Performance-enhancing technologies of beef production

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Implications

- Exponential growth in global human population and a general increase in per capita consumption of animal products require technologies that will produce more animal protein while using fewer resources. At the same time, the quality and safety of the final product should not be compromised.
- Conventional technologies such as structural genomics, anabolic implants, and ionophores are now complemented by new innovations such as functional genomics, various "omic" sciences, essential oils as antimicrobials, and β agonists.
- The traditional focus on higher yields in development of technologies has shifted to include sustainability and reduction of the carbon footprint caused by production of animal products.

Key words: anabolic implants, beta adrenergic agonists, environmental impact, essential oils, genome-wide association studies, ionophores

Introduction

The Food and Agriculture Organization predicts that the global population will increase from the current 7 billion people to 9.5 billion by the year 2050 and will need 70% more meat, milk, and eggs (FAO, 2009). While the total and per capita consumption of poultry meat enjoyed the largest growth over the past decades, beef consumption also increased 18% (1990 to 2009). The livestock industry is therefore under pressure to invest in technologies that will increase efficiency, e.g., using fewer resources to produce more meat since competition for available land, water, food from plant origin, and energy intensifies due to the growing population.

While technologies in the past mostly focused on improving productivity, e.g., growth rate, feed efficiency, and increased weight of the slaughter unit (Capper, 2011) at all cost (Figure 1), Capper and Hayes (2012) and other studies emphasized the importance of commitment to sustainability, consideration of environmental impact, and animal welfare to maintain the social license in a demand-driven market. When further considering that variability in palatability were the major reasons for decline in beef consumption in Australia and the USA during the 1980s and 1990s (Bindon and Jones, 2001; Howard et al., 2013), careless utilization of technologies that impact negatively on eating quality will influence the consumer's attitude toward beef.

Performance-enhancing technologies may include genetics, feed technologies and feeding strategies, growth-enhancing substances, and management strategies to mention some but not all. We focused on selected technologies that enhance performance, but at the same time, we also considered their relationships to sustainability, animal welfare, and product quality.

Genetics

For decades, the traditional method of progeny testing was used in animal breeding with obvious limitations, such as long generation intervals and low accuracy of estimated breeding values due to interrelationships between sire/dam and progeny (Akanno et al., 2014). During the 1990s, the focus in animal breeding changed to finding genes and quantitative trait loci associated with traits of economic importance by means of microsatellite markers (Lipkin et al., 1988). Today, whole-genome sequencing technologies using single-nucleotide polymorphism panels are used in combination with pedigree and phenotype data to speed up genetic progress by greater accuracy and shorter turnover times (Sharma et al., 2015). A single-nucleotide polymorphism is the variation in a single nucleotide that occurs at a specific position in the genome where each variation is present to some appreciable degree within a population. Going forward, single-nucleotide polymorphism technology was used to identify and map quantitative trait loci for traits of economic importance in regards to reproduction, growth, yield, and quality to describe the whole genome–i.e., genome-wide association studies. Genome-wide association studies were initially applied in human studies to identify genes related to complex diseases. Normally different regions and different genes are associated with the same trait in different breeds due to the variation in genetic makeup of breeds and the polygenic nature of complex traits. Therefore, genomic estimated breeding values generated for one breed would have considerably lower accuracy when applied in other breeds or multi-breeds (de Roos et al., 2008). Sharma et al. (2015) and others emphasized the benefit of using genome-wide association studies to solve this problem because the method could identify genes related to economically important traits that are associated with various breeds and because it shed light on the gene-induced mechanisms of complex traits. Recent developments in gene technology allow for higher density single-nucleotide polymorphisms (e.g., 800K chips instead of 50K often used in the earlier days of genomic estimated breeding values) to increase the accuracy of estimating the single-nucleotide polymorphisms effects. Combined with pooling of animals of different breeds in so-called training sets and the use of validation sets (groups of reference animals), higher accuracy of genomic estimated breeding values are achieved (Goddard et al., 2010).
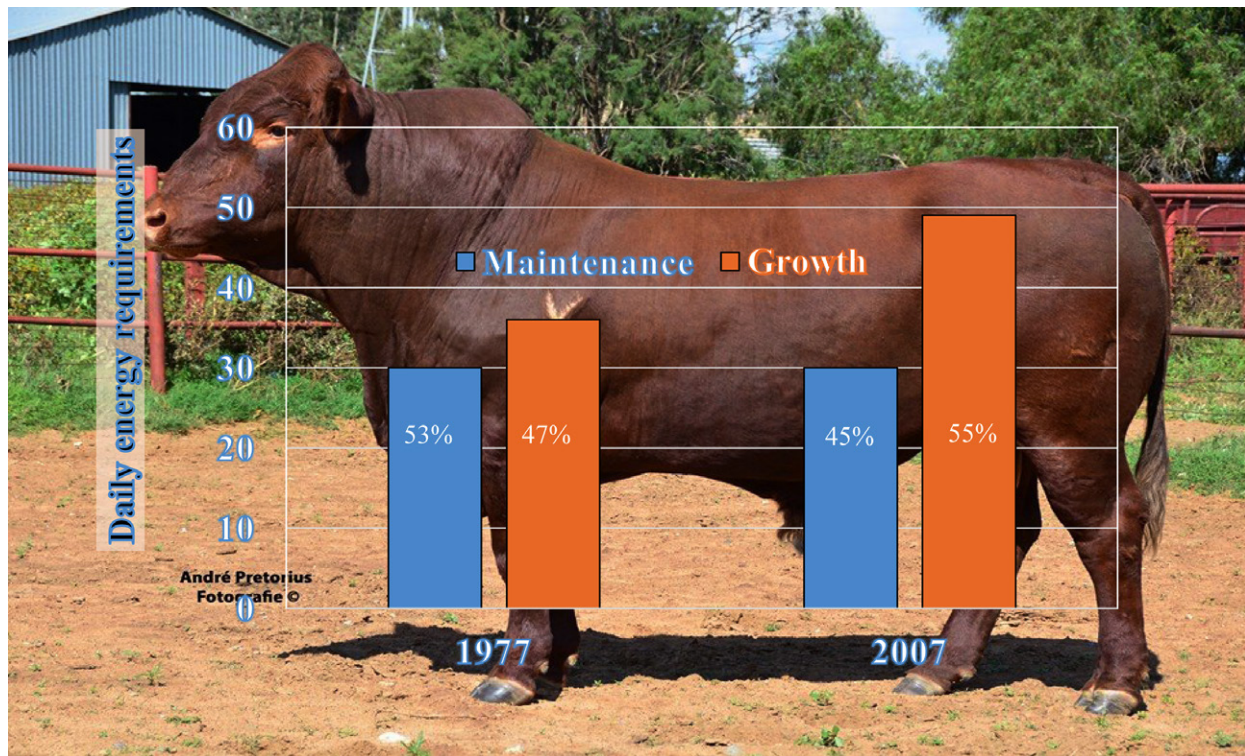
Figure 1. The effect of increased growth rate on distribution of daily energy requirements (MJ ME/d) of the average US steer between 1977 and 2007 due to performance-enhancing technologies. Steers in 2007 grew 60% faster, used 13 MJ less per kilogram of beef produced, and reached their slaughter weight in 124 d less than steers in 1977. Increased performance diluted the energy needed for maintenance (Capper, 2011). *Photo of champion Bonsmara bull: André Pretorius.*

In line with performance enhancement, Bolormaa et al. (2011) and Snelling et al. (2010) reported positive results on feedlot and growth traits, namely, residual feed intake, average daily gain, and midpoint metabolic weight and height for *Bos taurus, B. indicus*, and *B. taurus × indicus* breeds using 10K and 50K single-nucleotide polymorphism to perform the genome-wide association studies. In addition, the studies also elucidated genetic mechanisms of growth by identifying gene encodings for various metabolic pathways. New advancements made in genetics, therefore, focus much more on how genes express themselves in processes by tracing proteins and metabolites. It should be emphasized that not only improved genetic technologies contribute to these successes, but also the so-called "omics" sciences such as transcriptomics, proteomics, and metabolomics, and also bioinformatics tools and computational advances (Hocquette et al., 2007).

Traditional breeding focuses on Mendelian inheritance that mostly involves long-term breeding programs. As discussed, the latter can be addressed by single-nucleotide polymorphism technologies. However, it is also important to take note of epigenetics in the context of accelerated genetic progress or so-called "flash evolution" (Scholtz et al., 2014). Epigenetics refers to alterations in DNA function or expression without alterations in DNA sequence, and these functional alterations are heritable, at least in the short term. Tollefsbol (2004) states that epigenetic changes are mediated at the molecular level by DNA methylation, histone variants, post-translational modifications of histones and histone inactivation, non-histone chromatin proteins, non-coding RNA, and RNA interference. Epigenetic mechanisms could be any factor (nutrition, environment, and management practices) that alters gene expression and shapes the activity of the gene to achieve homeostasis or adaptation to new conditions. It al-

lows organisms, therefore, to respond to the environment through changes in gene expression and plays a role especially during development of the organism but could also manifest as an animal ages. As an example of the epigenetic influence during development, Yahav and McMurry (2001) demonstrated that increased thermotolerance was achieved in chickens when young chicks were exposed to high temperatures. Scholtz et al. (2014) suggest that epigenetic or "soft" inheritance could be very valuable to adapt to changing production environments (e.g., challenges due to climate change or increased production requirements) than the slow reactivity of Mendelian or "hard" inheritance.

Dietary Additives

The rumen is the most important organ in the ruminant digestive system. Effective management of the rumen function will enhance animal performance by increasing feed efficiency and reducing morbidity, mortalities, and environmental impact. Feed additives are mostly non-nutritive compounds used to improve rumen conditions. Attributes of ideal dietary additives are (Adesogan, 2009):

- Improve efficiency of ruminal energy utilization by reducing methane production and decreasing the acetate to propionate ratio.
- Increase ruminal organic matter and fiber digestibility; improve the efficiency of ruminal nitrogen utilization by reducing proteolysis and other processes causing HH_3 production and losses, inhibiting the activity of unfavorable protozoa, and enhancing microbial protein synthesis.
- Reduce the risk of metabolic disorders, such as diarrhea, bloat, and acidosis.
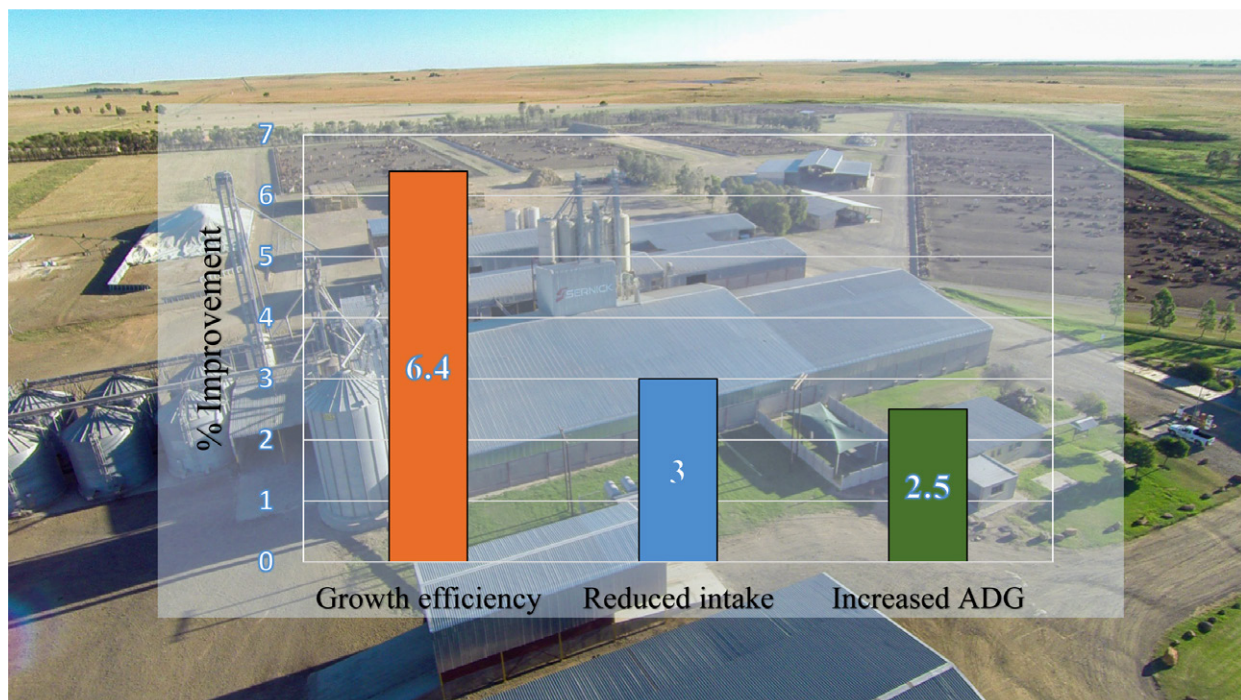
Figure 2. The positive effect of the ionophore, monensin, on average daily gain and growth efficiency, mainly as a result of lower feed intake and positive adjustment of rumen microorganisms (Duffield et al., 2012). *Photo of feedlots and feed factory: Sernick Group, South Africa.*

Ionophores

Ionophores are organic compounds with antimicrobial properties and are mainly derived from *Streptomyces* fermentation. They facilitate the selective transportation of ions across the cell membrane that leads to cytoplasmic acidity and ultimately cell death (McGuffey et al., 2001). Ionophores improve rumen conditions by selective elimination of Gram-positive bacteria that lack the complex cell wall of Gram-negative bacteria. Gram-positive bacteria ferment nutrients into less desired products like acetate, NH_3, and methane. Ionophores promote propionate production in the rumen to the cost of butyric and acetic acids, resulting in more energy (higher feed efficiency) through increased glucose supply (Lomax et al., 1979; Baird et al., 1980). Furthermore, ruminal nitrogen metabolism is enhanced through reduced peptidolysis and amino acid deamination, methane production is suppressed, and the risks of bloat and lactic acidosis are reduced (Schelling, 1984; Wallace, 2012). Ionophores also have anticoccidial properties (European Medicine Agency, 2007).

Monensin, the most widely used of the ionophores, is classified as a polyether antibiotic derived from extraction of *Streptomyces cinnamonensis* fermentations (Yang et al., 2007). Monensin improved growth efficiency by 6.4% (0.53 kg less feed per kg weight gain), reduced feed intake by 3% (0.27 kg), and increased average daily gain by 2.5% (0.029 kg) on average according to a meta-analysis (Duffield et al., 2012) (Figure 2). It is interesting to note that the effects of monensin on growth efficiency declined in the last two decades from 2.5 to 3.5%, mainly as a result of increased net energy content of feedlot diets. When monensin is used in corn silage diets, for example, greater improvements in growth efficiency and larger effects on reduction of feed intake are experienced. Likewise, animals growing at a lower baseline rate also show greater improvements in average daily gain than fast-growing animals.

Essential oils

Ionophores and related substances, regarded as antibiotics used for non-medical purposes, were banned by European Union Legislation in January 2006 (EC number 1831/2003; European Union, 2003). As a result, natural substances such as essential oils, obtained from volatile fractions of plants (Patra and Saxena, 2010), and their bioactive compounds enjoy increasing attention as replacers of antibiotics in feed. These compounds are obtained from plants by steam volatilization or extraction using organic solvents.

In vivo studies with essential oils show that bioactive compounds of essential oils supplemented at levels lower than 0.75 g/kg diet dry matter inhibit methane production significantly as a result of a lower acetate-to-propionate ratio in the rumen (Khiaosa-ard and Zebeli, 2014). Higher doses seemed to be less effective. The positive effect of essential oils on rumen environment is apparently most pronounced in beef cattle due to lower rumen pH and more consistent diet composition compared with dairy cattle and sheep. Higher doses of > 0.20 g/kg dry matter decreased protozoa numbers while low doses had the opposite effect. Meyer et al. (2009) showed that essential oils combined with tylosin had the same effect on feed intake and feed efficiency than monensin combined with tylosin. However, the positive effect of essential oils was negated when tylosin was excluded from the diets. Benchaar et al. (2006) noted that in most cases, diets supplemented with essential oils gave better results than baseline diets with no supplements such as monensin and tylosin. Some studies showed that essential oils had beneficial effects on intake only at the start of the feeding period (Yang et al., 2010).

From the limited results available for performance of beef cattle, there is evidence that monensin can be replaced by essential oils although the inclusion of tylosin is necessary for significant effects on feed efficiency (Meyer et al., 2009). This relationship warrants further investigation because the different modes of action do not suggest that biological synergy

Environmental Impact

Environmental impact of performance-enhancing technologies is quite difficult to determine as many different parameters are used to determine the impact. Very often campaigners for different production systems, e.g., grain fed vs. grass fed, use different criteria for environmental impact.

Capper and Hayes (2012) argued that performance-enhancing technologies mainly used in grain-fed systems, such as β-agonists, anabolic implants, and ionophores, save 2.83 million t of feedstuffs and 265 000 ha of land to produce the same amount of beef in the USA. In addition, manure production is reduced by 1.8 million t accompanied by less carbon emissions. In Australia, the national herd of 28.04 million head (2007) would have had to increase to 29.75 million head to produce the same tonnage of beef without the use of anabolic implants (Hunter, 2010).

Countries such as Argentina, Uruguay, and Brazil where beef production has traditionally focused on grass-feeding systems are increasingly faced with reduction in natural pasture due to increased grain cropping. Therefore, technologies are focused on improved pastures, grain supplementation, and confinement feeding to reduce the energy cost of product output. These practices also coincide with reduced methane emissions (Rearte and Poromingo, 2014).

Genetics are also used to address environmental impact. The traditional way of selection for higher feed intake for increased feed efficiency resulted in animals growing faster and having increased mature size and increased maintenance and feed requirements (Crews, 2005). Although first proposed by Koch et al. (1963), residual feed intake has recently become popular to select animals with lower maintenance cost and therefore greater efficiency (Figure 3). Residual feed intake is defined as the difference between an animal's actual feed intake and expected feed intake based on its size and production status. Selecting for favorable residual feed intake is also an indirect approach for reducing enteric methane emissions in cattle (Basarab et al., 2013).
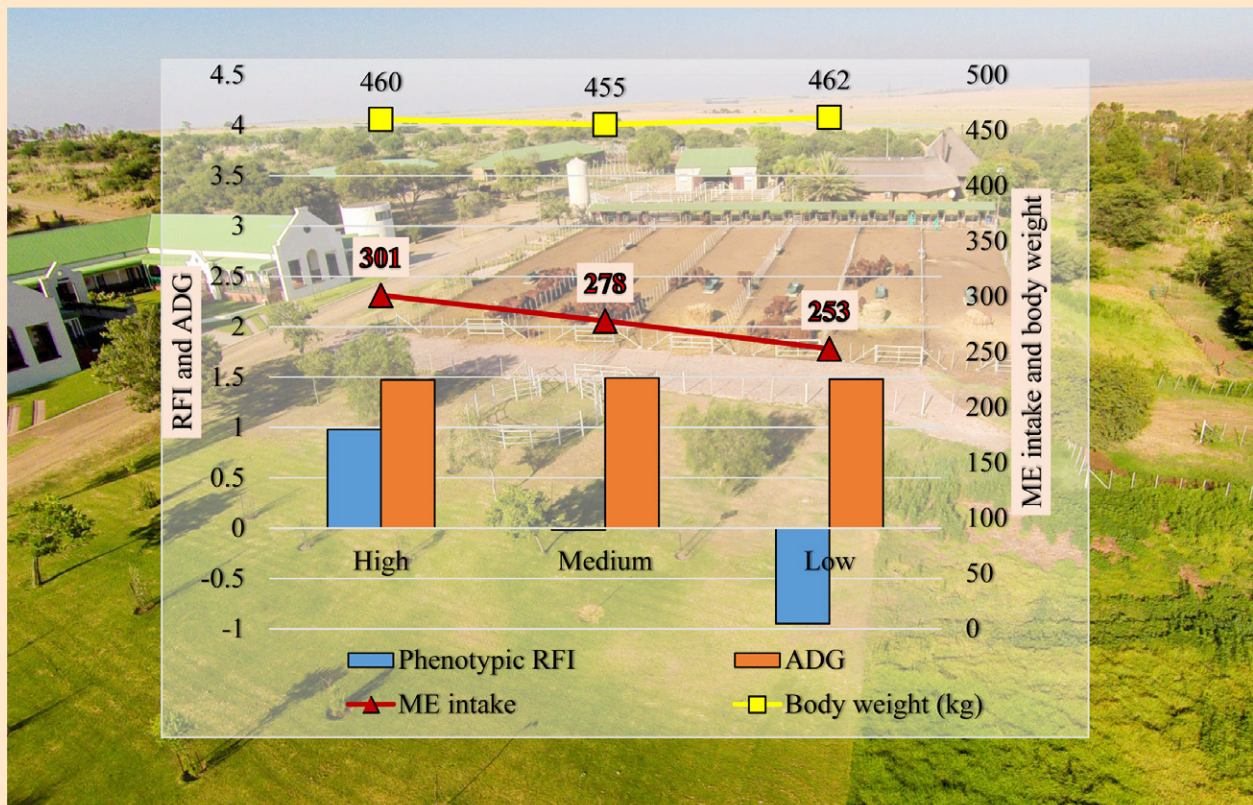
Figure 3. The effect of phenotypic differences in residual feed intake (RFI) on energy intake [MJ ME/(kg$^{0.75}$× d)]. Selection for RFI did not affect ADG or body weight (kg), yet animals became more efficient. Selection for ADG (kg/d) often increases size and energy costs (Nkrumah et al., 2007). *Photo of RFI facilities, Sernick Group, South Africa.*

would occur. Due to the considerable variation in chemical nature, source, and activity of essential oils, their effects on rumen fermentation are generally still very inconsistent.

Dietary additives and technologies used to improve fiber digestion

Irrespective of grass or grain feeding, forage plays an important part of the ruminant diet for economic considerations and maintenance of rumen health (Krause et al., 2003). However, forage cell walls have variable nutrient availability as rumen conditions for fiber digestion are often not optimal. Improving fiber digestion can be realized by treatment of forages to alter chemical structure of cell walls and increase accessibility/availability by rumen microbes. Other technologies can enhance rumen conditions to improve efficacy of fibrolytic bacteria. Feedstuffs high in low-digestible fiber may originate from crop residues, forages, or from by-products of the distiller and biofuel industries (distillers grain and solubles).

Processes such as mechanical size reduction (chopping and extrusion), chemical hydrolyses (alkalis, dilute acids, ammoniation, or peroxides), heat and hydration treatment (steam), and enzymatic hydrolysis can be used to pre-treat biomass and enhance the access of cellulose by rumen microbes (Digman et al., 2010; Donkin et al., 2013). These process are often combined, for example, the use of mechanical processing followed by alkali or acid treatment (Johnson et al., 1999) and Donkin et al. (2013) or the use of calcium oxide combined with water that has the added benefit of spontaneous heat generation (Kaar and Holtzapple, 2000).

Enzymes, yeasts, and *Aspergillus oryzae* are feed additives used to enhance fiber digestion and enhance rumen conditions for increased feed efficiency. Enzymes can be used as a pre-treatment or as a food additive working in the rumen environment and are produced from fungi (*Aspergillus oryzae* and *Trichoderma reesei*) and bacteria (*Bacillus subtilis*, *Lactobacillus acidophilus*, *Lactobacillus plantarum*, and *Enterococcus* spp.) (Kung, 2006). Since a vast array of enzymes is required to degrade the complex structural carbohydrates of cell walls, mixtures are often formulated to suite a range of feed types. However, this lack of consideration to specificity causes variation in success of this technology. The lack of understanding of the carbohydrase and microbial interaction within the rumen ecosystem further contributes to inconsistent results. Meale et al. (2014) reported an improvement in feed efficiency as high as 36% in forage-based diets and 11% in grain-based diets containing barley, but no success was achieved with maize. The latter was attributed to the fact that starch digestion is not limited in the rumen when grains are adequately processed. Furthermore, it was speculated that enzyme specificity is important in the outcomes of enzyme treatments, and in the studies discussed by Meale et al. (2014), xylanase and cellulose formulations worked for barley grain and forages but not for corn. The mechanism involved in successful outcomes are therefore still poorly understood although Meale et al. (2014) are convinced that new technologies such as metagenomics, metatranscriptomics, proteomics, and functional genomics can provide a better understanding of processes in the rumen, characterizing the carbohydrase produced in the rumen without relating them to a specific microorganism, looking for novel and specific hydrolytic enzymes involved in structural plant digestion, and finding carbohydrase lacking in the ruminal environment.

Yeasts are single-celled carbohydrate-fermenting fungi and are sold in commercial products as a mixture of live and dead S*accharomyces cerevisae* cells. Dead cells are sold with growth medium as yeast cultures (Newbold and Rode, 2006). Yeasts (or live yeasts) stimulate the growth and ac-

tivity of total and cellolytic bacteria that will ultimately enhance animal performance and efficiency by increasing fiber digestion, feed intake, and microbial protein synthesis (Adesogan, 2009). In addition, they sequester ruminal oxygen (from water, rumination, and salivation), thus improving conditions for the growth of obligate anaerobic bacteria. The risk of bloat and acidosis is also reduced by yeast cultures by the stimulation of starch-engulfing bacteria that ferment starch to less acidogenic volatile fatty acids.

Aspergillus oryzae is produced as an extract of fungal spores and mycelium dried onto a wheat bran base, e.g., Amaferm and Vitaferm (Biozyme Enterprises, Inc) and is still mostly used in dairy cattle. The exact mode of action is unclear, but *Aspergillus oryzae* improves fiber digestibility, probably through the presence of cellulose, xylanase, and esterase enzymes (Wallace, 2012). Like yeast, *Aspergillus oryzae* also increases total and fibrolytic bacteria and may contribute to favorable rumen pH conditions.

Various novel techniques are now investigated to increase plant fiber digestibility for both the biofuel and ruminant feed industries. The nature of the structure and association of lignin polymers determines the digestibility of high-fiber biomass by ruminants. Chen and Dixon (2007) have used RNA technology to alter the pathways of lignin polymer formation by successfully knocking out six critical reactions in lignin biosynthesis to generate six alfalfa plants with increased glucose release rumen digestion. Scharf et al. (2010) used DNA technology to find the lignin-digesting properties of the enzymes employed by termites to break down lignin and release cellulose from plant biomass.

Beta Adrenergic Agonists and Anabolic Implants

Beta agonists are dietary growth promoters that evolved on a commercial scale over the past two decades. Beta agonists are fed to feedlot cattle for the final 20 to 40 d on feed, and in most cases, withdrawal periods of three or more days are required. Zilpaterol hydrochloride and ractopamine hydrochloride are the two products most commonly used for cattle in selected countries where regulatory bodies have approved the products. Ractopamine has been used in the USA for some time, but zilpaterol hydrochloride is a fairly recent development and was registered for use first in South Africa (1995) and Mexico (1996) followed by the USA in 2006 and Canada in 2009 (Delmore et al., 2010). Beta agonists have also been registered in 11 other countries but have never been permitted in Europe (Kuiper et al., 1998).

Beta agonists bind to β-adrenergic receptors located in the cellular membranes and simulate the physiological action of norepinephrine and epinephrine (Mersmann, 1998). Their action through β-receptors leads indirectly to decreased lipogenesis (fat synthesis and storage) and increased lipolysis (fat mobilization and hydrolysis) accompanied by profound and rapid repartitioning of nutrients from fat to protein, in particular zilpaterol hydrochloride (Lean et al., 2014).

Mean effects over a large number of studies showed an average improvements of 8 kg (0.4 standard deviations; **SD**) in body weight, 0.15 kg average daily gain (0.9 SD), 0.1 kg/day feed intake (0.5 SD), and 0.02 (1.4 SD) gain-to-feed-intake ratio for zilpaterol hydrochloride (Lean et al., 2014). Carcass weight is increased by 15 kg (1.3 SD). The disproportionate increase in carcass weight relative to live weight means that dressing percentage is also positively affected by 1.7% units (2.2 SD) (Delmore et al., 2010; Lean et al., 2014). The large increase in carcass weight, accompanied by the repartitioning of fat to protein, lead to increased muscle yield as witnessed by the 8 cm^2 increase in longissimus muscle area reported by Lean et al. (2014) while others (Strydom et al., 2009; Delmore et al., 2010)

Challenges Associated with
Performance-Enhancing Technologies

Figure 4 demonstrates how beef yield per animal increased between 1977 as a result of performance-enhancing technologies. There are, however, also a few downsides to these successes.

Recent studies evaluating the effect of increased carcass weights accompanied by fatter carcasses due to longer periods of grain feeding have demonstrated negative effects on meat color shelf life, muscle water-holding capacity, and post-mortem aging of beef (Strydom & Rosenvold, 2014). Because muscle has a low conductivity, increased carcass size and fatness result in high temperatures when muscle enters rigor (pH = 6), which in turn will result in increased protein denaturation and loss of protein functionality—a condition termed high rigor temperature condition. The problem is exacerbated by the increased use of electrical inputs, such as carcass immobilizers, electrical stimulators, and electrical stunners that accelerate the rate of pH decline.

A second problem worth mentioning is the increased incidence of lameness and mortality associated with the use of β-agonists in the USA, in particular, zilpaterol. This lead to the suspension of sales of cattle on β-agonists by Tyson (USA and Canada) in 2013. The condition was termed "fatigued cattle syndrome" as blood profiles of affected animals were similar to those of pigs with fatigued pig syndrome (Ismael, 2013). The investigation of Loneragan et al. (2014) revealed that 40 to 50% of general feedlot deaths could be associated with the administration of β-agonists while other reports indicated that the problem of lameness only occurred at the slaughter plant. Grandin (2013) explained the causes of the problem as a combination of increased animal size, easier fatigue of more white fiber types in β-agonist-administered animals, and hot weather. Poor mixing of feed and lack of proper sorting of animal types resulting in overdoses of β-agonists were also mentioned as causal factors.
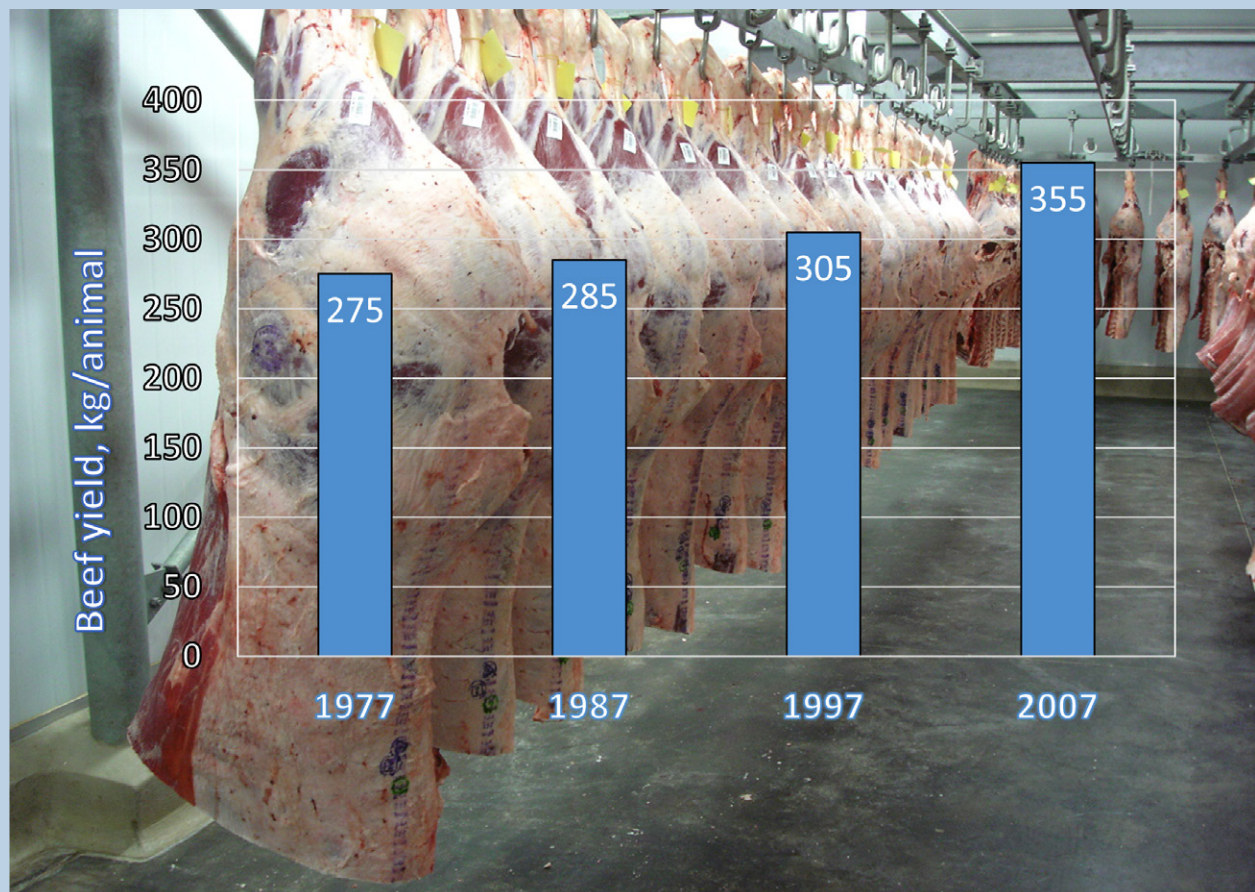
Figure 4. Changes in average beef yield per animal of USA cattle slaughtered between 1977 and 2007 due to performance-enhancing technologies (Capper, 2011). *Photo of beef hind quarters: PE Strydom, South Africa.*

also reported higher yields of other hind quarter cuts. Fat deposition within the muscle and in other depots is also affected negatively with USDA marbling scores of 14 units (0.9 SD) lower and a decrease in rib fat depth of 1 mm (0.7 SD) compared with no zilpaterol hydrochloride used.

Tenderness is affected negatively because the growth-enhancing mechanism of zilpaterol hydrochloride may involve the proteolytic enzyme of the calpain system, causing higher activities of calpastatin (Strydom et al., 2009, 2011) that could impair aging ability of meat. Some studies showed that β agonists-induced toughness can be overcome with extended aging (Lean et al., 2014) and that mechanical measurement of tenderness (e.g., Warner-Bratzler shear force) and trained panels may show the negative effect more clearly while naïve consumers may not discriminate to the same extent against zilpaterol hydrochloride treated meat. Other slaughter technologies, such as electrical stimulation of the carcass, also seem to reduce the effect of zilpaterol hydrochloride on tenderness, but the negative effects may prevail even after extended aging (Strydom et al., 2011). Muscles throughout the carcass are also not equally affected by zilpaterol hydrochloride, and certain muscles of the buttock are not significantly affected at all.

Ractopamine shows average improvements of 8 kg (0.4 SD) in body weight, 0.19 kg average daily gain (0.8 SD), and 0.018 (0.8 SD) in gain-to-feed ratio (Lean et al., 2014). The increased average daily gain is not mediated through increase feed intake as in the case of zilpaterol hydrochloride and also explains the slightly smaller advantage in gain-to-feed ratio compared with zilpaterol hydrochloride. Likewise, the magnitude of ractopamine effects on carcass

weight (6 kg), rib eye area (1.8 cm^2), dressing percentage (0.3% units), and USDA marbling score (5 units lower) is significantly less than that of zilpaterol hydrochloride (Lean et al., 2014). Ractopamine does not have the same detrimental effect on meat tenderness as zilpaterol hydrochloride, i.e., an average increase in Warner-Bratzler shear force of 0.2 kg against the 0.8 kg of zilpaterol hydrochloride. Furthermore, it seems like prolonged aging will mitigate the effects much sooner than for zilpaterol hydrochloride (Scramlin et al., 2010).

The effects of β-agonists on all production, yield, and quality outcomes depend on dose and duration although downregulation of the effects occurs above certain levels and with prolonged duration.

Anabolic implants are growth-enhancing products containing either male (testosterone) and/or female (estrogen, progesterone) sex hormones or their derivatives (trenbolone acetate, male derivative). Anabolic implants are registered for use in more than 30 countries and are extensively used in countries like the USA, Canada, Australia, South Africa, and certain South American countries. Anabolic implants have been prohibited in all Western European countries since 1986 (Preston, 1999).

While implants have been used for several decades, Preston (1999) emphasized that most studies focused on optimizing delivery rates of hormones (carrier matrixes), timing of application, types and dosages of msubstances (single, combined, type), pay-out patterns, and finding hormone analogs with higher anabolic potential (e.g., trenbolone acetate vs. testosterone). Although there may still be uncertainty about the exact mode of action of implants, their mode of action is most likely mediated through increasing levels of insulin-like growth factor I initiated by estrogens through a chain of processes starting at the somatotropic axis. This leads to increased muscle protein synthesis. Androgens bind to corticosteroid cell receptors in muscle, causing a reduction in protein breakdown.

It is difficult to pin down exact figures for the advantages of using anabolic implants as a vast array of implant strategies are followed under different production systems. Preston (1999) summarized the benefits of implants stating an increase in average daily gain of 10 to 30%, higher growth efficiency of 5 to 15%, and reduced carcass fat of 5 to 15%. Duckett and Pratt (2014) added an increased carcass weight of 5% and ribeye area of 4%. In Australia, where a large proportion of beef is produced from pasture, or at least backgrounded

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extensively for finishing in the feedlot for different markets, implants (mostly estrogenic) could increase average daily gain by 0.05 to 0.1 kg/day. This management tool assists in advancing cattle to meat market specifications for higher-type markets in terms of weight and age before seasonal deterioration of pastures occur (Hunter, 2010). In countries where mainly grain feeding is used to finish cattle, such as the USA or South Africa, almost 100% of cattle (97% in USA) receive at least one implant during the finishing period (Duckett and Pratt, 2014). Eighty percent of Australian feedlot cattle receive an implant on entering the feedlot.

Dikeman (2007) and other studies showed that aggressive implants and implant strategies (repeated implants, including combinations) may increase the occurrence of "dark cutters" and decrease marbling scores that could both affect consumer confidence. Implants also have a negative effect on meat tenderness; although research reports are not in agreement as to the magnitude of the effect, most studies agree that combination implants compared with single estrogenic implants (Hunter, 2010) and repeated implants (Dikeman, 2007) increase the risk of producing a steak with unacceptable tenderness. Extended post mortem ageing will reduce this risk, and the magnitude of the negative effect is probably far less than that of β-agonists, in particular zilpaterol hydrochloride. Watson (2008) quoted an increase in shear force value of 0.27 kg and a decrease in sensory score of 5.4 units on a 100-unit scale averaged over 20 studies.

Conclusion

The increased global demand for food in general and animal protein in particular will accelerate the need for innovation to increase production efficiency and yield in cattle. Various existing performance-enhancing technologies such as conventional genetics, anabolic implants, β agonists, and dietary additives such as ionophores are still key increased challenges. However, improved techniques such as single-nucleotide polymorphism technology and epigenetics can accelerate the progress made in genetic improvements. Likewise, novel and existing technologies to utilize plant biomass high in fiber content (lignin) will expand the utilization of perceived poor sources of energy for meat production.

Literature Cited

Adesogan, A.T. 2009. Using dietary additives to manipulate rumen fermentation and improve nutrient utilization and animal performance. In: Proc. 20th Florida Ruminant Nutrition Symposium. Univ. of Florida, IFAS, Dep. of Anim. Sci., Gainesville. p. 13–38.

Akanno, E.C., G. Plastow, B.W. Woodward, S. Bauck, H. Okut, X.-L. Wu, C. Sun, J.L. Aalhus, S.S. Moore, S.P. Miller, Z. Wang, and J.A. Basarab. 2014. Reliability of molecular breeding values for Warner-Bratzler shear force and carcass traits of beef cattle—An independent validation study. J. Anim. Sci. 92:2896–2904. doi:10.2527/jas.2013-7374.

Baird, G.D., M.A. Lomax, H.W. Symonds, and S.R. Shaw. 1980. Net hepatic and splanchnic metabolism of lactate, pyruvate and propionate in dairy cows in vivo in relation to lactation and nutrient supply. Biochem. J. 186:47–57. doi:10.1042/bj1860047.

Basarab, J.A., K.A. Beauchemin, V.S. Baron, K.H. Ominski, L.L. Guan, S.P. Miller, and J.J. Crowley. 2013. Reducing GHG emissions through genetic improvement for feed efficiency: Effects on economically important traits and enteric methane production. Animal 7:303–315. doi:10.1017/S1751731113000888.

Benchaar, C., J.L. Duynisveld, and E. Charmley. 2006. Effects of monensin and increasing dose levels of a mixture of essential oil compounds on intake, digestion and growth performance of beef cattle. Can. J. Anim. Sci. 86:91–96.

Bindon, B.M., and N.M. Jones. 2001. Cattle supply, production systems and markets for Australian beef. Aust. J. Exp. Agric. 41:861–877. doi:10.1071/EA01052.

Bolormaa, S., B.J. Hayes, K. Savin, R. Hawken, W. Barendse, P.F. Arthur, R.M. Herd, and M.E. Goddard. 2011. Genome-wide association studies for feedlot and growth traits in cattle. J. Anim. Sci. 89:1684–1697. doi:10.2527/jas.2010-3079.

Capper, J.L. 2011. The environmental impact of United States beef production: 1977 compared with 2007. J. Anim. Sci. 89:4249–4261. doi:10.2527/jas.2010-3784.

Capper, J.L., and D.J. Hayes. 2012. The environmental and economic impact of removing growth-enhancing technologies from United States beef production. J. Anim. Sci. 90:3527–3537. doi:10.2527/jas.2011-4870.

Chen, F., and R.A. Dixon. 2007. Lignin modification improves fermentable sugar yields for biofuel production. Nat. Biotechnol. 25:759–761. doi:10.1038/nbt1316.

Crews, D.H. 2005. Genetics of efficient feed utilization and national cattle evaluation: A review. Genet. Mol. Res. 4:152–165.

Delmore, R.J., J.M. Hodgen, and B.J. Johnson. 2010. Perspectives on the application of zilpaterol hydrochloride in the United States beef industry. J. Anim. Sci. 88:2825–2828. doi:10.2527/jas.2009-2473.

de Roos, A.P.W., B.J. Hayes, R.J. Spelman, and M.E. Goddard. 2008. Linkage disequilibrium and persistence of phase in Holstein-Friesian, Jersey and Angus cattle. Genetics 179:1503–1512. doi:10.1534/genetics.107.084301.

Digman, M.F., K.J. Shinners, M.D. Casler, B.S. Dien, R.D. Hatfield, J. Hans-Joachim, R.E. Muck, and P.J. Weimer. 2010. Optimizing on-farm pretreatment of perennial grasses for fuel ethanol production. Bioresour. Technol. 101:5305–5314. doi:10.1016/j.biortech.2010.02.014.

Dikeman, M.E. 2007. Review: Effects of metabolic modifiers on carcass traits and meat quality. Meat Sci. 77:121–135. doi:10.1016/j.meatsci.2007.04.011

Donkin, S.S., P.H. Doane, and J.C. Michael. 2013. Expanding the role of crop residues and biofuel co-products as ruminant feedstuffs. Anim. Front. 3(2):54–60. doi:10.2527/af.2013-0015.

Duckett, S.K., and S.L. Pratt. 2014. Meat science and muscle biology symposium—anabolic implants and meat quality. J. Anim. Sci. 92:3–9. doi:10.2527/jas.2013-7088.

Duffield, T.F., J.K. Merrill, and R.N. Bagg. 2012. Meta-analysis of the effects of monensin in beef cattle on feed efficiency, body weight gain, and dry matter intake. J. Anim. Sci. 90:4583–4592. doi:10.2527/jas.2011-5018.

European Medicine Agency. 2007. Veterinary medicines and inspections: Committee for Medicinal Products for Veterinary Use: Monensin. http://www.ema.europa.eu/docs/en_GB/document_library/Maximum_Residue_Limits_-_Report/2009/11/WC500015096.pdf.

European Union. 2003. Regulation (EC) no. 1831/2003 of the European Parliament and of the Council of 22 September 2003 on Additives for Use in Animal Nutrition. Off. J. Eur. Union 10/18/2003:L268/29–L268/43. http://www.reach-compliance.eu/english/REACH-ME/engine/sources/regulations/1831-2003-EC.pdf. (Accessed 14 Apr. 2016.)

FAO. 2009. How to feed the world in 2050. http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf. Food and Agriculture Organization of the United Nations, Rome. (Accessed 14 Apr. 2016.)

Goddard, M.E., B.J. Hayes, and T.H.E. Meuwissen. 2010. Genomic selection in livestock. Genet. Res. Cambr. 92:413–421. doi:10.1017/S0016672310000613.

Grandin, T. 2013. Temple Grandin explains animal welfare problems with beta-agonists. http://beefmagazine.com/processors/temple-grandin-explains-animal-welfare-problems-beta-agonists. Beef, 9 Sept. 2013. (Accessed 14 Apr. 2016.)

Hocquette, J.-F., S. Lehnert, W. Barendse, I. Cassar-Malek, and B. Picard. 2007. Recent advances in cattle functional genomics and their application to beef quality. Animal 1:159–173. doi:10.1017/S1751731107658042.

Howard, S.T., D.R. Woerner, J.A. Scanga, D.L. Van Overbeke, G.G. Mafi, J.L. Igo, M.D. Salman, J.D. Tatum, and K.E. Belk. 2013. North American beef tenderness survey 2011–2012: Benchmarking tenderness and sample shipping procedures. J. Anim. Sci. 91:5981–5988. doi:10.2527/jas.2013-7040.

Hunter, R.A. 2010. Hormonal growth promotant use in the Australian beef industry. Anim. Prod. Sci. 50:637–659. doi:10.1071/AN09120.

Ismael, W. 2013. How beta-agonists figure into fatigued-cattle syndrome. http://beefmagazine.com/animal-welfare/how-beta-agonists-figure-fatigued-cattle-syndrome. Beef, 24 Oct. 2013. (Accessed 14 Apr. 2016.)

Johnson, L., J.H. Harrison, C. Hunt, K. Shinners, C.G. Doggett, and D. Sapienza. 1999. Nutritive value of corn silage as affected by maturity and mechanical processing: A contemporary review. J. Dairy Sci. 82:2813–2825. doi:10.3168/jds.S0022-0302(99)75540-2.

Kaar, W.E., and M.T. Holtzapple. 2000. Using lime pretreatment to facilitate the enzymatic hydrolysis of corn stover. Biomass Bioenergy 18:189–199. doi:10.1016/S0961-9534(99)00091-4.

Khiaosa-ard, R., and Q. Zebeli. 2014. Meta-analysis of the effects of essential oils and their bioactive compounds on rumen fermentation characteristics and feed efficiency in ruminants. J. Anim. Sci. 91:1819–1830. doi:10.2527/jas.2012-5691.

Koch, R.M., L.A. Swiger, D. Chambers, and K.E. Gregory. 1963. Efficiency of feed use in beef cattle. J. Anim. Sci. 22:486–494. doi:10.2527/jas1963.222486x.

Krause, D.O., S.E. Denman, I.M. Roderick, M. Marrison, A.L. Rae, G.T. Attwood, and S. McSweeney. 2003. Opportunities to improve fibre degradation in the rumen: Microbiology, ecology, and genomics. FEMS Microbiol. Rev. 27:663–693. doi:10.1016/S0168-6445(03)00072-X.

Kuiper, H.A., M.Y. Noordam, M.M.H. van Dooren-Flipsen, R. Schilt, and A.H. Roos. 1998. Illegal use of beta-adrenergic agonists: European Community. J. Anim. Sci. 76:195–207. doi:10.2527/1998.761195x.

Kung, L. 2006. Direct-fed microbial and enzyme feed additives. In: Direct fed microbial, enzyme and forage additive compendium. The Miller Publishing Company, Minnetonka, MN. http://d2vsp3qmody48p.cloudfront.net/wp-content/uploads/2014/02/DirectFedMicrobialsandEnzymes.pdf. (Accessed 14 Apr. 2016.)

Lean, I.J., J.M. Thompson, and F.R. Dunshea. 2014. A meta-analysis of zilpaterol and ractopamine effects on feedlot performance, carcass traits and shear strength of meat in cattle. PLoS One 9(12):E115904. doi:10.1371/journal.pone.0115904.

Lipkin, E., M.O. Mosig, A. Darvasi, E. Ezra, A. Shalom, A. Friedmann, and M. Soller. 1988. Quantitative trait locus mapping in dairy cattle by means of selective milk DNA pooling using dinucleotide microsatellite markers: Analysis of milk protein percentage. Genetics 149:1557–1567.

Lomax, M.A., G.D. Baird, C.B. Mallinson, and H.W. Symonds. 1979. Differences between lactating and non-lactating dairy cows in concentration and secretion rates of insulin. Biochem. J. 180:281–289. doi:10.1042/bj1800281.

Loneragan, G.H., D.U. Thomson, and H.M. Scott. 2014. Increased mortality in groups of cattle administered the b-adrenergic agonists ractopamine hydrochloride and zilpaterol zydrochloride. PLoS One 9:E91177. doi:10.1371/journal.pone.0091177.

McGuffey, R.K., L.F. Richardson, and J.I.D. Wilkinson. 2001. Ionophores for dairy cattle: Current status and future outlook. J. Dairy Sci. 84:E194–E203. doi:10.3168/jds.S0022-0302(01)70218-4.

Meale, S.J., K.A. Beauchemin, A.N. Hristov, A.V. Chaves, and T.A. McAllister. 2014. Board-invited review: Opportunities and challenges in using exogenous enzymes to improve ruminant production. J. Anim. Sci. 92:427–442. doi:10.2527/jas.2013-6869.

Mersmann, H.J. 1998. Overview of the effects of beta-adrenergic receptor agonists on animal growth including mechanisms of action. J. Anim. Sci. 76:160–172. doi:10.2527/1998.761160x.

Meyer, N.F., G.E. Erickson, T.J. Klopfenstein, M.A. Greenquist, M.K. Luebbe, P. Williams, and M.A. Engstrom. 2009. Effect of essential oils, tylosin, and monensin on finishing steer performance, carcass characteristics, liver abscesses, ruminal fermentation, and digestibility. J. Anim. Sci. 87:2346–2354. doi:10.2527/jas.2008-1493.

Newbold, C.J., and L.M. Rode. 2006. Dietary additives to control methanogenesis in the rumen. Intl. Cong. Series 1293:138–147.

Nkrumah, D.J., J.A. Basarab, Z. Wang, C. Li, M.A. Price, E.K. Okine, D.H. Crews, and S.S. Moore. 2007. Genetic and phenotypic relationships of feed intake and measures of efficiency with growth and carcass merit of beef cattle. J. Anim. Sci. 85: 2711–2720. doi:10.2527/jas.2006-767.

Patra, A.K., and J. Saxena. 2010. A new perspective on the use of plant secondary metabolites to inhibit methanogenesis in the rumen. Phytochemistry 71:1198–1222. doi:10.1016/j.phytochem.2010.05.010.

Preston, R.L. 1999. Hormone containing growth promoting implants in farmed livestock. Adv. Drug Deliv. Rev. 38:123–138. doi:10.1016/S0169-409X(99)00012-5.

Rearte, D.H., and A.J. Poromingo. 2014. The relevance of methane emissions from beef production and the challenges of the Argentinean beef production platform. Meat Sci. 98:355–360. doi:10.1016/j.meatsci.2014.06.021.

Scharf, M.E., and D.G. Boucias. 2010. Potential of termite-based biomass pretreatment strategies for use in bioethanol production. Insect Sci. 17:166–174. doi:10.1111/j.1744-7917.2009.01309.x.

Schelling, G. 1984. Monensin mode of action in the rumen. J. Anim. Sci. 58:1518–1527. doi:10.2527/jas1984.5861518x.

Scholtz, M.M., J.P. van Zyl, and A. Theunissen. 2014. The effect of epigenetic changes on animal production. Appl. Anim. Husb. Rural Develop. 7:7–10.

Scramlin, S.M., W.J. Platter, R.A. Gomez, W.T. Choat, F.K. McKeith, and J. Killefer. 2010. Comparative effects of ractopamine hydrochloride and zilpaterol hydrochloride on growth performance, carcass traits, and longissimus tenderness of finishing steers. J. Anim. Sci. 88:1823–1829.

Sharma, A., J.S. Leea, C.G. Dang, P. Sudrajad, H.C. Kim, S.H. Yeon, H.S. Kang, and S.-H. Lee. 2015. Stories and challenges of genome wide association studies in livestock—A review. Asian-australas. J. Anim. Sci. 28:1371–1379. doi:10.5713/ajas.14.0715.

Snelling, W.M., M.F. Allan, J.W. Keele, L.A. Kuehn, T. McDaneld, T.P.L. Smith, T.S. Sonstegard, R.M. Thallman, and G.L. Bennett. 2010. Genome-wide association study of growth in crossbred beef cattle. J. Anim. Sci. 88:837–848. doi:10.2527/jas.2009-2257.

Strydom, P.E., L. Frylinck, J.L. Montgomery, and M.F. Smith. 2009. The comparison of three β-agonists for growth performance, carcass characteristics and meat quality of feedlot cattle. Meat Sci. 81:557–564. doi:10.1016/j.meatsci.2008.10.011.

Strydom, P.E., M. Hope-Jones, L. Frylinck, and E.C. Webb. 2011. The effects of a beta-agonist treatment, Vitamin D3 supplementation and electrical stimulation on meat quality of feedlot steers. Meat Sci. 89:462–468. doi:10.1016/j.meatsci.2011.05.012.

Strydom, P.E., and K. Rosenvold. 2014. Muscle metabolism in sheep and cattle in relation to high rigor temperature—overview and perspective. Anim. Prod. Sci. 54:510–518. doi:10.1071/AN13437.

Tollefsbol, T.O. 2004. Advances in epigenetic technology. In: T.O. Tollefsbol, editor, Epigenetics protocols—Methods in molecular biology. Humana Press, Inc., Totowa, NJ. p. 1-10.

Wallace, R.J. 2012. Manipulating ruminal fermentation: Current status and future prospects. In: Proc. 8th INRA-Rowett Symp. Gut Microbiol. Clermont-Ferrand/Thiex, France (Abstr.). p. 21.

Watson, R. 2008. Meta-analysis of the published effects of HGP use on beef palatability in steers as measured by objective and sensory testing. Aust. J. Exp. Agric. 48:1425–1433. doi:10.1071/EA07174.

Yahav, S., and J.P. McMurry. 2001. Thermotolerance in broiler chickens by temperature conditioning early in life– the effect of timing and ambient temperature. Poult. Sci. 80:1662–1666. doi:10.1093/ps/80.12.1662.

Yang, W.Z., B.N. Ametaj, C. Benchaar, M.L. He, and K.A. Beauchemin. 2010. Cinnamaldehyde in feedlot cattle diets: Intake, growth performance, carcass characteristics and blood metabolites. J. Anim. Sci. 88:1082–1092. doi:10.2527/jas.2008-1608.

Yang, W.Z., C. Benchaar, B.N. Ametaj, A.V. Chaves, M.L. He, and T.A. McAllister. 2007. Effects of garlic and juniper berry essential oils on ruminal fermentation and on the site and extent of digestion in lactating cows. J. Dairy Sci. 90:5671–5681. doi:10.3168/jds.2007-0369.

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