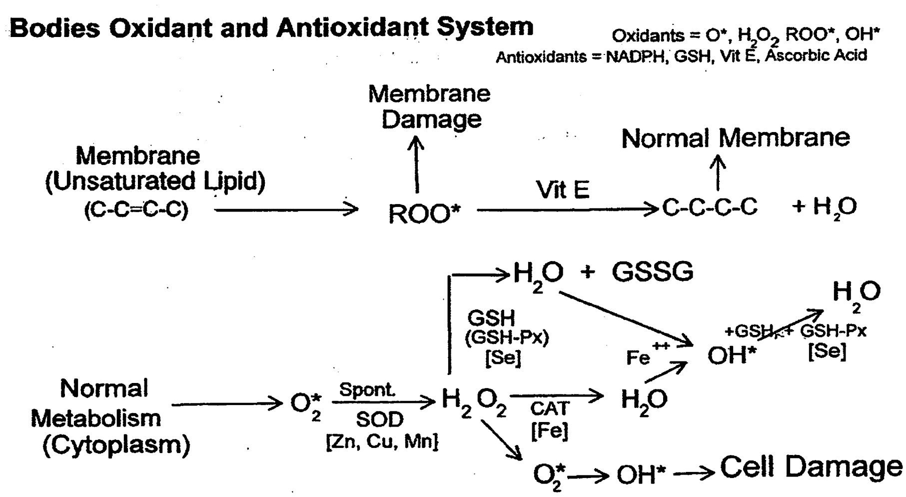


Figure 8. Schematic use of several nutrients and their affect on the bodies antioxidant system



PCVAD: When Immunology goes wrong, life on the farm becomes very expensive

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Sumary

As veterinarians are conducting farm trials to find answers for their clients, researchers are testing theories about how this virus can be associated with the variable clinical expressions and mortality observed across a wide range of production situations. Pharmaceutical and biological companies are striving to provide quality vaccines. Research, effective vaccines, improved diagnostics and enhanced management are all tools to help prevent and minimize the clinical signs associated with exposure to PCV2 and lessen the devastating losses.

Introduction

The first finding of circovirus was in 1974 in a continuous porcine kidney cell line (PK-15).[1] This first identified porcine circovirus (now known as PCV1) was found to be widespread in the pig population and non-pathogenic for pigs.[1] Since the emergence of a disease causing severe wasting, ill-thrift and elevated mortality in nursery pigs was first described in western Canada in 1997 by Drs. John Harding and Ted Clark, Postweaning Multisystemic Wasting Syndrome (PMWS), as it was initially called, has been identified in most swine-producing countries worldwide. The disease has resulted in significant health challenges and economic damage in the swine industry. Porcine circovirus type 2 (PCV2) was subsequently identified as an integral component of the disease process.[2] Debate continues regarding the possible role of other co-factors. The disease is not transmissible to humans and pork from pigs exposed to PCV2 is safe to eat.

PCV1 and PCV2 are the smallest known viruses that affect swine and are closely related to psittacine beak and feather disease circovirus. A number of circoviruses have been found that include canary, bovine, goose, columbid, ostrich, raven and a closely related TT virus, a circovirus found in humans that belongs to the Circoviridae family, Anellovirus genus. Evidence indicating exposure to PCV2 has been found in stored swine serum in Europe as far back as 1969.[1] Veterinarians in the US have discussed finding PCV2 in tissue submissions for over 10 years but have not understood the significance of finding this virus as a co-infection. Historically in North America, the disease manifested itself as a sporadic occurrence of growth retardation and weight loss in nursery-aged pigs (6 to 12 weeks of age) but usually in co-infections with PRRS virus. Recently, however, a different presentation has been described resulting in severely elevated acute mortality in older pigs usually 6 to 18 weeks of age. In addition, other clinical presentations were also being associated with PCV2 infection.

American Association of Swine Veterinarians action

In an effort to determine the significance of this disease in the North American swine herd, the American Association of Swine Veterinarians (AASV) formed a task force in 2006 to investigate the emergence of a more severe and varied clinical presentation of disease associated with exposure to porcine circovirus type 2. The task force developed a dynamic case definition of the disease in an attempt to provide some guidance to practitioners faced with trying to diagnose and manage the disease. The group also proposed the adoption of a new name, Porcine Circovirus Associated Disease (PCVAD), to cover the list of now somewhat varied clinical presentations. The name is an attempt to better describe the disease process as it occurs today and recognizes that PMWS is not the only clinical expression; although it is one of the more severe and economically damaging.

In the past few years, a heightened awareness of this problem has swept across all major swine producing areas in the United States and Canada. The rapid appearance of severe clinical disease is only one interesting aspect of a very complex problem. The AASV task force was given the charge to gather information and address the concerns of the association's membership. They held a special session during American Association of Swine Veterinarians (AASV) 2006 Annual Meeting where members discussed what was being observed in the field. The task force immediately acted on the charge and began developing a long list of issues that needed to be addressed. In addition, the task force worked closely with the National Pork Board to insure the concerns of swine producers and processors were also recognized and to aid in the development of educational materials and the dissemination of information.

Current "versions" of the virus

Dr. Raymond Rowland, a virologist with Kansas State University, and Dr. Carl Gagnon, from St. Hyacinthe, has reported that two versions of PCV2 have been identified. The proposal is to use PCV2a and PCV2b for each version. PCV2b is associated with the more severe form of PCVAD. It appears that PCV2b would correspond with an RFLP pattern 3-2-1 and PCV2a would correspond with a RFLP pattern of 4-2-2. A Swedish group has proposed a genotype 3 which appears to be equivalent to PCV2b. Dr. A. Olvera, Barcelona, Spain indicates that PCV2 could be divided into two groups (1 and 2) and eight clusters (1A to 1C and 2A to 2E). It is my understanding that the isolate that we know as PCV2b would be equivalent to Olvera's 1A.

Clinical expressions and case definition

Currently, a number of variable clinical presentations are being described and associated with PCV2 infection. However, due to its ubiquitous nature, exposure to PCV2 is a common finding in pigs submitted for diagnostic work-up. Thus, it was recognized that a set of criteria was needed to determine when a disease manifestation was likely associated with PCV2 infection. PMWS is recognized as a major clinical manifestation of PCVAD but not the only one. Although research has yet to confirm Porcine Dermatitis Nephropathy Syndrome (PDNS) as one aspect of PCVAD, it is included as one of the possible or potential clinical expressions until further knowledge becomes known.

While individual animals may exhibit clinical signs, the herd does not always experience PCVAD which may lead to misdiagnosing the problem. To derive the following case definition, the committee adopted the approach utilized by the Centers for Disease Control and Prevention (CDC) to define "cases" in human medicine where a definitive etiology remains unknown. The following criteria were selected as the basis of a case definition so all researchers and veterinarians will know what constitutes PCVAD. This case definition is considered to be a dynamic document which will be altered as additional information becomes available.

PCVAD can be subclinical (at least PCV2 can be subclinical) or include one or more of the following clinical manifestations concurrently:

1. Multisystemic disease with weight loss (formerly known as PMWS)
2. High mortality: Doubling of historical mortality rate without introduction of a new known pathogen.
3. Respiratory signs including pneumonia
4. Porcine Dermatitis and Nephropathy Syndrome (PDNS)
5. Enteric signs including diarrhea and weight loss
6. Reproductive disorders including abortions, stillbirths and fetal mummification (diagnosis requires the presence of fetal myocarditis associated with PCV2 antigen in lesions. Experimentally infecting gestating animals with PCV2 has caused abortions and premature farrowing without fetuses showing myocarditis lesions, Park et al.)

PCVAD is a broad categorization of multisystemic diseases that are confirmed by documentation of the following histopathological findings in affected pigs:

1. Depletion of lymphoid cells
2. Disseminated granulomatous inflammation in one or more tissues (e.g. spleen, thymus, ileum, lymph nodes (sternal, bronchial, inguinal and mesenteric), lung, kidney, liver, tonsil, etc.)
3. Detection of PCV2 within the lesions
4. PCV2 associated reproductive disease diagnosis requires the presence of PCV2 antigen in fetal myocarditis lesions.

Economic concerns

In addition to the obvious health and welfare concerns, numerous commodity newsletters and corporate news reports by their corresponding CEO's have mentioned PCVAD as a leading cause for economic concern within the pork industry. Mortality, underweight market pigs and increased culls all represent lost opportunity and increase costs. The disease also results in the need for additional animal health, labor and housing expenditures. By some reports, losses associated with increased mortality, and decreased average daily gain and feed efficiency cost the industry $6.60 per pig.[3] A second method of establishing economic loss that focuses on mortality, cull and under valued animals will be discussed during the lecture.

Vaccine response

The response that veterinarians and producers have observed in North America has been extremely good when considering mortality alone. A common comment has been that "mortality rates have not been this low in years"! One data set that will be discussed during the lecture will show that in addition to a reduction in mortality rates, other production parameters have shown improvements, i.e. in this data set the lean percentage of the carcass was improved.

Educational web sites

The list of web sites that contain educational information on PCVAD are numerous although the following are the major ones that this author uses and that are listed on the AASV PCVAD committee page. The AASV PCVAD committee page is available to AASV members who can open the AASV web site. Once the web site is accessed the next step is to find the menu bar across the upper portion of the page and under the AASV button, click on committee in the drop down menu.

www.pmwsinpigs.org

www.pcv2.org

www.thepigsite.com

www.pcvd.org

www.pighealth.com

Summary

As veterinarians are conducting farm trials to find answers for their clients, researchers are testing theories about how this virus can be associated with the variable clinical expressions and mortality observed across a wide range of production situations. Pharmaceutical and biological companies are striving to provide quality vaccines. Research, effective vaccines, improved diagnostics and enhanced management are all tools to help prevent and minimize the clinical signs associated with exposure to PCV2 and lessen the devastating losses.

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3. Gillespie, T., Okones, J., Edler, R., Anderson, G., Kolb, J., and Holck, T., Seasonally adjusted economic impact of PCV 2 Associated Disease (PCVD) in a US grow/finish swine unit. *Proceeding of 19th IPVS Congress, Denmark*, 2006, pg 280.

Where are Ingredient and Hog Prices going in the Coming Months?

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Summary

The rapid expansion of the U.S. ethanol industry has resulted in a large and quite possibly permanent increase in the level of corn prices. Higher corn prices are lifting the prices of other farm crops as farmers shift acres into corn production, and are increasing the cost of raising livestock. Despite increased breakeven prices due to higher feed costs, the U.S. hog inventory is slowly increasing. Fortunately so is pork demand. Barring the next unforeseen development, hog prices are expected to remain close to year-earlier levels and annual profits close to zero for the typical farrow to finish operation.

Ethanol Production

Perhaps the most significant development in U.S. agriculture in the last 25 years has been the development of the bio-fuels industry. High gasoline prices, along with a 51 cent per gallon federal tax credit for blending ethanol with gasoline, have caused ethanol plants to be very profitable. This has led to a rapid expansion in U.S. ethanol production capacity. In 2000, the U.S. produced 1.63 billion gallons of ethanol. In 2006, ethanol production totaled 4.86 billion gallons. Production in 2007 is expected to total 7 billion gallons, and 2008 ethanol production is likely to exceed 10 billion gallons.

Because nearly all U.S. ethanol is made from corn, the amount of corn milled for ethanol production has made a similar jump. Six percent of the 2000 U.S. corn crop was milled to produce ethanol. Ethanol production claimed 14% of the 2005 U.S. corn crop, 20% of the 2006 corn crop and is expected to use 26% of the 2007 crop. This last figure is despite a huge jump in corn acres.

Since fuel ethanol is a substitute for gasoline, the price of gasoline is a crucial determinant of the profitability of ethanol production. Energy prices are notoriously difficult to predict, but based on crude oil futures, it appears likely that wholesale gasoline prices will average well above $2 per gallon during the next five years. Since a bushel of corn can produce 2.75 gallons of ethanol, this means the ethanol value of corn should average above $5.50 per bushel, providing most ethanol continues to be priced similar to gasoline. According to USDA's Office of the Chief Economist, it costs about $2 to process a bushel of corn into ethanol.

Feed Price Outlook

Farms historically have produced grain crops as food for people and feed for livestock. The ethanol industry is adding a third major use – fuel for automobiles. The rapidly expanding bio-fuels industry is having a major impact on crop prices.

Crop Acreage

The fast growing use of ethanol from corn for automobile fuel has rapidly driven up corn prices. Strong corn prices during the spring of 2007 caused a dramatic shift in crop acreage. U.S. farmers planted 92.88 million acres to corn in 2007, 14.5 million acres more than in the previous year and the largest corn acreage since 1944. There was a corresponding decline in other crops. Soybean acres were down by 11.4 million, and cotton acres dropped by 4.2 million. The decline in soybean and cotton acres has driven up the prices of those crops and of protein feeds. Dramatically higher prices for soybeans this summer makes it unlikely we will see another big jump in corn acres in 2008.

Corn Prices

Summer weather is the primary determinant of corn prices. Good weather produces high yields and usually low prices. Poor weather cuts per acre production and tends to boost corn prices. Over the past century, corn prices have trended higher in something of a stair step fashion. During the 35 years from 1908-1942, the farm price of corn averaged $0.78 per bushel. During the 30 years 1943-1972, U.S. corn prices averaged $1.26/bushel. The average corn price for 1973-2006 was $2.37/bushel. It appears likely that the new demand for corn to produce ethanol for fuel is moving corn prices to a new, higher step. Barring a change in the federal ethanol tax credit, or a drop in crude oil prices, it appears that corn prices will have to exceed $4/bushel in order to halt the construction of additional ethanol plants.

DDGS

Dried Distiller Grains with Solubles (DDGS) is a co-product of ethanol production. Each bushel of corn that is dry milled for ethanol produces approximately 17 pounds of DDGS. The protein, fat, fiber and mineral content of a pound of DDGS are approximately three times that of a pound of corn. The energy level of DDGS is comparable to that of corn. Because of its high fiber content, DDGS has seen limited use in swine and poultry rations. Due to concerns about potential micotoxins in DDGS, many dairymen are reluctant to feed DDGS. Thus, most DDGS are being fed to beef cattle.

As ethanol production expands so does the amount of DDGS produced. Over the last few years, the price of DDGS has slowly declined relative to the price of corn. During 2001-2003, the average price of a ton of DDGS in Central Illinois averaged 114% of that of a ton of corn. During 2004-06, DDGS prices in Central Illinois averaged 102% that of corn. Thus far in 2007, DDGS prices are averaging below that of corn. It is reasonable to expect that the price of a ton of DDGS will decline further relative to that of a ton of corn. As this relative price decline occurs, DDGS feeding is incentivized and beef production gains a slight relative cost advantage over pork and poultry production.

Soybean meal

Although DDGS are high in protein (typically 27-30% crude protein) the increasing use of DDGS in the feed supply has not had a particularly negative impact on the price of soybean meal. This is probably because most DDGS are being fed to beef cattle which are not big consumers of soybean meal.

Over the past 12 months, the price of soybean meal has gone up with the price of soybeans, which are being pushed up as U.S. soybean acres decline due to increased corn acreage. USDA's July 2007 forecast was that 2008 soybean meal prices would average above $200/ton, 5% higher than in 2007 and 23% higher than in 2006.

Hog Outlook

U.S. pork production has set records in each of the last five years. These records have come in part from a larger breeding herd, in part from increased herd productivity, and in part from increased imports of live hogs from Canada. Pigs weaned per litter have been above year ago levels for the last 15 quarters according to USDA. The average slaughter weight of barrows and gilts was 7 pounds heavier in 2006 than in 2000. The U.S. imported a record 8.76 million hogs from Canada in 2006, 4.4 million more than were imported in 2000. The primary reason for the recent growth in imports of Canadian hogs appears to be a labor cost advantage U.S. packers hold over their Canadian counterparts. In total, commercial pork production per sow has increased by roughly 2.8% per year during the last 18 years. Since this is nearly three times as fast as the growth in the U.S. population, it means a constant size sow herd can result in both larger exports and larger per capita pork supply.

Pork Exports

U.S. pork exports were record high in 2006 for the 15th consecutive year. Last year, exports consumed 14.3% of U.S. pork production. The expansion of exports, and in the last three years, a decline in imports, has reduced the supply of pork on the U.S. market, helping to support hog prices at profitable levels. According to calculations made by John Lawrence, the typical Iowa farrow-to-finish enterprise enjoyed 35 consecutive months of profits from February 2004 through December 2006. This was the longest string of profits in the last 40 years.

Unfortunately, U.S. pork exports during the first five months of 2007 were 2.9% below year-ago levels. The decline in total exports has been primarily due to a 29% drop in shipments to Mexico, our second largest foreign customer. The reason for the decline in purchases by Mexico is unclear.

Hog Inventory

Each quarter, USDA conducts a survey of the U.S. swine inventory. The June inventory survey indicates the U.S. swine herd is slightly larger than a year earlier. See Table 1. The market hog inventory at the start of June was estimated to be 1.8% larger and the breeding herd 0.9% larger.

USDA's survey of producers reported March-May farrowings were up 1.3% compared to the year before and said producers intentions were to farrow 1.6% more litters during June-August and 0.4% more during September-November than 12 months earlier (Table 2).

Pork Demand

Since 85% of U.S. pork production is consumed within the U.S., domestic demand for pork is crucial to the profitability of U.S. hog farms. The level of U.S. pork demand depends on many factors, including the price of competing meats and consumers' desire to eat meat. The outlook for beef prices is very bright. The 2004 U.S. calf crop was the smallest since 1951. It has continued to be small in recent years and is likely to remain low. The broiler industry reduced production in 2007 in response to financial losses in 2006. Thus, it appears that there will be few low priced alternatives to drag down pork prices.

Per capita consumption of meat has grown over time, primarily due to rising incomes. The average American now consumes in excess of 50 pounds more meat than Americans did 50 years ago. Meat demand was especially strong during 2004 and 2005 when high protein-low carbohydrate diets were very popular. A strong economy with low unemployment is positive for meat demand. High gasoline prices tend to depress meat demand.

Economists usually calculate pork demand based on per capita consumption and deflated retail prices. Grimes' calculations show pork, beef and turkey demand were all up in the first half of 2007. Broiler demand was down compared to the first half of 2006.

Hog Outlook

U.S. commercial hog slaughter was record high in 2004 and each year since. Based on USDA's latest inventory survey, it looks like 2007 slaughter will total about 107.7 million hogs (up 2.95% from 2006) and 2008's total will be approximately 109.7 million head, up 1.8% compared to 2007. See Table 3. The larger slaughter is due to a combination of increased farrowings, increased sow productivity, and larger imports of live hogs from Canada. At this point, it is reasonable to expect 2009 U.S. hog slaughter to exceed 110 million head.

The average negotiated base price for barrows and gilts in Iowa-Minnesota during 2006 was $62.88/cwt of carcass weight. See Table 4. My expectation is the average barrow and gilt price will be close to $63.50/cwt this year and $62.00/cwt in 2008. Forecasting hog prices two years ahead is very uncertain, but at this point, a 2009 barrow and gilt average price in the low $60s looks reasonable.

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Lawrence, John. "Estimated Livestock Returns" Department of Economics, Iowa State University.

Source: USDA/NASS's Quarterly Hogs & Pigs

Table 1.
U.S. Swine Inventory, June 1

Group	% of year ago
All Hogs and Pigs	101.7
Kept for Breeding	100.9
Market Hogs	101.8
Under 60 pounds	101.8
60-119 pounds	101.5
120-179 pounds	101.2
180 pounds & up	103.0

Source: USDA/NASS's Quarterly Hogs & Pigs

Table 2.
U.S. Sows Farrowed, Actual & Forecast

Quarter	% of year ago
September-November 2006	101.7
December-February 2007	101.6
March-May 2007	101.3
June-August 2007	101.6*
September-November 2007	100.4*

*farrowing intentions
Source: USDA/NASS's Quarterly Hogs & Pigs

Table 3.
U.S. Commercial Hog Slaughter, Actual and Forecast, Million head by Quarter, 2006-2008

	2006	2007	2008
1st Qtr	26.208*	26.686*	27.330
2nd Qtr	24.839*	25.523*	25.830
3rd Qtr	25.810*	26.425	27.165
4th Qtr	27.880*	29.100	29.400
Year	104.737*	107.734	109.725

*actual

Table 4.
Iowa-Minnesota Negotiated Hog Prices, Actual and Forecast, Base Carcass Price, $/cwt, by Quarter, 2006-2008

	2006	2007	2008
1st Qtr	$56.37*	$60.65*	$61-65
2nd Qtr	$65.41*	$69.60*	$64-68
3rd Qtr	$68.24*	$62-66	$61-65
4th Qtr	$60.76*	$57-61	$56-60
Year	$62.68*	$62-65	$60-64

*actual

Energy Sources For Pigs – How Do We Cope?

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Summary

Rapidly expanding ethanol production in the United States has resulted in a large increase in swine feed costs because of increased competition for energy in swine diets that has traditionally been supplied as corn. There is then, quite naturally, an interest in any means whereby dietary energy costs can be reduced. Some producers may have an opportunity to use various byproducts but that dietary change probably has a relatively limited potential to help many producers. The use of exogenous enzyme addition to diets has more potential for broad application. Additionally, a change in the means of expression of dietary energy to a net energy basis is now warranted to capitalize on its more accurate description of dietary energy components.

Introduction

International policies affect so many industries in so many ways. As a result of tensions in the Middle East, price and availability of crude oil is impacted. As a result of crude oil issues, federal policies to reduce US dependence on foreign oil are pressed. Renewable domestic energy production is pushed. This results in increased ethanol production from corn. And that is where the Middle East impacts swine production. The use of corn for fermentation into ethanol has had a major impact on the supply/demand ratio for corn. Because of the huge increase in demand for a relatively fixed supply of corn, price obviously increases. Because corn is the base of US swine feed production, the cost of production is markedly increased. And now the question is where are we going to get the energy in our diets and can we get it any cheaper than using corn?

Alternative energy sources

With least cost formulation programs, a nutritionist can easily and quickly determine which of innumerable feedstuff options will be the most cost-effective alternative to increasingly expensive cereals. However, this does not really represent anything new as an option for a nutritionist as a result of the run-up in corn price during the last year. Most energy options were already in local databases and were options before the ethanol-'fueled' increase in feed costs. Adding new, or previously unconsidered, byproducts to a feedstuff database would expand the options of a nutritionist. But new byproducts may not always be as much of an option as one might initially think because of trucking costs associated with byproduct procurement or space availability for storage of the byproduct. Issues of volume of byproduct availability and consistent supply are also important issues for larger producers. Beyond the points of cost and logistics are the biological issues related to using a byproduct with which one is not familiar. Is the book feeding value (mean nutrient values and digestibility) suitable for an individual production situation? What is the variability of nutrient levels in that byproduct? What nutrient values does one, then, put into the formulation matrix (as this certainly affects when it will price into the formulation)? Are there any 'mins' or 'maxs' that need to be added to the matrix? And with any new byproduct with which one has little experience, what quality control standards or specifications does one use as a part of the procurement process? Thus, there are a lot of issues related to each alternative byproduct or cereal that is considered for use in a swine diet.

Exogenous enzymes

A potential dietary addition for consideration in these times of energy-cost concern is an item that was quite denigrated in decades past. That item/additive is exogenous enzymes. Before thinking about this from an energy perspective, perhaps we should look back at the best example of enzyme benefit to date and that is phytase. During the past 20 years there has been abundant research with this enzyme. Initial research demonstrated the biological benefit in releasing an unavailable nutrient and making it biologically available to the pig. This demonstrated that, with the enzyme, there was both reduced nutrient supplementation needs and reduced nutrient excretion. The initial research was followed with dose titrations of the enzyme and, now, with alternative sources of the enzyme. As a result of the collective and cooperative effort of the feed supply industry, academia, and the swine production industry, an idea became a concept which eventually became what is now a routine reality.

As with phosphorus and phytase, the same is developing with regard to energy and the release/recovery of that energy which has routinely been voided in the waste. There is energy in feces and it is unfortunate not to take advantage of that which has been consumed and is already passing through the animal. And as producers use more byproducts and switch away from a high-demand commodity like corn, the diet will contain ever more fiber and non-starch polysaccharides (NSP). These less-digestible energy products clearly will increase the opportunity for different types or increased levels of enzymes.

Omogbenigun et al. (2004) demonstrated the value of enzyme combinations in a diverse cereal and protein supplement diet that was pelleted for young pigs. The diversity of feedstuffs included corn, wheat, oats, barley, peas, soybean meal, and canola meal. The enzyme combinations included combinations of xylanase, glucanase, amylase, protease, invertase, phytase, cellulase, galactanase, mannanase, and pectinase. A combination of enzymes was used because the presence of complex substrates in feedstuffs may not have been adequately matched with endogenous enzyme activities suitable for effective and adequate hydrolysis of those complex substrates. In the two studies conducted, all enzyme combinations assessed improved daily gain and feed efficiency and also increased ileal digestibility (Table 1) of dry matter, starch, gross energy, crude protein, phytate, and NSP. In addition to the ready observation that improved digestibility would have economic value, it should be noted that the improved digestibility in young pigs may expand the number of ingredients that a nutritionist is willing to consider (or the maximum inclusion level that is set in the formulation matrix) for young pigs.

A combination of exogenous enzymes (α-1,6-galactosidase, β-1,4-mannanase, and β-1,4-mannosidase) was also used by Kim et al. (2003) with nursery pigs to observe the effects on performance and nutrient digestibility and to determine if there was opportunity for pigs to utilize α-1,6-galactosides and β-galactomannan found in normal corn-soybean meal diets as energy sources. The enzyme combination did elicit an improved performance and it was associated with an improved digestibility of both energy and amino acids (Table 2). Only 5 amino acids were statistically improved (that is at $P < 0.05$), but it is difficult to envision a selective amino acid improvement. Indeed, the pooled comparison of all amino acids demonstrated an improvement ($P < 0.05$) with the enzyme supplement. It can be noted that only valine and proline were not numerically improved; the chance of 16 of 18 amino acids being improved if the enzyme combination did not improve amino acid digestibility is $P < 0.01$; thus, the improvement in amino acid digestibility would appear to be of a more general nature than is suggested simply by looking at those that had $P < 0.05$.

Some of the same effects noted in young and growing pigs have also been noted in sows. de Souza (2003) and de Souza et al. (2007) evaluated enzyme combinations in sows over multiple parities when fed a standard corn-soybean meal diet and determined that there were improvements during lactation that were not observed during gestation (Table 3). The improvements in overall dry matter digestibility observed in lactation (Table 4) were contributed to by clear improvements in ileal digestibility of crude protein (i.e., nitrogen) and tendencies for improvement of fiber digestibility. The improvements in N digestibility were associated with a general improvement in amino acid availability (Table 5). The amino acid results illustrated that even in situations where there is a demonstrated increase in N digestibility (as for Enzyme 2; $P < 0.05$) there is not necessarily a clear, statistically significant, increase in the individual amino acid digestibility. However, for Enzyme 2 the digestibility of all 10 essential amino acids was numerically greater than that of the control fed sows. The probability of that occurring by chance if the enzyme product was not efficacious is P = 0.001. When this is coupled with the fact that all 8 nonessential amino acids evaluated were numerically greater for Enzyme 2 (data not shown), the probability of having 18 positive responses for 18 amino acids by chance is P = 0.000004. This disproportionate number of positive responses leads to the conclusion that the null hypothesis of a common amino acid digestibility for control sows and sows fed Enzyme 2 is to be rejected. Additionally, as a matter of interest, 15 of 18 amino acids were numerically greater for sows fed Enzyme 1 (P = 0.003).

These examples of enzyme benefit are not meant to suggest that any and all enzyme additions are of benefit. Certainly examples can be provided of studies in which no benefit was observed (for example, as the lack of benefit in gestation observed by de Souza [2003]). There are many factors that could affect potential enzyme efficacy. Certainly there must be a coordination of enzyme and substrate both with regard to amount and type of substrate and enzyme. Age of animal and overall nutrient density of the diet may be factors for consideration. Another factor that may be overlooked is normal particle size of the dietary feedstuffs. Mavromichalis et al. (2000) demonstrated an interaction of enzyme and particle size. The reduction of particle size (from 1300 to 600 to 400 microns) improved nutrient digestibility in a wheat-soybean meal diet as expected. When a xylanase enzyme was added to the diet, improved dry matter and nitrogen digestibility was observed with the larger particle size but not with the smaller particle size (P < 0.11).

Energy Evaluation Scheme

The energy content of feedstuffs, and the values used in formulation programs, in much of North America is expressed primarily as either Digestible Energy (DE) or Metabolizable Energy (ME). In many parts of the world, however, the much more biologically relevant value of Net Energy (NE) is used. The DE and ME content of any existing feedstuff, and any new feedstuff, is relatively easy to determine; the NE content is not as easily determined. This is undoubtedly one factor involved in the use of DE and ME in North America. Another factor is that diets in North America have historically been less diverse with respect to the variety of feedstuffs utilized compared to many other parts of the world. Because of the cheap energy costs in North America, nutritionists have not had to use as many byproduct feeds and have not had to deal with the realization that DE and ME formulations were not as precise and may not have been accomplishing the desired outcomes. To the extent that there may be less-than-optimal expression of true energy values with DE and ME, when a relatively limited number of routinely-used ingredients are used, whatever inaccuracies may be present can be addressed by 'tweaking' a formulation program or ingredient matrix in a variety of ways when a nutritionist knows their pigs need 'a little more' or 'a little less' energy when certain ingredients enter the formulation. When the ingredient matrix begins to grow and contains widely divergent feedstuffs with major differences in nutrient profile, then 'tweaking' ceases to be a means to address those inaccuracies.

A flow diagram of energy distribution is presented in Figure 1 that illustrates the places in which portions of the gross energy of a feedstuff are lost. Examples of the DE, ME, and NE content of some feedstuffs available in North America are provided in Table 6. It can be seen that there is a reasonably tight relationship between ME and DE (the ratio ranging from 0.91-0.99); however, when proceeding to NE, the relationship of NE to ME varies considerably among feedstuffs. If one assumes that a reference diet would have an NE:ME ratio of 0.75, then a problem with DE and ME systems is that they systematically overestimate the energy content of fiber-rich (i.e., wheat middlings) or protein-rich (i.e., canola meal and soybean meal) feedstuffs and underestimate the energy content of fat-rich (i.e., tallow) and, to a degree, starch-rich (i.e., corn) feedstuffs. Changing formulation programs from a DE/ME basis to an NE basis will then affect how quickly, and the degree to which, various ingredients will price into a formulation. If new byproducts or feedstuffs are available, an NE value for them can be calculated from various proximate analysis values (Noblet et al., 1994). A comparison of energy systems has previously been made at this conference (Patience et al., 2004) and a description of how to implement the usage of an NE system is provided by Payne and Zijlstra (2007).

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Table 1. Apparent ileal digestibility (%) of nutrients in weaned pigs fed diets supplemented with multienzyme preparations in Exp. 1[a] (taken from Omogbenigun et al., 2004)

	Diet[b]					
Item	Control	Control + Enzyme A	Control + Enzyme B	Control + Enzyme C	SEM	*P*-value
Dry matter	60.1[c]	65.8[d]	66.1[d]	66.7[d]	1.5	0.001
Starch	86.7[c]	92.6[d]	94.6[d]	95.3[d]	1.1	0.02
Gross energy	62.8[c]	70.0[d]	69.7[d]	71.4[d]	0.9	0.001
Crude protein	62.1[c]	71.5[d]	71.4[d]	73.2[d]	1.5	0.0002
Phytate	59.2[c]	71.7[d]	69.1[d]	69.7[d]	2.3	0.04
Nonstarch polysaccharides	10.1[c]	14.9[d]	16.4[d]	21.4[c]	1.4	0.01

[a]Average weight of pigs after the 7-d adaptation period was 7.0 ± 0.42 kg, and the trial lasted 4 wk. Values are means of 6 individually housed pigs.

[b]Enzyme preparations provide 250 units of xylanase, 150 units of glucanase, 0.001% amylase, 0.0003% protease, 0.002% invertase, and 400 units of phytase activities/kg of diet and differed in the type of plant cell wall-degrading activities. Enzyme A contained cellulase, galactanase, and mannanase; Enzyme B contained cellulase and pectinase; and Enzyme C contained cellulase, galactanase, mannanase, and pectinase.

[c,d,e]Means within a row with different superscripts differ at the *P*-value shown.

Table 2. Effect of carbohydrase supplementation on apparent ileal digestibility (%) of energy and amino acids in Phase III diets by nursery pigs (Exp. 2 of Kim et al. [2003])[a]

	Control	Carbohydrases (0.1%)	SEM[b]
Gross energy	64.4[c]	68.6[d]	0.79
Essential amino acids			
Arginine	86.6	87.1	0.34
Histidine	80.0[e]	81.5[f]	0.33
Isoleucine	78.0	78.0	0.83
Leucine	79.6	81.0	0.89
Lysine	80.0[e]	81.0[f]	0.28
Methionine	84.5	85.3	0.45
Phenylalanine	80.3	81.8	0.54
Threonine	67.9[e]	71.6[f]	0.88
Tryptophan	80.0[e]	83.1[f]	0.74
Valine	77.0	76.4	0.38
Nonessential amino acids			
Alanine	71.7	74.7	1.36
Aspartate	75.7	79.2	0.98
Cysteine	59.7[e]	67.6[f]	1.81
Glutamate	79.7	83.1	1.11
Glycine	59.5	62.7	1.14
Proline	64.6	63.4	3.39
Serine	75.8	79.2	1.13
Tyrosine	76.2	79.9	1.20
All amino acids	76.2[e]	78.4[f]	0.41

[a]Values are means for 5 pigs.
[b]Pooled standard error of the means.
[c,d]Within a row, means without a common superscript letter differ ($P < 0.01$).
[e,f]Within a row, means without a common superscript letter differ ($P < 0.05$).

Table 3. Enzyme effects on apparent ileal and total tract digestibility (%) during gestation and lactation (adapted from de Souza et al., 2007)

Item	Diets[a] Control	Enzyme 1	Enzyme 2	RMSE[b]
Gestation				
Ileal DM	80.6	79.4	79.9	1.82
Ileal N	81.2	79.4†	79.3†	2.36
Total tract DM	89.3	89.3	89.4	0.91
Total tract N	87.7	87.9	87.6	1.46
Lactation				
Ileal DM	77.3	79.3	81.7**	1.75
Ileal N	81.2	82.5	84.3*	1.72
Total tract DM	89.8	90.7*	90.8*	0.62
Total tract N	89.0	90.1†	90.6*	0.82

[a]Enzyme 1 – contained primarily protease and cellulase activity, with side activities of α-galactosidase (0.1% Allzyme VegPro®); Enzyme 2 – contained xylanase activity (0.1% Fibrozyme®). There are a total of 11, 11, and 10 observations/diet, respectively in gestation and 4, 5, and 5 observations/diet, respectively, in lactation.

[b]RMSE – Root mean square error; when divided by the square root of the number of observations provides the standard error associated with each mean. Statistical comparisons are of each treatment mean to the control value; statistical significance is denoted by †$P < 0.10$; *$P < 0.05$; **$P < 0.01$.

Table 4. Enzyme effects on apparent ileal digestibilities (%) during lactation (adapted from de Souza, 2003)

Item	Diets[a] Control	Enzyme 1	Enzyme 2	RMSE[b]
Dry matter	77.3	79.3†	81.7**	1.75
Nitrogen	81.2	82.5	84.3*	1.72
Gross energy	79.5	81.5†	83.8**	1.64
Acid detergent fiber	37.3	38.0	40.9	10.20
Neutral detergent fiber	39.6	46.1	47.1†	6.46

[a]Enzyme 1 – contained primarily protease and cellulase activity, with side activities of α-galactosidase (0.1% Allzyme VegPro®); Enzyme 2 – contained xylanase activity (0.1% Fibrozyme®). There are a total of 4, 5, and 5 observations/diet, respectively.

[b] RMSE – Root mean square error; when divided by the square root of the number of observations provides the standard error associated with each mean. Statistical comparisons are of each treatment mean to the control value; statistical significance is denoted by †$P < 0.11$; *$P < 0.05$; **$P < 0.01$.

Table 5. Enzyme effects on apparent ileal amino acid digestibility (%) during lactation (adapted from de Souza et al., 2007)

	Diets[a]			
Item	Control	Enzyme 1	Enzyme 2	RMSE[b]
Nitrogen	81.2	82.5	84.3*	1.72
Essential amino acids				
Arginine	93.4	93.6	93.5	0.70
Histidine	91.3	92.3	91.9	0.90
Isoleucine	87.3	88.1	88.6	1.25
Leucine	88.4	89.2	89.5	1.20
Lysine	92.0	91.7	92.1	1.21
Methionine	91.5	92.2	92.6	1.10
Phenylalanine	88.3	89.1	89.4	1.05
Threonine	83.1	83.7	84.7	1.95
Tryptophan	90.4	90.0	90.6	1.37
Valine	85.1	86.2	86.7	1.48

[a]Enzyme 1 – contained primarily protease and cellulase activity, with side activities of α-galactosidase (0.1% Allzyme VegPro®); Enzyme 2 – contained xylanase activity (0.1% Fibrozyme®). There are a total of 4, 5, and 5 observations/diet, respectively.

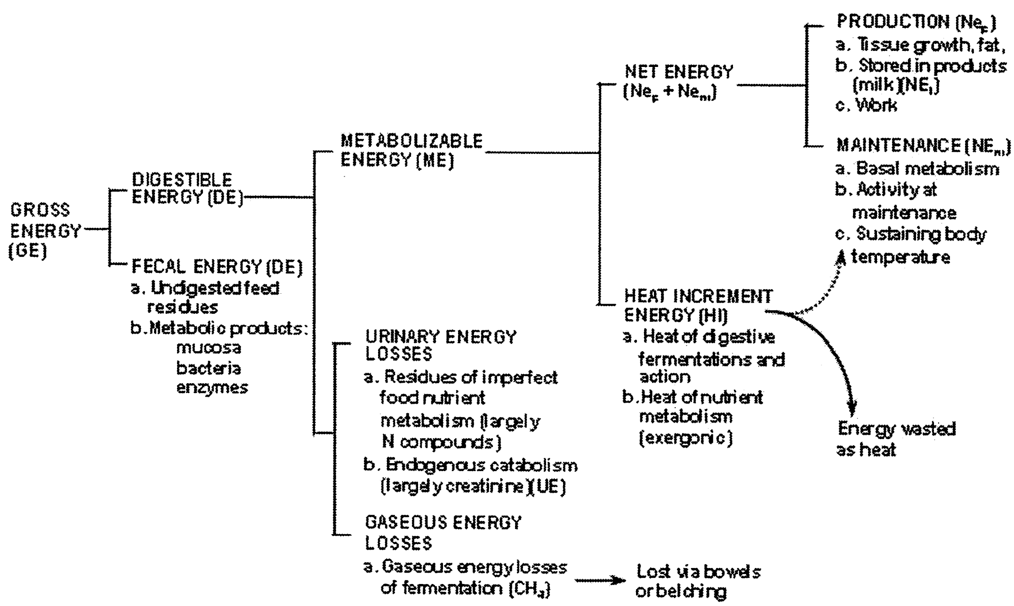
[b] RMSE – Root mean square error; when divided by the square root of the number of observations provides the standard error associated with each mean. Statistical comparisons are of each treatment mean to the control value; statistical significance is denoted by $*P < 0.05$.

Table 6. Energy values of selected ingredients used in North America [a]

Feedstuff	DE, kcal/kg	ME, kcal/kg	NE, kcal/kg	ME:DE	NE:ME
Barley	3,070	2,970	2,280	0.97	0.78
Corn	3,390	3,310	2,650	0.98	0.80
Canola meal	2,760	2,530	1,510	0.92	0.60
Soybean meal (48% CP)	3,520	3,210	1,940	0.91	0.60
Wheat	3,310	3,210	2,510	0.97	0.78
Wheat middlings	2,650	2,530	1,830	0.95	0.72
Tallow	7,964	7,914	7,104	0.99	0.90

[a]Values are taken from Sauvant et al., 2004.

Figure 1. Energy distribution scheme (as presented in Maynard et al., 1979)



Feeding DDGS to pigs: What is new?

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SUMMARY

The usage of distillers dried grains with solubles (DDGS) in the swine industry is rapidly increasing and it is expected that the usage will further increase in the future. However, the quality of DDGS may vary and in particular, the concentration of digestible lysine in DDGS has been shown to vary, which is a concern because lysine is usually limiting in diets containing DDGS. Some DDGS products have been heated to an extent that the concentration and the digestibility of lysine has been reduced and it is, therefore, important that the concentration of lysine is measured in DDGS before it is used. If the furosine concentration is also measured, the concentration of reactive lysine can be calculated. If DDGS is included in diets fed to pigs, pig performance may be maintained if the inclusion is limited to 20% although even at this inclusion level, pig performance has sometimes been reported to be reduced. On the other hand, greater inclusion levels have also been used on some occasions without reducing pig performance. It is not known at this point why these different responses to DDGS are obtained but it may be related to the quality of DDGS used or to the way diets containing DDGS were formulated. In most instances, however, the iodine value of the belly fat of pigs fed DDGS will increase, but the mechanisms behind this observation are not fully understood. Many new fractionated products from the ethanol industry will become available in the future. Most of these products will have lower concentrations of fiber and fat but greater concentrations of protein compared with conventional DDGS. The feeding value of a few of these new products has been measuredc, but as more products enter the market, more research to describe the value of these products is needed.

Fractionated co-products

The traditional co-product from the ethanol industry is distillers dried grains with solubles (**DDGS**). This product consists of the entire corn kernel except the starch that was removed during fermentation in the ethanol plant. Most ethanol plants are constructed to only remove the starch and DDGS is, therefore, by far the most dominant co-product from the industry. However, several plants are now either fractionating the corn kernel prior to fermentation or fractionating the DDGS produced after fermentation and it is expected that more ethanol plants will start fractionation in the future. This will result in many new co-products becoming available to the feed industry.

Fractionation of the corn kernel prior to fermentation consists of removal of the hulls and the germ from the kernel. The hulls are marketed to ruminant animals because of their relatively high concentration of fiber, but the corn germ is marketed to monogastric animals. This product, which is different from corn germ meal produced from wet milling, contains approximately 18% fat and 1.10% P. The concentration of DE and ME in corn germ and the digestibility of P are similar to corn, but the digestibility of AA is similar to DDGS (Widmer et al., 2007a). The feeding value of corn germ in diets fed to pigs is relatively high and there is evidence that the inclusion of corn germ in diets fed to finishing pigs results in improved belly firmness and reduced iodine values (Widmer et al., 2007b).

When the degermed and dehulled corn has been fermented in the ethanol plant, a high-protein, low fat and low fiber co-product is produced. The solubles produced during this process are usually added to the corn hulls and not to the distilled grain. Therefore, a distillers dried grains (**DDG**) product rather than a DDGS product is produced and because of the relatively high protein concentration in this product (approximately 40% CP) it is called high protein DDG (**HP DDG**). The digestibility of AA and P in HP DDG is similar to conventional DDGS, but because of the lower fiber concentration, the DE and ME in HP DDG is greater than in conventional DDGS (Widmer et al., 2007a). The inclusion of 20% HP DDG in diets fed to pigs is recommended, but if 40% is used, feed intake may be reduced during the growing period (Widmer et al., 2007b).

Other fractionation technologies use down-stream fractionation. The most simple form of down-stream fractionation consists of removal of some of the oil in the distilled grain. This oil can then be marketed to higher priced markets or used in the bio-diesel industry. The resulting DDGS contains 4 to 6% crude fat rather than 9 to 10% fat. No experiments have been conducted to measure the nutritive value of this product, but it is expected that the energy value is reduced by at least 10 to 15% compared with conventional DDGS. The low-fat DDGS product is, therefore, less valuable if fed to monogastric animals compared with conventional DDGS.

Other down-stream technologies consist of removal of some of the fibers from DDGS after fermentation. At this point, there are no data available on the feeding value of these products to pigs, but some of these products are marketed to the aquaculture and pet food markets. It is expected that new fractionation technologies will be introduced in the future and that new co-products will become available to the feed industry.

Estimation of heat damage in DDGS

The digestibility of Lysine in DDGS is more variable than the digestibility of most other AA (Fastinger and Mahan, 2006; Stein et al., 2006). The reason for this observation is most likely that drying of DDGS induces heat damage because of Mailard reactions that result in a reduced concentration of lysine as well as a reduced digestibility of lysine. It has been shown that the DDGS samples that have the lowest concentration of lysine usually also have the lowest digestibility, which is consistent with this hypothesis (Stein, 2007). It has also been shown that 60% of the variability in lysine digestibility in DDGS can be explained simply by the lysine concentration and it is, therefore, recommended that the lysine concentration be measured in DDGS to estimate the concentration of digestible lysine. If the CP concentration is also measured, the lysine concentration as a ratio of CP can be calculated. Because the Mailard reaction reduces lysine concentration in the sample, but not the CP concentration, this ratio will be reduced if samples are heat damaged. The average lysine:CP ratio in DDGS is 2.86%, but samples with a ratio as low as 2.20% have been measured (Stein, 2007). It is recommended that only samples with a ratio greater than 2.80% is used in diets fed to swine.

Other procedures to estimate heat damage of lysine in DDGS includes measuring the concentration of reactive lysine using a homoarginine or a furosine procedure. Both of these procedures have been shown to estimate lysine digestibility with an accuracy of approximately 70%. However, the homoarginine procedure is relatively tedious and slow to perform and may not be practical as a routine measure of lysine damage. In contrast, furosine can be measured relatively easy using HPLC analysis and may be used as a routine measurement by DDGS producers and feed mills.

The Mailard reaction in its later stages introduces browning reactions and theoretically, a measure of color may be used to estimate the degree of heat damage in DDGS. However, color measurements are influenced by particle size and it has been shown that color measurements of DDGS samples obtained from a large number of ethanol plants cannot be used to accurately predict the digestibility of lysine. However, it is possible that color measurements of DDGS samples obtained over time from the same ethanol plant can be used as a predictor of lysine digestibility, but this hypothesis has not yet been experimentally verified.

Feeding value of DDG vs. DDGS

During production of DDGS, the solubles and the distillers grain are mixed together. Newer data indicate that the heat damage to lysine is mainly a result of the addition of solubles to distillers grain (Pahm et al., 2007). As a consequence, if the addition of solubles to distillers grain is avoided, which would result in the production of DDG rather than DDGS, then it is expected that the risk of heat damage is greatly reduced. Unfortunately, no research has been conducted to specifically test this hypothesis. However, it has been shown that the digestibility of lysine in one source of DDG is greater than in DDGS (Pahm et al., unpublished). This observation is consistent with the hypothesis that the addition of solubles to the distillers grain increases the risk of heat damage in the product. The practical consequence of this observation is that the risk of reduced lysine concentration and reduced lysine digestibility is lower in DDG than in DDGS.

DDGS from the beverage industry vs. DDGS from the ethanol industry

The majority of DDGS that is available to the feed industry is a co-product from the ethanol industry but a significant amount of DDGS is also produced by the beverage industry. Only limited research has been conducted to compare the quality and the feeding value of these two sources of DDGS. However, based on the available data it is concluded that the quality of DDGS cannot be predicted on the basis of where it comes from and it was recently shown that the digestibility of AA in beverage DDGS is not different from the digestibility in ethanol DDGS (Pahm et al, unpublished). Within both ethanol DDGS and beverage DDGS, the quality can be poor or great dependent on the way the product was produced and the temperature used during drying.

Concentration and digestibility of phosphorus in DDGS

The concentration of phosphorus in DDGS has been reported to be between 0.72 and 0.78% (NRC, 1998; Spiehs et al., 2002). However, the average P concentration in 45 sources of DDGS was recently reported at only 0.61% (Stein, 2007). The reason for this much lower value is unknown, but recent measurements in the feed industry have verified this lower value.

It has also been reported that the apparent total tract digestibility (**ATTD**) of P is approximately 59% in DDGS as well as in HP DDG (Pedersen et al., 2007; Widmer et al., 2007). This value is much lower than the 77 to 85% relative availability of P that has been previously reported (NRC, 1998; Fent et al., 2004). However, values for relative availability are not digestibility values and cannot be directly compared with values for ATTD. To compare these values, it is necessary to know the digestibility of the P-source that is used as a standard for the assessment of the relative availability. As an example, if the 77% relative availability of P that is reported by NRC was obtained by comparing the availability of P in DDGS to the availability of P in dicalcium phosphate and if the ATTD of P in dicalcium phosphate is 80% (Petersen and Stein, 2006), then the calculated ATTD of P in DDGS would be 77% of 80, which is 62%. This value is in good agreement with the ATTD of 59% reported by Pedersen et al. (2007). Bottom line is that it is important to distinguish between values for ATTD and values for relative availability of P. In practical feed formulation, values for ATTD should be used.

Formulation of diets containing DDGS

Several experiments have been conducted recently using DDGS in diets fed to sows, weanling, growing, and finishing pigs. In some of these experiments, it was reported that DDGS can be included at concentrations of 20 or 30% without affecting pig or sow performance (Cook et al., 2005; DeDecker et al., 2005; Song et al., 2007; Spencer et al., 2007; Widmer et al., 2007b). However, in other experiments, reduced pig performance was reported if DDGS was included in the diets (Linneen et al., 2006; Whitney et al., 2006; Hinson et al., 2007). It is not known why these different responses are obtained, but it is possible that differences in the quality of DDGS used in the experiments may explain these differences because poor pig performance would be expected if DDGS with a low concentration of digestible lysine is used. It is also possible that the poor pig performance reported from some experiments is a result of the way diets containing DDGS were formulated because the inclusion of DDGS in the diets was accompanied by an increase in the CP concentration of the diets. The reason for this increase is that the protein in DDGS contains a relatively low concentration of lysine and tryptophan. This problem can be easily overcome in diet formulations by increasing the inclusion of crystalline sources of these AA in diets containing DDGS. However, if the inclusion of crystalline AA is not increased, then the concentration of CP in the DDGS containing diets will increase. This can result in reduced feed intake, reduced dressing percentage, and reduced intestinal health, which in turn will reduce pig performance. In all the experiments, in which reduced pig performance has been reported as a result of inclusion of DDGS, diets were formulated without inclusion of increased levels of crystalline AA and the DDGS containing diets had, therefore, greater concentrations of CP than the control diet. As a consequence, the effects of increased concentrations of DDGS cannot be distinguished from the effects of increased concentrations of CP and it is not possible to determine if the reduced performance reported for pigs fed these diets is a result of the increase in DDGS or the increase in CP. However, in experiments where diets were formulated in such a way that the concentration of CP did not increase as DDGS was included in the diets, no difference in pig performance was observed (Song et al., 2007; Widmer et al., 2007b). It is, therefore, important that research be conducted to investigate the independent effects of DDGS and of dietary CP, but until results of such research has been completed, it is recommended that diets containing DDGS be formulated without increasing the concentration of CP.

Effects of DDGS on product quality

The inclusion of DDGS in diets fed to finishing pigs does not influence the palatability of bacon or pork chops and a person would not be able to distinguish between products originating from pigs fed corn-soybean meal diets and pigs fed corn-soybean meal-DDGS diets (Widmer et al., 2007b). However, the inclusion of DDGS in diets fed to finishing pigs will result in pigs developing softer bellies with increased iodine values compared with pigs fed corn soybean meal control diets (Whitney et al., 2006; Widmer et al., 2007b). This increase in the iodine value of the belly is greater if pigs are fed diets containing DDGS than if they are fed a diet containing a similar amount of pure corn oil and it appears that the iodine values in bellies of pigs fed DDGS cannot be fully explained by the iodine value of the diet. The reason for this observation is unknown but research to elucidate this effect is needed to better understand the effects of DDGS on belly firmness.

Conclusions

The amount of DDGS that is available to the feed industry will continue to increase and it is important that strategies for including DDGS in diets fed to pigs continue to be refined. Based on the current body of research, it is concluded that lactating, weanling, growing, and finishing pigs can be fed diets containing up to 20% DDGS provided that a good quality of DDGS is used. Diets fed to gestating sows may contain 40% DDGS. However, in many experiments greater inclusions of DDGS has been reported not to compromise pig performance, but in other experiments, pig performance has been reduced even at modest inclusions of DDGS. There is, therefore, a need for more research to investigate the reasons for these different responses to inclusion of DDGS in diets fed to pigs. It is also important that the reasons for the increase in belly iodine values that has been reported for pigs fed DDGS are investigated to make sure that product quality is not compromised. If DDGS is used, it is important that the diets are formulated in such a way that the concentration of CP is not increased. All diets should be formulated on the basis of digestible AA and digestible P and DDGS should be used only if the lysine to CP concentration is greater than 2.80. It is, therefore, important that the lysine and CP concentrations be measured in DDGS before it is included in diets fed to swine.

In the future, many new co-products from the ethanol industry will become available to the feed industry. However, each of these new products needs to be characterized in terms of concentration and digestibility of energy and nutrients before they can be included in diets fed to pigs.

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The Impact of Added Diet Fat on Carcass Fat Quality

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Summary

Added dietary fat is very common in swine diets and there are many types available to nutritionist. There are advantages to feeding some added fat in a diet, namely increased caloric content of diet (fat is roughly 2.5 times as much energy on a weight basis compared to other ingredients used), reduces feed intake (often times the animal eats to satisfy energy needs), increases weight gain, improves feed efficiency, improves feed quality, improves reproductive efficiency and reduces heat increment. Depending on fat type used in a swine diet, the impact on carcass fat quality can be very different. Fat quality associated with meat products can be partitioned into three categories (physical, sensory, and chemical). Physical assessment of fat quality is evaluated through fat firmness, cohesiveness and color, while sensory assessment measures palatability. Because of the impact composition has on fat quality, determination of fatty acid composition of fat tissue is crucial. Varying melting points of different fatty acids affects fat firmness. Therefore, fatty acid composition has an important effect on fat quality. In addition, unsaturated fatty acids are more prone to lipid oxidation, because the double bonds in their chemical structure are subject to free radical attack. The ability of unsaturated fatty acids to rapidly oxidize affects shelf life of meat.

INTRODUCTION

One of the strongest determinants of carcass fat quality in pigs is the level and composition of triacylglycerols in the diet. Because the utilization efficiency of dietary fat is 90% in pigs fed above maintenance (Freeman, 1983) and the transfer coefficient of dietary fat to carcass lipid is high, 31-40% depending on the specific fatty acid (Kloareg et al., 2007), the carcass lipid composition is a reflection of dietary fat. Dietary lipids may have different effects or carcass lipid depending on the timing of feeding during growth and finishing phases. Stress, management, and environmental conditions play important roles in fat metabolism and thus carcass quality. These factors result in hormonal and physiological responses which stimulate changes in growth performance and lipid metabolism. Understanding and managing the factors that control carcass fat quality is a challenge for swine producers and provides opportunities to improve final carcass quality and profitability of pork production.

Dietary Fat Sources and Carcass Lipid Quality

Dietary triacylglycerol composition plays a major role in determining adipose tissue composition. Monogastric animals directly incorporate dietary fatty acids into tissue lipid deposits (Azain, 2001; Wiseman, 2006) and, therefore, to manipulate carcass lipid quality, it is important to understand the effects of dietary triacylglycerol sources and characteristics. Because unsaturated dietary fatty acids are minimally hydrogenated before deposition into swine adipose stores, carcass fatty acid profile closely mimics dietary fatty acid profile (Allen et al., 1976; Azain, 2001).

Dietary Fat

Dietary triacylglycerols primarily alter carcass lipid composition by changing level of saturation in the carcass fatty acid profile (Azain, 2001). Saturated fatty acids are fatty acids with no double bonds and are generally solids at room temperature. Mono-, di- and poly-unsaturated fatty acids have one or more double bonds. As the number of double bonds increases, so does the liquidity and level of unsaturation. The ratio of saturated to unsaturated fatty acids is a way of describing the relative composition of a fatty acid profile (Azain, 2001). Iodine value is a measure of double bonds and is another way of standardizing the characteristics of lipids into a composite number (Madsen et al., 1992; Azain, 2001). The level of saturation and iodine value of the feed lipid source will thus be reflected in the carcass fatty acid profile. Vegetable oils are typically high in linoleic acid, have an unsaturated to saturated fatty acid ratio of 12:1 (Wiseman, 2006) and an iodine value greater than 100 (Azain, 2001). Diets high in these unsaturated vegetable oils will result in oily, soft carcass fat (Azain, 2001). Conversely, tallow, which is high in palmitate and stearate, has a saturated to unsaturated fatty acid ratio of 1:1 (Wiseman, 2006), an iodine value of 40 or 45 (Azain, 2001) and will result in firmer carcass fat when fed in the diet.

Bacon Quality

The belly is one of the most valued primal cuts of the carcass, thus, the quality of bacon produced from the belly is linked to overall carcass value. The industry has shifted to genetically lean lines with decreased backfat and thus, the bellies of these pigs have also become thinner, leaner, and softer (Morgan et al., 1994; Gatlin et al., 2003). Thinner bellies are typically softer, produce fewer grade one slices, and have increased problems with processing, tissue separation, storage stability (Morgan et al., 1994; Gatlin et al., 2003). Providing dietary fat from a more saturated source has been shown to increase belly thickness and improve belly firmness (Gatlin et al., 2003). Also, feeding conjugated linoleic acid (CLA) has been shown to improve belly firmness in finish pigs (Gatlin et al., 2003; Weber et al., 2006).

Bacon is scored according to lean content and slice thickness to identify premium quality slices (Person et al., 2005). Premium slices have greater than 50% lean content and are wider than 1.9 cm at all points (Person et al., 2005). Accordingly, bacon slices are graded as either number one slices, number two slices or as ends and pieces (Person et al., 2005). Pork bellies that are classified below standard based on these characteristics represent a decrease in carcass value.

Carcass Lipid Quality

Acceptable quality standards for pork carcasses vary between processors and researchers according to IV, ratio of saturated to unsaturated fatty acids, belly firmness, and percent lean in bacon. High levels of unsaturated fatty acids result in rapid oxidation which decreases shelf life (Wood, 2003). Furthermore, high levels of unsaturated fatty acids in the diets also produce bacon which is smeary, separates and causes processing difficulties (Pearson et al., 2005).

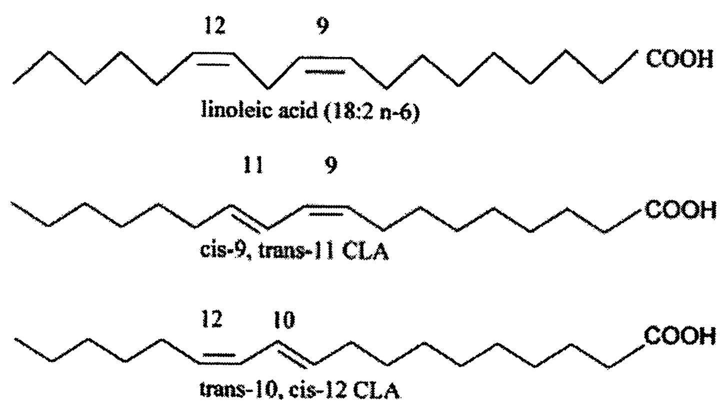
Increased IV (Madsen et al., 1992) and decreased saturated to unsaturated fatty acid ratios (Azain, 2001) indicate decrease in carcass quality due to decreased fat firmness. Many processors utilize IV as numerical evaluation of carcass quality and thus have goal IV values. An IV > 65, for some processors may be unacceptably high (Eggert et al., 2001), while an IV > 75 may be the threshold for other processors.

Conjugated Linoleic Acid

Conjugated linoleic acids (CLA) are a group of polyunsaturated fatty acids that are positional and geometric isomers of linoleic acid (C18:2). Because CLA is naturally produced during bacterial fermentation in the rumen of ruminant animals, the main sources of CLA in human nutrition are dairy products and ruminant meats (Wang and Jones, 2004; House et al., 2005). There are numerous isomers of CLA though the main isomers are *cis*-9, *trans*-11(c9t11) and *trans*-10, *cis*-12 (t10c12), shown in Figure 1.2. Though the main isomer produced by ruminants is c9t11, commercially available products commonly contain equal proportions of c9t11 and t10c12 (Wang and Jones, 2004; House et al., 2005). Research in rodents, pigs, and humans has been conducted on the effects of CLA and has shown beneficial effects of CLA against obesity, cancer, atherosclerosis, and diabetes, some of which are isomer specific (Belury, 2002; Wang and Jones, 2004; House et al., 2005).

Many studies have shown CLA is able to reduce adipose tissue depots in rodents, pigs, and humans and that this effect is specific to the t10c12 isomer or a mixture containing greater than 50% t10c12 (Belury, 2002; Wang and Jones, 2004). Postweanling mice fed 1% CLA for 28-30 d and had a 50% reduction in total adipose tissue compared to control mice (Park et al., 2001). In pigs, CLA inclusion in feed has resulted in decreased backfat thickeness in grow-finish pigs (Tischendorf et al., 2002; Wiegand et al., 2002). Recent work in overweight or obese

Figure 1. Structure of linoleic acid, *cis*-9, *trans*-11 CLA and *trans*-10, *cis*-12 CLA, adapted from Evans et al., 2002.



people given CLA for 12 weeks had reduced body fat mass but their body mass index remained unchanged (Blankson et al., 2000).

Another noted effect of CLA is the inhibition of cancer, specifically, mammary, prostate, skin, colon, and forestomach cancers (Belury, 2002). The anti-carcinogenic effects of CLA have been mainly attributed to the c9t11 isomer (Wang and Jones, 2004). In studies transplanting mammary and prostate cancer cell lines into mice, feeding 1% CLA significantly reduced growth of the cancerous cells; however, some studies exaiming the same types of cancer have shown no effect with CLA feeding (Belury, 2002).

Another area of CLA research has shown that it is able to reduce atherosclerotic plaque formation (Belury, 2002). Inclusion of 0.5g/day in hypercholesterolemic diets fed to rabbits for 12 weeks resulted in significantly reduced serum triacylglycerols, low density lipogprotein (LDL) cholesterol levels and atherosclerotic plaque formation in the aortas (Lee et al., 1994). The reduction of plaque deposits by CLA was proposed to be due to changes in LDL oxidative susceptibility (Belury, 2002).

Effects of CLA on the onset of diabetes and insulin resistance are contradictory and complex. Rats fed CLA have shown significantly reduced fasting glucose, insulinemica, triglyceridemia, free fatty acids, and leptinemia (Belury, 2002). Butter enriched with c9t11 CLA failed to reduce glucose tolerance, lower adipose tissue or enhance glucose uptake leading to the conclusion that perhaps it is the t10c12 isomer which is responsible for the antidiabetogenic responses (Belury, 2002). Insulin tolerance testing on CLA-fed mice showed marked insulin resistance without changes to blood glucose concentrations after oral glucose tolerance testing (Tsuboyama-Kasaoka et al., 2000). Other studies have examined the reduction of plasma leptin by CLA and the concomitant changes in blood glucose level due to regulation by leptin (Wang and Jones, 2004). Feeding male mice high-fat diets with 1% CLA has resulted in reduced plasma leptin levels in one study (DeLany et al., 1999) while resulting in no change in plasma leptin or glucose levels in another (West et al., 2000).

Feeding CLA in Swine Production

The effects of including CLA in livestock diets have been examined in numerous studies to elucidate their effect on fat quality (Cox et al., 2004). Gilts fed 1% CLA for seven wk had firmer bellies, higher levels of saturated fatty acids, lower levels of unsaturated fatty acids and decreased IV when compared to control (Eggert et al., 2001). When CLA was included in a grow-finish diet at 0.75% inclusion rate, barrows feed CLA had improved feed efficiency, decreased backfat, and improved loin marbling and firmness when compared to controls (Wiegand et al., 2001). When CLA was fed to genetically lean gilts for eight weeks, an increase in average daily gain and the gain:feed ratio was observed (Weber et al., 2006). The same study also noted an increase in saturated fatty acids, decrease in unsaturated fatty acids, and an increased level of saturation of the belly tissue (Weber et al., 2006). Several other studies have also shown that CLA feeding increases fatty acid saturation, and firmness in back fat and belly fat (Ostrowska et al., 1999; Aalhus and Dugan, 2001; Dugan et al., 2004).

Dried Distillers Grains with Solubles

Distillers dried grains with solubles (DDGS) are the byproduct of the yeast fermentation of grains such as corn (Newland and Mahan, 1990). During fermentation, corn starch is converted into alcohol for fuel and the remaining grain components, protein, fat, fiber, minerals, and vitamins, are left in a highly concentrated form (Newland and Mahan, 1990). The nutritional value of corn DDGS is variable and dependent of lysine content (Newland and Mahan, 1990; Cromwell et al., 1993).

There are two processes by which ethanol can be extracted from corn, wet milling and dry grinding. Dry grinding has become the more common production procedure, accounting for 70% of ethanol production (Rausch and Belyea, 2005). Dry grinding focuses on extracting the maximum value from the corn as ethanol while wet milling extracts other products such as oil and corn gluten meal during the process (Bothast and Schlicher, 2005; Rausch and Belyea, 2006). The dry grind process begins by grinding the corn and mixing it with water. The resulting mash is then heated with enzymes to convert the starches to sugars which can be fermented by yeast. The product contains particulates and solubles which are distilled and dehydrated, producing ethanol and wet distiller's grains. The distiller's grains are then dried in order to increase shelf life (Bothast and Schlicher, 2005; Rausch and Belyea, 2005).

The nutritional values of DDGS for pigs are influenced by the processing procedure and production plant equipment and techniques (Spiehs et al., 2002; Belyea et al., 2004). Regardless of processing advances, DDGS remain highly variable even within the same production site. Typical content ranges are: dry matter, 87-94%; crude protein, 24-31%; crude fat, 3-12%; ash, 3-6%; and lysine, 0.59-0.89% (Shurson et al., 2004). Two limiting factors for including DDGS in swine diets are the high level of unsaturation in the dietary fatty acid profile and the high fiber content (Newland and Mahan, 1990; Rausch and Belyea, 2005). These two factors have been shown to result in both decreased feed intake and greatly increase the unsaturated content of adipose tissue. In a trial utilizing 0, 10, 20, and 30% DDGS in grow-finish diets, pigs fed 20 or 30% DDGS showed decreased growth performance and increased IV when compared to control fed pigs (Whitney et al., 2006).

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