Symposium Summary and Challenges for the Future

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ABSTRACT The poultry industry has grown and prospered over the past 50 yr by a repeated pattern of careful analysis of factors limiting production, followed by replacement of biological functions with management practices. Examples include assisted incubation, selection of sires, and survival via novel housing. Each resulted in a period of enhanced product output. Trends developing over the past decade raise the potential for consideration of another intervention, that of assisted reproduction. Examples illustrating the need to consider, and adopt at several levels, assisted reproduction are provided. Three critical aspects of poultry production should be monitored by careful documentation of: 1) genetic throughput from pedigree to product, best assessed by monitoring number of chicks produced per male; 2) product cost, best assessed by optimizing rate of lay and fertility of laid eggs for each hen; and 3) product quality, reflected in the homogeneity of progeny for desired traits. Each segment of the industry (turkey, egg or broiler; breeder or producer) will find unique solutions to these interacting factors. Presentations within the symposium are reviewed and integrated, and comments are provided relative to challenges facing the industry in the 21st century.

(Key words: reproduction, broiler, turkey, genetic selection, economic impact)

INTRODUCTION

Poultry Production: A Historical Pattern of Adjustment

Reflection on the history of domestication of animals reveals a transition from their residence in a natural habitat, with all its associated activities, to those imposed by humans for economic gain (within the limits accepted by society). Once domesticated, those animals that survived underwent a similar pattern of evaluation as they were incorporated into common practice. Over this period, product output exhibited a repeated pattern (Figure 1). The iterative evaluations and refinements in management: 1) began with recognition of a developing bottleneck in production of product; 2) required careful prior validation of economic value associated with a pending change; 3) endured a period in which the entire industry resisted necessary capital expenditures; and 4) a bold industry leader was willing to break the paradigm. This evaluation was followed by a period when, sequentially: 1) an additional venturous company(ies) tested the concept; 2) market share was rapidly consolidated by those few companies with a clear economic advantage over those lagging behind in technology; and finally 3) all other companies declined or disappeared. A cursory summary of that history is found in Landauer (1967) and Hanke et al. (1972).

Thousands of species of birds reproduce in the wild, with only a few domesticated for efficient production of protein for human consumption. In general, each wild species exists at low population density, is responsive to critical elements of its environment such as nutrition and photoperiod, and features elaborate courtships developed around male and female behaviors (Hale, 1969). In the case of the domestic chicken (a granivore), exhibiting modest territorial tendencies and minimal mating behavioral traits, a maternal pattern existed wherein the hen laid 12 to 20 eggs associated with copulation with the male(s), incubated the eggs for a few weeks, reared the young for another few weeks, and then returned to another phase of egg laying. The birds thrived, but humans raising such birds could not make a profit under this intermittent pattern of progeny production.

By the Middle Ages, a critical observation was made that revolutionized the industry. It was that onset of maternal behavior could be delayed by frequent removal of eggs from the nest. This procedure was refined in succeeding centuries and evolved to the current situation in which periods of lay exceeding 200 d are achieved. These advances in assisted incubation technology were the first application of assistance technology by the poultry industry, and allowed the current industry to emerge.
About 50 yr ago, a few innovative companies recognized the potential for another quantal advance. Mating by preference had allowed the "rules of the wild" to dictate the characteristics of all progeny. If the breeder conducted intensive assisted selection of sires, by identifying and then using only those males with traits of highest perceived economic value, the nature of progeny could be shaped to yield products of greatest value. The explosive return from those advantages turned poultry from premium animal protein, with frequently unaffordable cost to the consumer, to one of the least expensive protein sources. Combination of these assistance technologies required development of mass housing of birds to maximize return on labor, which, in turn, led to development of assisted survival with highly specialized feeding programs and efficient modes of disease control. Reproduction, a central force in biology and a limiting factor in the cycle of nature, was forced to a subservient position in the schemes.

The industry now faces another potentially revolutionary period driven by a fascinating combination of factors. Spectacular successes in progeny construction over the past 50 yr drove costs down and opened huge new markets, at the expense of the basic patterns of reproduction. Potential for equally spectacular advances via modern molecular genetics provides the opportunity to open expansive market opportunities via new product characteristics. However, these advances can happen only if the industry considers the impact of: 1) separation of sexes for optimum management of each; and 2) assisted reproduction to assure that desired genetic features reach the market in the shortest period of time. All of this must be considered in terms of the overall needs to satisfy market demands.

**Effect of Reproductive Effectiveness on Financial Stability of the Industry**

Reproductive effectiveness, which deals with the interaction of the hen and rooster to produce chicks, can be defined (Hammerstedt, 1992) as an integrated system that is the product of four variables; (ovulation rate) × (male fertility and female fertility) × (hatch) × (posthatch survival). To optimize total chick production, under a given management condition, the manager must take these terms and normalize them to a convenient value to allow focus on the hen, rooster, or their combination.

The overall structure of the industry is outlined (Figure 2) to introduce terms. Survival of a primary breeder depends on continual generation of unique potential products from gene pools and pedigree products. In analogy to other forms of industry, these expenses represent one form of research and development within the company. Those discoveries must be moved to the market place faster than those of competitors if the primary breeder is to gain (or retain) market position. The company must: 1) identify and be cognizant of the magnitude of the expense; and 2) seek maximum return on its very large investment in this form of research and development.

Genetic selection in the industry places highest value on the rooster, with the hen serving as a high quality factory to move the desired genes to progeny with the least dilution. Thus, product quality is directly related to intensity of genetic selection, and exploitation of those genes. The fewer males needed to generate a given number of chicks, the higher potential quality should result in those progeny, both in mean product character as well as in the variance within the final product sold. Impact of the hen is quite different, in that hen maintenance is the dominant cost factor in producing progeny. Hence, any productive hen (laying many fertilizable eggs) should be kept, whereas those hens laying few eggs, or rarely fertilized eggs, should be culled.

Two additional aspects are dominant. Unit cost is important at all levels (from pedigree to product) and must be monitored continually. Product quality, by contrast, is most critical at the great-grandparent and grandparent levels.

The production unit of any company must balance competing demands between two other internal units: 1)
Changing Demands on the Primary Breeder Introduced by the Overall Economic Structure of the Poultry Industry

Poultry products have assumed a dominant role in human nutrition because of the remarkable ability of the industry to force, and then absorb, advances in genetics, nutrition, and disease control. Each segment, egg and meat (broiler, turkey) has specific requirements and solutions. Refinement and specialization in the industry resulted in segmentation into companies providing elite genetic stock (the primary breeders) and the producer/integrators who grow out the final product for sale. Economic realities dictate that: 1) the producer/integrator must make a profit if anyone in the industry is to survive; 2) in commodity agriculture, the producer/integrator does not control price, but rather earns profit by continually cutting costs; 3) periodic critical, and often irreversible, loss of market position forces exit of primary breeders, leaving smaller and smaller numbers to service the producer/integrators; and 4) the consumer seeks a range of products (e.g., beef, fish, and pork) to satisfy desires. Over the past 50 yr, the poultry industry gained a tremendous advantage over other meat products, as reflected in ever increasing per capita consumption. However, that rapid gain may be slowing as other products accumulate desirable traits and become either more price competitive or are more effectively marketed.

To date, the primary way to reduce cost of product has been to reduce cost to produce the product, by virtue of genetic selection for advantageous feed conversion or high rate of growth. Very impressive cumulative effects have been achieved (Figure 3). Although reasons and future extrapolated endpoint are unknown (Barbato et al., 1983; Barbato, 1996), it is clear that this major source of cost reduction will have a smaller and smaller role in satisfying requirements of the producer/integrator. Another major cost reduction strategy has been the restructuring of the industry and elimination of cost centers (vertical integration). In general, that approach has been fully implemented in the U.S. Industry survivors must expand their search for cost-reduction strategies to areas ignored in previous generations. Primary among these strategies is exploiting reproductive biology.

The Developing Problem of Male Reproduction in the Poultry Industry

The producer/integrator prefers mass mating to produce hatching eggs. Fertility has been maintained by creative management strategies such as: 1) increasing the male:female ratio (up to a limit imposed by social behavior in the flock); 2) “spiking” or replacing males over the life cycle of hens; and 3) dual feeding systems. Several facts emerge from retrospective analyses over the past decades. It is evident that these strategies provided only “band-aid” solutions. Reddy and Sadjadi (1990) documented a progressive decline in fertility of about 0.5 percentage units per generation despite all reasonable management strategic changes. Reasons are unclear, but may be due to the observation that growth rate has a slight negative correlation to the overall phenotypic trait of fertility (discussed in Reddy, 1996). If true, then no relief via genetics can be expected as long as traditional selection intensities, entirely ignoring reproductive traits, are retained. In terms of Figure 1, a new limit might be approaching.

From a management and financial perspective, it is critical to understand exactly how male and female fertilities have been maintained at apparently acceptable
levels. A valuable fact can be abstracted from analysis of the number of males needed to produce a constant number of chicks (Figure 4) from a fixed number of hens, although this reflects changes in both males and females over the decades involved. Introduction of dual feeding strategies in the early 1980s delayed the onset of a severe decline in male:female ratio required for adequate reproduction, but only for less than a decade. Current practice of spiking flocks with extra males (to the point of replacing the entire male complement several times during the life cycle span of the hens) is rapidly degrading the value of genetic selection.

The potential seriousness of this management practice differs within industry components (Figure 2). For the producer/integrator, cost of males in the parent flock represents a rapidly growing, but still minor, cost of the final product. For the primary breeder, however, males are important and the practice of spiking males greatly reduces (possibly by > 50%) the value obtained from their multi-million dollar investment in pedigree identification. The problem will continually get worse unless selection for reproductive traits, as suggested by Amann (1999), is integrated into planning by the primary breeder.

Where will the future cost reductions be found? One place might be via provision by the primary breeder of “boutique blends” of genetic merit, represented by males with traits uniquely capable of satisfying production losses (e.g., extreme disease resistance). Thus, inability to further lower cost by decreasing the time to grow to market weight is replaced by lower cost through decreased mortality. Another place for cost reduction might be provision of males designed to provide a bountiful harvest of fertile sperm from males collected four times a week, allowing a group of males to provide semen for two groups of hens. Any such strategy would require capability to transmit newly identified genetic merit from pedigree pools to product with minimal loss of genetic merit through the amplification phases, in sufficient amounts and in the shortest time.

In general, reproductive efficiencies are lower in pure lines (pedigree to grandparent) held by the primary breeder, where heterosis does not provide an assist as for hybrid crosses (parent or product) held by the producer/integrator (as discussed by Pollock, 1999). Consequently, problems in amplification of merit can become very important for the primary breeder.

**The Critical Interaction of Market Position and Male Reproduction**

Shultz (1986) succinctly summarized the dilemma of the primary breeder with regard to these competing interests. His essential point was that genetic gain has a linear response to selection pressure for economic traits, but that economic value is nonlinear, with critical breakpoints in its response curve. Three critical points emerged from his presentation. First, if the stock is at the bottom relative to competitors, the breeder must quickly improve or exit the business. Second, if the stock is at the top relative to competitors, further selection pressure on that trait is wasted. It still is necessary to apply selection pressure because a lead in dominant traits always is challenged by competitors, the competitors always emphasize their advantage in secondary traits, and sales in selected niche markets might be missed. Finally, selection pressure raises unit cost, but makes the product more attractive to potential customers.

Shultz (1986) used two parameters from the turkey industry to illustrate (Figure 5), namely fertility [(male fertility) × (female fertility)] and egg size. Under one case, in which the company lags behind all competitors (zone A), extreme selection pressure is necessary for survival. Under other circumstances (zone B), the company might be in a position in which a modest increase in selection pressure will radically increase market share such that a modest increase in unit cost can be tolerated. Finally, the optimum position (zone C) is one in which the primary breeder can relax selection pressure (for now), reduce unit price, and enjoy healthy profits.

In the decade since those concepts were provided, the potential importance of rapid response to changing market conditions has grown because: 1) product cycle time is shrinking, as consumers and competing industries force rapid introduction of novel product traits; 2) genetic gains in dominant economic traits (e.g., conformation, growth rate) complicate the traditional reproductive processes that have sustained the industry; and 3) large volume purchasers of poultry products steadily decrease...
Assisted reproductive technologies have potential to address each by: 1) increasing use of elite males to allow skipping a generation; 2) bypassing natural mating when appropriate or when it limits reproduction; and 3) using fewer males for progeny generation to reduce variance in final product. Although useful in concept, the critical challenge is finding a manner to introduce management changes within the financial and biological constraints of the entire production system.

RELATION TO INFORMATION PRESENTED BY OTHERS IN THIS SYMPOSIUM

The other presentations in the symposium provide excellent and detailed summaries of the types of problems that the input segment of the industry (Pollock 1999, speaking for the primary breeder) and production segment (Singh, 1999, speaking for the producer/integrator) must address to provide flow through the entire system. The linkage between recognition of a market need and capacity to respond to that need depends on effective combination of reproductive capacity of the males (addressed by Amann, 1999) and exploitation of the full genetic potential inherent in the available stock.

To illustrate these linkages in qualitative terms, selected aspects are summarized (Figure 6). The X-axis represents the care with which the breeder extracts reproductive potential from each elite male by maximizing sperm harvest. The Y-axis represents the care with which the breeder uses those sperm to produce progeny. And the Z-axis represents the return to the user, expressed in terms of weekly chick production. Although the shape of the curve will vary with many factors and their interactions, it is clear that maximizing sperm recovery from a male while minimizing the number of sperm needed to maintain a high percentage of fertilized eggs can increase progeny output from each male ≥ 10-fold.

Another representation (Figure 7) is used to illustrate the interactions between the industry segments illustrated in Figure 2. The X-axis represents the summation of all aspects of reproductive performance (as discussed by Amann, 1999; Wishart and Staines, 1999; and Donoghue, 1999) and the Y-axis represents the economic potential identified by the primary breeder (presented by Pollock, 1999). The Z-axis represents the ultimate value to the producer/integrator and consumer (represented by Singh, 1999). Finally, the presentation by Barbato (1999) illustrates the critical interaction between the X-axis (reproductive performance) and the Y-axis (genetic features of greatest economic value). Genetic selection for reproductive traits can only be attempted when their effects on other traits of importance are understood.

Industry survival depends on the ability to effectively use males to transfer genetic merit from pedigree to product (see Figure 4 of Hammerstedt, 1992). Current conventional male management in the amplification scheme yields a final product that has lost up to two generations worth of genetic value during the expansion between pedigree and parent. If male use is optimized, it should be possible to reduce that loss to one generation worth of genetic value. Thus, taken to its extreme, altered strategies could effectively move genetic merit from pedigree to product 1 yr quicker than current management practices.

CHALLENGE TO THE INDUSTRY OF THE 21ST CENTURY

The dominant primary breeders provided service to the industry in the 20th century by delivery of chicks of outstanding merit to the producer/integrator. Primary
breeders surviving in the 21st century will deliver DNA to the industry. Those primary breeders will have mastered all factors necessary for: 1) discovery (or construction) of that DNA in pedigree flocks; and 2) delivery of that DNA to receptive customers using state-of-the-art technologies. The case for Factor 1 is clear from studies in model systems, but has yet to be established in practice. The essential nature of Factor 2 is appreciated to a lesser extent, but assumes an increasingly important role because of the changing nature of the search for genetic merit.

Genetic selection to date has been built upon a careful analysis of the population at hand, identification of sires of outstanding merit (islands of excellence), with resultant continual movement over generations towards a general population with the desired characteristics. The cumulative effect of this selection is emergence of select populations with the desired traits built upon a sound physiological support base. In graphic terms, the traits of excellence found by traditional selection methods can be represented as mountains of granite built upon a foundation of bedrock. Such mountains persist through generations. As a result, if the primary breeder spends a million dollars this year for identification and placement of merit into the pedigree pool, that investment must be recovered over a period of years by progressive movement of that merit into product for sale, after amplification through the primary breeder to the final producer/integrator.

Emerging molecular genetic technologies represent an impatent approach, with the potential for very rapid genetic advance. However, their successful application will demand an alternative reward system. The breeder will make the desired sire via information gained from genome projects or linkage analysis. These traits will be "force fit" on top of a genetic base that has not progressed to the point at which it can support those traits with ease. In graphic terms, the traits of excellence built by modern genetic technologies can be represented as mountains of sand built upon a foundation of the same sand. They provide a commanding vantage point, but soon are flattened if not lost. As a result, the primary breeder spending a million dollars this year for identification and placement of merit into the pedigree pool, via modern genetic technologies, cannot use the traditional amplification scheme from pedigree to product—this is precluded by dilution of merit and passage of time. The investment must be recovered over only a few years by rapid movement from breeder to product via an abbreviated amplification process. That process demands selective use of assisted reproduction technologies.

MANAGEMENT OF THE MALE FOR MAXIMUM CHICK PRODUCTION

Efficiency vs Effectiveness

Reduction of concepts presented earlier to practice and profit demands that the manager develop critical questions to elicit essential data. From those data, adjustments of operation paradigms can be devised to yield desired results. Final action is no better than the question asked and the approach used to measure the system under study. Although simple in concept, this is difficult to accomplish because: 1) exact costs for individual steps are not easily identified or even recognized, and often are lumped together in general categories; and 2) many different aspects are interdependent and cannot be categorized in isolation. As often is the case, serious problems arise from simple nomenclature. A very useful discussion of the dilemma presented by these factors is presented by Mintzberg (1989).

The structural relationship within and between the primary breeder and producer/integrator was presented (Figure 2). Success of the system demands that all segments interact in a mutually beneficial manner. Each segment has a common set of operations (Figure 8) needed to produce its product for use downstream in the system. The goal is to provide for continual shipment of chicks over the entire year to the next segment in the overall scheme (e.g., grandparent chicks to be used to produce parents). To accomplish that task, a continual release of hatched chicks from multiple facilities must be completed. To fill hatcheries, eggs (hopefully fertilized) must be released from multiple breeding houses. Those houses, in turn, must be filled with sexually mature females and
The objective is continual release of chicks from multiple hatcheries ($A_c$), provide chicks at all levels of the poultry production scheme. The second term, effectiveness, provides a contrast in each may vary over time (as in Figure 3), so the manager of the breeding house should not be judged on simple criteria just because they are easy to measure.

**How Do You Measure Success?**

Management of factors highlighted in previous sections revolves around production of many eggs, most of which have potential to be fertilized (female management), harvest and use of sperm with high fertilization potential (male management), and production of embryos (male plus female management).

As in most corporate decisions, critical examination of the denominator used in the calculation is obligatory. Data presented must be normalized and the choice is very important: “production per what?” The question must be posed to allow evaluation of managers of each unit for his/her proportional contribution to success of the entire operation. Each breeding company must define success, ideally related to overall effectiveness of the company, not efficiency of any given subsegment.

Several examples are illustrative. Consider a simple and easily measured parameter: total number of chicks shipped per year. Choice of denominator (year) illuminates various parts of the system. Chicks shipped per hatchery is perhaps the most simple variable, allows focus on unit cost, but gives minimal emphasis on quality of chick. The parameter chicks shipped per egg received in a hatchery allows focus on hatchery management, and if cause of unhatched eggs is known, can also provide one evaluation of the breeding house. Eggs provided to the hatchery per breeder house is a simple calculation, but a decrement is not easily assigned to either of two probable causes (hen mortality or low egg production). Eggs shipped per hen, reveals the egg production per hen. Chick shipped per male used, provides a measure of chick quality, but does not provide an estimate of unit cost.

**CONCLUDING STATEMENTS**

Paradigms are part of our lives, reflecting written or unwritten sets of rules and regulations that: 1) establish or define boundaries; and 2) guide behavior inside the boundaries. Will the paradigm always yield success? The effect of paradigms on scientific behavior was elucidated by a scientific historian, Thomas S. Kuhn (Kuhn, 1970; Horwich, 1993). Numerous examples are available to illustrate how past experiences shape the way scientists view new information. The concepts have
proven applicable to a wide set of actions in business, society, and general human behavior (Barker, 1992). All scientists (or managers) struggle with paradigms as they review novel information and its potential for addressing distant problems. The lag period between when a limit to success is first noticed and when actions are taken to overcome that limit (Figure 1) often reflect the time needed until a few individuals step beyond conventional wisdom and introduce practices outside of the boundaries of previous behavior. They shift the paradigms, and all competitors following the old practice are at a severe business disadvantage. Success due to practices followed before the paradigm shift now lead to failure. The people who forced the paradigm shift asked the question: Regardless of what has been done before, what one item (practice, or convention) would I change to allow movement to my new and now current objective?

To the author, the need for examining potential changes in management to accommodate reproduction is clear. Appropriate changes offer huge value, if implemented, in the ever shortening time allowed between what the market demands in product features and how efficiently the industry can respond.

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REFERENCES

Landauer, W., 1967. The Hatchability of Chicken Eggs as Influenced by Environment and Heredity. rev. ed. Storrs Agricultural Experiment Station, Storrs CT.