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Physiological limits to growth and the related effects on meat quality ☆

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ABSTRACT

Commercialisation of animal agriculture changed the phenotype and production characteristics of livestock. The sigmoidal growth curve and sequence of physiological events remained virtually unchanged, but the rate and extent of these processes increased remarkably. Physiological limits to growth are apparent in species selected for accelerated growth and production, like stress sensitivity, PSE and DFD syndromes in livestock, double-muscled cattle, the callipage gene in sheep, ascites and associated metabolic defects in broilers, leg problems in layers, abortions in Angora goats, wet carcass syndrome in sheep, and other tissue defects as well as reproductive failure due to interactions between the growth hormone cascade, gonadotrophic axis and endocrine factors that regulate metabolism like thyroxin and leptin.

Although, the physiology of animals is generally quite forgiving, there are warning lights on the horizon. The challenge in livestock production should shift towards synchronising the best genotypes in a specific environment with the most appropriate and environmentally acceptable technologies available to produce consistently high quality meat. Manipulation of the quality of animal products through feeding, breeding and physiology will become increasingly important, provided that these technologies are practical, economical and do not detract from the intrinsic and extrinsic attributes of animal products, or any other aspect relating to environmentally acceptable or ethical livestock production.

1. Introduction

Domestication of livestock, poultry and pigs occurred during the Neolithic period (5000 and 11,000 years ago) or "Neolithic revolution" in different regions around the world and forever changed the history and fate of humankind (Childe, 1936; Gupta, 2004). The domestication of livestock is characterised by five major shifts, each of which was brought about mainly by the increasing demand for a sustainable supply of good quality protein for human consumption, but the process was also accelerated by a number of biological, environmental, economical and ethical limitations. The current high demand for products from animal origin and the associated dynamics of animal breeding in developing countries due to the increasing population, urbanisation and disposable incomes are pertinently described as the "livestock revolution" (Steinfeld, 2004).

It is predicted that the livestock revolution will have major consequences on animal and human health and probably change the face of modern agriculture in decades to come. The contribution of developing countries to world livestock production and consumption is expected to increase considerably, while the opposite is expected in most developed countries (Steinfeld, 2004). Higher levels of animal production can be achieved either through an increase in the number of livestock or an increase in productivity. The latter usually involves more intensive feeding, fattening, shorter production cycles and higher product yields.

The increase in livestock production and consumption in developing countries will probably be achieved through more intensive animal production systems, selecting animals based

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on production efficiency, making use of modern feeding and breeding technologies and increasing use of cereal-based animal feeds. Developed countries exhibited similar trends since the 1970s, but consistent selection pressure on production efficiency has yielded mixed results. Increasing demands for products from animal origin have significant consequences on natural recourses like the availability and quality of water, soil, pastures as well as concomitant effects on biodiversity and environmental pollution. Intensive livestock production results in an increased recycling of the minerals N, P and K and heavy metals Cu, Zn and As via faeces back into the environment (Yao and Dang, 2006). These adverse effects of intensive feeding are becoming a world-wide dilemma.

There is also evidence that some of the modern breeds of livestock have reached their physiological limits resulting in more difficulties in terms of adaptation, reproduction and the quality of animal products. The aim of this overview is to examine the consequences of selection for growth and production efficiency on meat quality.

2. Dynamics of livestock domestication

The domestication of animals was driven primarily by peoples' need to secure food for times when hunting was poor. Consequently people were “freed” from the labour of collecting food into doing other work resulting in the establishment of sedentary communities across the world (Webb, 2006). This represents the first important shift in the domestication of livestock, namely that from hunter–gatherer to agriculturalists.

Domestication and the increasing dependence on animal agriculture eventually prompted the “then developing” livestock industry to focus on increasing livestock numbers, followed by maximum yield. The latter endeavour was achieved through improved breeding, feeding, caring, management and health of domestic animals. Developing countries are currently going through such a phase, characterised by a greater increase in productivity of livestock compared to the increase in livestock numbers (Steinfeld, 2004).

In developed countries an increase in livestock numbers is severely limited by the availability of agricultural land, so increasing demands for animal products can only be met by improvements in the productivity of livestock. The livestock sector was very successful in improving productivity through improved breeding, nutrition and manipulating the underlying principles of growth notably hypertrophy, hyperplasia and differentiation (Webb, 2006; Harris, 1970). This represents the second important shift namely that from merely providing food, to providing a consistently high amount of food for financial gain.

These quantitative production goals for many years dominated the livestock industry and were propagated at all major agricultural fairs and shows until the early 1950s. However, it soon became apparent that injudicious animal breeding and selection is a risky business that requires a more scientifically responsible approach. Again the emphasis in livestock breeding shifted — this time towards more accurate measurement and quantification of a variety of internal and external effects and their interactions on genetic and phenotypic variation. This occurred almost simultaneously along with the focus on efficiency of livestock production, limited resources and the economy of feeding and fattening livestock in semi-extensive and intensive production systems. Animals were selected for functional efficiency by means of visual appraisal and other objective measurements of efficiency like average daily gain and feed conversion efficiency. This probably represents the third shift notably from maximum yield to efficiency. Although the emphasis on production efficiency remained an important goal in livestock production, Harris (1970) concluded that there is little benefit to producers other than increased production, while the products may be more affordable to consumers. The emphasis on efficiency in livestock production systems also focussed more attention on intensive fattening and finishing systems and the effects of animal handling and stress on animal welfare and product quality. It is now widely accepted that proper animal handling and reduced stress improve the productivity, welfare and quality of animal products (Grandin, 1998).

Significant progress has been made in terms of the quantification of growth and growth limits, the factors that affect growth and development, nutrition and nutrient partitioning, and growth manipulation through nutritional interventions and endocrine and genetic manipulation. The recent advent of molecular techniques, identification of quantitative trait loci (QTL), candidate genes and single nucleotide polymorphism (SNP) markers have also added a new dimension to our understanding of these processes (Andersson and Georges, 2004; Green et al., 2007; Blasco, 2008). These technologies represent the epitome of modern animal production.

However, recently the concept of product “quality”, was adopted which exposed the multi-dimensional nature of consumers' perceptions regarding meat quality. Consumers are becoming increasingly more concerned about what animals are fed and how these feed additives affect the wholesomeness and safety of animal products (Sapkota et al., 2007). There is an increasing perception that animal feeding practices result in the presence of antibiotic-resistant bacteria, prions, arsenicals and dioxins in products from animal origin. This situation is deteriorating despite the implementation of feed rules, the ban on the use of antibiotic substances and selected growth promoting substances in feedstuffs and more evidence (Eckel et al., 2008) that substances like heavy metals also accrue from atmospheric deposition.

The challenge in livestock production is now shifting towards synchronising the best genotypes in a specific environment with the most appropriate and environmentally acceptable technologies available (such as functional genomics, proteonomics and metabolomics) to produce consistently high quality meat in accordance with consumer needs.

3. Use of transgenic livestock and genomics to improve growth and production

Although only a few transgenic animals are commercially available, progress has been made in terms of improving livestock production through transgenic technologies, which remain one of the promising alternatives on the horizon. The first techniques to genetically modify livestock were developed during the 1980s. The use of pronuclear microinjection