THESIS

EFFECTS OF GROWTH IMPLANTS ON ANIMAL PERFORMANCE, INTAKE, CARCASS CHARACTERISTICS, FEEDING BEHAVIOR, ENTERIC METHANE EMISSIONS, AND ECONOMIC PROFITABILITY OF FINISHING ANGUS STEERS

Submitted by

Maya Swenson

Department of Animal Sciences

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Master's Committee:

Advisor: Sara Place

Kim Stackhouse-Lawson
Nathan Delay
Terry Engle

ABSTRACT

EFFECTS OF GROWTH IMPLANTS ON ANIMAL PERFORMANCE, INTAKE, CARCASS CHARACTERISTICS, FEEDING BEHAVIOR, ENTERIC METHANE EMISSIONS, AND ECONOMIC PROFITABILITY OF FINISHING ANGUS STEERS

Methane (CH_4) is a potent greenhouse gas (GHG) with a global warming potential 28-34 times greater than carbon dioxide (CO_2), making it a significant contributor to climate change (IPCC, 2019). Livestock production, particularly feedlot systems, is a major source of CH_4 emissions from cattle, influenced by diet composition, microbial fermentation, and animal-specific traits (FAO, 2013; Beauchemin et al., 2020). Advances in CH_4 measurement techniques including respiration chambers, SF_6 tracer methods, and automated head chamber systems (AHCS), have improved emissions quantification in feedlot settings (Harper et al., 1999; McGinn et al., 2019; Ungerfeld et al., 2022). Mitigations strategies include dietary interventions like high-concentrate diets, which promote propionate production over methanogenesis, and feed additives like 3-nitrooxypropanol (3-NOP), ionophores, seaweed, and nitrates, which can reduce CH_4 emissions by 10-80% (Vyas et al., 2018; Almeida et al., 2021; Kebreab et al., 2023; Ungerfeld & Pitta, 2024). Additionally, manure management practices, such as anaerobic digesters and composting, can further reduce CH_4 emissions from the livestock operations (EPA, 2024). Anabolic growth promoting implants, widely used in the beef industry, enhance G:F and ADG, have the potential to indirectly reduce CH_4 emissions per unit of beef produced by 12-20% (Stackhouse et al., 2013; Reichhardt et al., 2021). Implants containing trenbolone acetate (TBA) and estradiol (E2) have been shown to increase average daily gain (ADG) by up to 28% and improve feed efficiency (G:F), reducing overall emissions intensity (Parr et al., 2011; Smith & Johnson, 2020). Therefore, the study's objective was to assess the relationship between animal performance, feed intake, carcass characteristics, feeding behavior, enteric CH_4 emissions, and economic profitability of implanted and nonimplanted finishing Angus steers. Sixty-two cattle were housed at the Climate Smart Research pens at Colorado State University and blocked by body weight into two pens. Each pen was equipped with GreenFeed automated head chambers and SmartFeed feeder for feed intake and behavior measurement (C-Lock, Rapid City, SD). The study was conducted as a randomized complete block design. Animals within each pen were randomly assigned a treatment: implanted with Component TE200 (IMP) (Elanco Animal Health, Greenfield, IN) or not implanted (CON). Body weight (BW) gain, feed intake, and enteric emissions were collected from each individual animal for 80 and 52 d. Data were analyzed in JMP Pro and significance was declared at $P < 0.05$ with tendencies at $P < 0.1$. IMP animals had a greater final BW (709 kg vs 670 kg) and ADG (2.4 kg/d vs 1.7 kg/d, $P < 0.0001$) compared to CON animals. A greater dry matter intake (DMI) was observed in IMP animals (11.3 kg/d) compared to CON animals (10.9 kg/d, $P = 0.01$). IMP animals had improved feed conversion (F:G) and G:F efficiencies when compared with CON animals ($P < 0.0001$). A difference was observed in hot carcass weight (HCW) between IMP and CON animals (414.8 kg vs 386.5 kg, $P < 0.0001$). Similarly, ribeye area (REA) was larger in IMP animals compared to CON animals ($P = 0.01$). No differences were observed in marbling score and USDA yield grade (YG) between the two treatments ($P > 0.05$). There was a difference in USDA quality grade (QG), where CON animals graded more frequently in higher grade categories (Choice, Choice+, and Prime) compared to IMP animals ($P = 0.04$). IMP animals tended to have larger session size (SS) (g DM/visit) than CON animals ($P = 0.08$). An interaction was observed where IMP animals fed for 80 d had greater enteric CH_4 emissions compared to CON animals within the same pen (199 g CH_4/d vs 177 g CH_4/d, $P = 0.04$). IMP animals had greater oxygen (O_2) consumption and hydrogen (H_2) emission than CON animals ($P < 0.05$). With animals fed for 52 d, IMP animals had reduced CH_4 emissions intensity (g CH_4/kg ADG) compared to CON animals ($P < 0.05$). Relative profitability was greater than $0 in both weight groups with mean differences of $111.76 and $143.39 for 52 and 80 DOF, respectively. In summary, anabolic implants improve feedlot animal productivity and efficiency, potentially reducing emissions per unit of beef produced while improving economic profitability.

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INTRODUCTION

Methane (CH_4), a potent greenhouse gas (GHG), has a global warming potential (GWP) 28–34 times greater than carbon dioxide (CO_2) over a 100-year period, making it a significant contributor to climate change (IPCC, 2019). Although CH_4 persists in the atmosphere for a relatively short period of approximately 12 years, its high radiative efficiency amplifies its climate impact, underscoring the importance of targeting CH_4 reductions for immediate environmental benefits (Shindell et al., 2024).

The agricultural sector, particularly livestock production, is a major source of CH_4, accounting for approximately 40% of global agricultural CH_4 emissions (O’Connor, 2024). Feedlot systems, which rely on high-concentrate diets to maximize efficiency, are essential for beef production. Ruminal fermentation results in enteric CH_4 emissions during microbial fermentation, which account for 27% of U.S. CH_4 emissions, and is the largest source of GHG emissions from livestock production (47%) (EPA, 2024). However, these systems emit CH_4 due to enteric fermentation and manure management practices (Haque, 2018; Almeida et al., 2021). Alongside enteric emissions, feedlot systems also accumulate manure, which also contribute to a smaller percentage of CH_4 from the agriculture sector. These emissions are further influenced by diet types in feedlot systems, which, while improving growth efficiency, can contribute to CH_4 production. Advances in dietary interventions, manure management technologies, and measurement methodologies offer actionable pathways to reduce CH_4 emissions. This paper synthesizes findings from peer-reviewed studies and technical reports to provide a comprehensive overview of CH_4 emissions from feedlot cattle, focusing on their sources, contributing factors, and mitigation strategies, as well as the use of growth technologies in the beef industry and their impact on GHGs.

GREENHOUSE GASES

Greenhouse gas emissions, including CO_2, CH_4, and nitrous oxide (N_2O), are the primary drivers of climate change. Since preindustrial times, CH_4 has accounted for 19% of radiative forcing from GHGs. (Riishojgaard and Tarasova, 2024). Agriculture contributes 10–14% of global anthropogenic GHG emissions, with CH_4 representing a significant proportion, primarily from livestock systems (Shindell et al., 2024). In the United States, livestock systems contribute 3.9% of total GHG emissions, with enteric fermentation alone responsible for 25% of national CH_4 emissions (EPA, 2024). CH_4 emissions not only pose environmental concerns but also represent inefficiencies in livestock production. CH_4 production accounts for 2–12% of gross energy intake (GEI) in cattle, highlighting the dual benefits of reducing emissions and improving feed efficiency through dietary interventions (Johnson et al., 1995; Beauchemin et al., 2020).

SOURCES OF CH_4 EMISSIONS FROM LIVESTOCK

Enteric fermentation is the dominant source of CH_4 emissions from ruminant livestock, with it making up about 90% of the CH_4 emissions from cattle, globally (FAO, 2013). This process occurs in the rumen, where methanogenic archaea utilize hydrogen (H_2) and CO_2 as substrates to produce CH_4. The production of CH_4 is influenced by the type and composition of the diet, the efficiency of fermentation processes, and the microbial population within the rumen (Beauchemin et al., 2020; Ungerfeld et al., 2022). In feedlot systems, high-concentrate diets are typically fed to maximize weight gain and feed efficiency. These diets reduce CH_4 emissions per unit of feed compared to forage-based diets by promoting the production of propionate, a volatile fatty acid (VFA) that competes with methanogenesis for H_2. However, CH_4 emissions are still substantial due to the concentration of animals and the overall feed intake in these systems (McGinn et al., 2019).

Manure management systems are the second-largest source of CH_4 emissions from livestock. CH_4 is produced when organic matter in manure decomposes under anaerobic conditions, which are common in liquid storage systems such as lagoons and slurry pits (IPCC, 2019). Feedlot systems often use dry-lot manure management, which produces lower CH_4 emissions compared to liquid systems but may lead to increased N_2O emissions depending on the handling and storage conditions (EPA, 2024). Innovative solutions, such as anaerobic digesters, can capture CH_4 for energy production, significantly reducing net emissions while generating renewable energy. In contrast and more applicable to most feedlot systems, solid manure storage systems, including composting, provide lower CH_4 outputs but require careful management to avoid secondary emissions such as N_2O.

INFLUENCES ON CH_4 EMISSIONS FROM LIVESTOCK

Animal-specific traits, including age, weight, breed, and feed efficiency, play a crucial role in CH_4 production, CH_4 yield, and CH_4 emissions intensity. Younger cattle generally produce less CH_4 daily due to their smaller size and lower feed intake. Conversely, older, heavier animals emit more CH_4 daily due to their larger size and higher feed intake, but their emissions per unit of meat produced are often lower due to improved feed efficiency (IPCC, 2019). Additionally, cattle with lower residual feed intake (RFI) exhibit improved feed efficiency and reduced CH_4 emissions per unit of feed consumed, making them potential candidates for genetic selection (Herd et al., 2016; Almeida et al., 2021). Incorporating RFI metrics into breeding programs could significantly enhance CH_4 mitigation efforts over the long term (Mercadante et al., 2015).

Diet composition is one of the most influential factors in CH_4 production. High-concentrate diets reduce CH_4 emissions by shifting fermentation pathways toward propionate production, which reduces H_2 availability for methanogenesis (Beauchemin et al., 2020). In contrast, forage-heavy diets produce more CH_4 due to slower digestion and higher fiber content, which increases H_2 production in the rumen (Johnson et al., 1995). Emerging feed additives, such as 3-nitrooxypropanol (3-NOP) and ionophores, have shown substantial potential for CH_4 reduction. These strategies demonstrate the critical role of diet manipulation in mitigating CH_4 emissions.

Environmental factors, including temperature and humidity, significantly influence CH_4 emissions. Warmer climates can accelerate microbial activity in manure, increasing CH_4 production, while dry conditions reduce anaerobic environments, lowering CH_4 emissions but potentially increasing ammonia (NH_3) volatilization (IPCC, 2019). Feedlot management practices, such as housing design and ventilation, can mitigate these effects by optimizing animal health and manure handling. Manure handling systems are equally important. Liquid-based systems, such as lagoons, produce high CH_4 emissions, whereas solid storage systems emit less CH_4 but require careful monitoring to prevent secondary GHG emissions. Composting and aerobic treatment methods provide alternatives with lower CH_4, output but may necessitate additional management inputs (Beauchemin et al., 2020).

QUANITFYING CH_4 EMISSIONS

Respiration chambers are widely regarded as the gold standard for CH_4 measurement due to their precision and reliability. In these chambers, animals are isolated, and gas concentrations are continuously monitored to measure CH_4 production directly. The system detects exhaled emissions, enabling a comprehensive assessment of metabolic processes. Chamber studies have been instrumental in evaluating the impact of dietary interventions (Johnson & Johnson, 1995). Despite their precision, respiration chambers are expensive to construct and maintain, do not allow animals to express natural behaviors, and their limited capacity makes them impractical for large-scale or long-term studies (McGinn et al., 2019; EPA, 2024).

The SF_6 tracer technique is a widely used field method for CH_4 measurement, especially in grazing or pasture-based studies. The method involves placing a small, calibrated amount of sulfur hexafluoride (SF_6) into the rumen via a slow-release capsule. As the animal exhales, both SF_6 and CH_4 are released, and the relative concentrations of these gases are measured using gas chromatography. This ratio allows researchers to estimate CH_4 emissions accurately in real-world conditions (Harper et al., 1999; IPCC, 2019). The SF_6 tracer technique has revealed significant variations in CH_4 production due to factors such as feed composition, animal breed, and environmental conditions (Ungerfeld et al., 2022). While more scalable and less resource-intensive than respiration chambers, the SF_6 method requires careful calibration and periodic maintenance of equipment to ensure accurate measurements (EPA, 2024).

Automated head chamber systems (AHCS), including GreenFeed systems (C-Lock Inc., Rapid City, SD), offer an innovative and practical solution for measuring CH_4 emissions in feedlot operations. These systems capture exhaled gases when cattle voluntarily interact with feeding units. GreenFeed devices measure CH_4 concentrations along with CO_2, H_2, and O_2, calculating emissions based on feeding duration and gas flow rates (McGinn et al., 2019). GreenFeed has been particularly effective in evaluating feed additives, such as encapsulated nitrate and monensin, under commercial feedlot conditions (Almeida et al., 2021). AHCSs are non-invasive, allow repeated measurements over time, and are scalable for herd-level assessments. However, the requirement for animal interaction with the device can introduce variability in measurement frequency, potentially affecting data reliability (EPA, 2024; Haque, 2018).

Micrometeorological methods, such as eddy covariance and flux towers, are used to estimate CH_4 fluxes over large feedlot areas. These methods measure CH_4 concentrations in the air and combine this data with wind speed and direction to calculate emissions. Unlike respiration chambers and SF_6 tracers, micrometeorological approaches capture system-level emissions, accounting for both animal and manure contributions (Harper et al., 1999). Eddy covariance techniques are particularly valuable for assessing CH_4 emissions under varying environmental conditions and management practices. However, their lower resolution compared to individual-level methods makes them less suitable for evaluating specific mitigation strategies, such as feed additives or genetic interventions (Johnson & Johnson, 1995).

Laser-based technologies, such as open-path lasers and cavity ring-down spectroscopy, represent emerging tools for CH_4 measurement. These systems use laser beams to detect CH_4 concentrations along a defined path or within a chamber, allowing for real-time monitoring of emissions from multiple animals simultaneously (Ungerfeld et al., 2022). Laser-based methods have demonstrated high precision and scalability, making them promising for large-scale feedlot applications. However, the initial investment costs for these technologies remain a barrier to widespread adoption (McGinn et al., 2019; Haque, 2018).

To improve the accuracy and comparability of GHG inventories, the IPCC developed a tiered system that countries and researchers can use to eliminate emissions from livestock. This system is particularly important for guiding national reporting and mitigation strategies. The IPCC Tier system provides a structured approach to CH_4 inventories. Tier 1 relies on default emission factors based on global averages for specific animal categories. While easy to implement, Tier 1 lacks specificity and may not reflect regional variations in diet, management, or animal performance (EPA, 2024). Tier 2 incorporates country-specific data, including feed composition, digestibility, and animal productivity. This level provides a more accurate estimate of CH_4 emissions by considering regional differences (IPCC, 2019). For example, U.S. feedlots using high-concentrate diets may report lower emissions per unit of feed compared to systems with forage-heavy diets. Tier 3 uses advanced models integrating direct measurements and process-based simulations to account for variability in emissions. Tier 3 approaches, combine real-time data on CH_4 production with predictive modeling, providing the most accurate estimates (Ungerfeld et al., 2022). Other methodologies expand on Tier 3 by incorporating additional variables like manure management and climate conditions, enabling nuanced assessments of CH_4 emissions in diverse systems (EPA, 2024).

MITIGATION STRATEGIES

Direct approaches

Direct strategies for CH_4 mitigation primarily involve the use of feed additives or supplements that actively reduce methanogenesis in the rumen. These strategies are considered potent, often leading to substantial reductions in CH_4 emissions within a short timeframe. 3-NOP has shown to be an impactful additive with its mechanism of action involving binding to the enzyme methyl-coenzyme M reductase, which catalyzes the final step of CH_4 production in methanogens (Kebreab et al., 2023). This inhibition disrupts the conversion of metabolic H_2 and CO_2 into CH_4. Studies consistently show that 3-NOP can reduce CH_4 emissions by 30–54%, depending on the dosage, diet composition, and feeding system (Garcia et al., 2022; Kebreab et al., 2023).

Meta-analyses reveal that the efficacy of 3-NOP is influenced by dietary components such as fiber and fat. High-fiber diets tend to reduce the effectiveness of 3-NOP because they promote acetate production, which indirectly supports methanogenesis. Conversely, low-fiber, high-concentrate diets enhance its performance by favoring propionate production as an alternative H_2 sink (Kebreab et al., 2023; Garcia et al., 2022). In feedlot systems, where high-concentrate diets are common, 3-NOP has proven especially effective. For instance, Vyas et al. (2018) reported a 41% and 137% reduction in total CH_4 emissions (g/d) and CH_4 yield, respectively, at an average 3-NOP dose of 125 mg/kg of DMI. The effects of diet NDF % has been shown to reduce the efficacy of 3-NOP on CH_4 reductions where animals on a higher forage diet (28.9% NDF) had increased CH_4 emissions by 51% compared to animals on a higher concentrate diet (14.8% NDF) (Kim et al., 2019). Despite its high efficacy, the cost of 3-NOP and its potential impact on consumer perceptions of "natural" beef products pose challenges. Additionally, CH_4 emissions tend to rebound to baseline levels shortly after 3-NOP is removed from the diet, necessitating consistent supplementation (Kebreab et al., 2023).

Ionophores such as monensin and lasalocid have long been used in cattle diets to improve feed efficiency and growth performance. Their impact on CH_4 reduction stems from their ability to alter ruminal microbial populations. Specifically, ionophores reduce protozoa and H_2-producing bacteria, which are closely associated with methanogens. Monensin has been shown to reduce CH_4 emissions by 10–20%, particularly in high-concentrate diets typical of feedlots (Guan et al., 2006; Russell & Strobel, 1989). Monensin works by increasing the proportion of propionate produced in the rumen, which acts as a competitive H_2 sink, reducing the availability of H_2 for CH_4 production. Additionally, monensin decreases the acetate-to-propionate ratio and lowers ammonia production by inhibiting proteolytic bacteria (Byers & Schelling, 1984). However, the CH_4-suppressing effect of monensin may diminish over time due to adaptation of the ruminal microbiota. Rotational use of ionophores or combinations with other additives may be necessary to maintain long-term efficacy (Guan et al., 2006).

Seaweed, particularly *Asparagopsis taxiformis*, contains bioactive compounds such as bromoform that are highly effective in reducing CH_4 emissions. By disrupting the enzymatic pathways of methanogenesis, seaweed additives can achieve reductions of up to 80% (Ungerfeld & Pitta, 2024). These reductions are among the highest reported for any feed additive. However, the use of bromoform-containing seaweed raises concerns regarding environmental safety, regulatory approval, and potential residues in animal products. A major advantage of seaweed is its natural origin, which aligns with consumer demand for eco-friendly solutions. However, scalability remains a challenge, as the production of *Asparagopsis* is not yet sufficient to meet global demand, and its high cost may limit adoption in commercial feedlots (Ungerfeld & Pitta, 2024).

Nitrates act as an alternative H_2 sink, competing with methanogens for metabolic H_2. Encapsulated nitrate supplements can reduce CH_4 emissions by 12–20% without negatively affecting feed intake or performance (Romero-Perez et al., 2019; Almeida et al., 2021). However, careful management is required to prevent nitrate toxicity, which can cause methemoglobinemia in cattle if not properly dosed. Encapsulation technologies have improved the safety and feasibility of nitrate supplementation in feedlot systems.

High-concentrate diets are a cornerstone of feedlot operations and have a substantial impact on CH_4 mitigation. By increasing the proportion of starch in the diet, these diets shift rumen fermentation from acetate to propionate production, a pathway that generates less H_2 and therefore less CH_4. Feedlot cattle consuming high-concentrate diets lose only 3–4% of their gross energy intake as CH_4, compared to 6–12% for cattle on high-forage diets (Beauchemin & McGinn, 2005; Haque, 2018). The type of grain used in high-concentrate diets also matters. Steam-flaked corn, for example, reduces CH_4 emissions by 20% compared to dry-rolled corn due to improved starch digestibility in the rumen (Hales et al., 2012). Similarly, barley-based diets produce higher CH_4 emissions than corn-based diets, likely due to differences in fermentation characteristics (Beauchemin & McGinn, 2005).

Dietary fats reduce CH_4 production by decreasing organic matter fermentation and fiber digestibility, therefore inhibiting methanogenesis and providing an alternative H_2 sink through biohydrogenation. Enteric CH_4 yield decreases by approximately 4% for every 1% increase in dietary fat (Almeida et al., 2021). Common fat sources include tallow, distillers' grains, and oilseeds. In comparison to saturated fats, unsaturated fats have a stronger inhibitory effect on methane production, interacting with rumen microbes and reducing archaea populations. These fats are able to act as H_2 sinks, whereas saturated fats do not. Additionally, medium chain fatty acids from coconut or palm oil have been shown to have pronounced methane mitigating effects (Jordan et al., 2006). However, excessive fat levels (>5% of dietary DM) can impair fiber digestibility and rumen function, limiting the practical use of this strategy (Haque, 2018).

Replacing soybean meal with microalgae such as *Spirulina* or *Chlorella* can reduce CH_4 emissions while providing a sustainable protein source. Microalgae supplementation reduces CH_4 yield by up to 10% per unit of degraded organic matter (Lobo et al., 2023). Additionally, microalgae have a favorable nutrient profile, including high levels of protein and essential fatty acids, making them a valuable dietary component in feedlot systems. These algae can be incorporated into rations with minimal disruption to existing feed infrastructure, however, the cost of production and processing of microalgae remains relatively high compared to conventional protein sources. Improving forage quality or processing forages to reduce particle size can lower CH_4 emissions in high-forage diets. High-quality forages are digested more efficiently, reducing CH_4 yield. Similarly, finely chopped, or pelleted forages decrease ruminal retention time, limiting CH_4 production (Haque, 2018; Ungerfeld & Beauchemin, 2022).

GROWTH PROMOTING IMPLANTS IN BEEF CATTLE

Growth promoting implants have been and continue to be a common practice in the beef cattle industry. These implants coincide with the primary objective of most producers to increase economic gain by increasing ADG and DMI to enhance the rate of live weight gain of an animal. Implant strategies have been shown to increase growth rates (ADG), improve lean tissue mass, and improve feed efficiency (G:F). In the U.S., over 90% of feedlot steers are given at least one phase of implantation for growth promotion (APHIS, 2013). This use of implants has given evidence to increases in economic returns of $20 – $75 per head (R.L. Preston, 1999; Reichhardt et al., 2021). Commercially available implants in the U.S. are classified into low-, medium-, and high potency with formulations consisting of naturally occurring, estrogen-like compounds, and /or the synthetically modified prodrugs. These include estradiol-17β, zeranol, and estradiol benzoate, sometimes in combination with progesterone, testosterone propionate, and trenbolone acetate (Smith & Johnson, 2020).

Growth implants consistently improve ADG and feed efficiency, with combination implants of trenbolone acetate (TBA) and estradiol (E2) being the most effective. Implants increase ADG by 8% to 28% and feed efficiency by 5% to 20% (Smith & Johnson, 2020; Duckett & Owens, 1997). Parr et al. (2011a) observed that implanted steers achieved ADG values of 1.6 kg/d compared to 1.25 kg/d in non-implanted controls, representing a 28% increase. Similarly, Duckett and Owens (1997) reported a 21% improvement in ADG for cattle receiving combination implants compared to non-implanted cattle. Feed intake also increases with implants. Parr et al. (2011b) found that implanted cattle consumed 9.4 kg/d of DM compared to 8.8 kg/d in non-implanted cattle. This increased feed intake is offset by improved feed efficiency (F:G), with implanted steers achieving efficiencies as high as 0.17 compared to 0.14 in controls (Parr et al., 2011a). From an environmental perspective, increased performance reduces the number of animals needed to meet production targets, thereby lowering land use and CH_4 emissions per unit of beef (Stackhouse et al., 2013; Reichhardt et al., 2021).

Implants enhance carcass weight, lean tissue accretion, and ribeye area (REA). Reinhardt (2007) reported that combination implants increased hot carcass weight (HCW) by 24.9 kg compared to non-implanted cattle. Parr et al. (2011a) found HCWs of 624 kg and 606 kg for steers implanted with Revalor-XS and Revalor-S, respectively, compared to 567 kg in non-implanted steers. Similar findings were documented by Guiroy et al. (2002), who observed a 6% increase in HCW among implanted cattle. However, marbling scores and the percentage of carcasses grading USDA Choice or higher tend to decrease with implants. Duckett and Owens (1997) reported a 17% reduction in marbling scores with combination implants. Reinhardt (2007) noted that while implants improved lean muscle growth, a reduction in intramuscular fat deposition (marbling) can be observed compared to non-implanted animals of the same BW, potentially leading to fewer carcasses with high quality grades. Despite these trade-offs, implants improve ribeye area by 5% to 10%. For example, Stackhouse et al. (2013) found that implanted cattle had ribeye areas of 85.6 cm^2, compared to 79-81 cm^2 in non-implanted cattle. This supports the economic sustainability of implants, as abundant marbling and large ribeye areas are valued in the beef market.

IMPACTS OF IMPLANTS

Emissions

CH_4 is the most significant GHG emitted by cattle, primarily produced during enteric fermentation in the rumen. The use of implants alters feeding efficiency and metabolic processes, which could have potential to indirectly reduce emissions. This impact could be seen based on a reduction in CH_4 emissions intensity (g CH_4/kg ADG or kg HCW) as implanted animals have been shown to increase in gain and HCW without always increasing emissions. (Stackhouse et al. (2013) reported that cattle treated with implants exhibited a 7% reduction in CH_4 emissions intensity per kilogram of HCW compared to non-implanted animals. This reduction was attributed to increased growth rates in implanted animals who produced larger carcasses at slaughter compared to non-implanted animals. CH_4 yield however, has been shown to be more variable when implant technologies are utilized with some studies reporting increased CH_4 yields (Stackhouse et al., 2013), and others reporting a decrease (Cooprider et al., 2011). An observed increase in CH_4 yield in implanted animals is most likely due to increased DMI, as increased DMI has been shown to be associated with higher emissions (Herd et al., 2016). There is potential in selecting for animals with improved feed efficiency, which is also improved by implants, where the expectation would be for those animals to produce less CH_4 per unit of product produced compared to other animals at the same level of production (Waghorn and Hegarty, 2011). For instance, Nkrumah et al. (2006) reported a decrease in CH_4 production of 28% and 24% in low residual feed intake (RFI) animals, compared to those with high and medium RFI.

Carbon dioxide is produced during respiration and microbial fermentation in the rumen. Stackhouse et al. (2013) documented CO_2 emissions reductions of 10% to 15% per kilogram of HCW in implanted cattle due to lower feed requirements and improved weight gains. Oxygen (O_2) consumption and H_2 production are key indicators of metabolic activity in cattle. Implants enhance anabolic pathways, increasing O_2 utilization for muscle growth and reducing the amount of fermentable substrates that produce H_2 (Smith & Johnson, 2020; Parr et al., 2011a). Parr et al. (2011a) found that implanted steers exhibited increased O_2 utilization rates compared to controls, reflecting the higher metabolic demand for lean tissue accretion. The respiration quotient (RQ), the ratio of CO_2 produced to O_2 consumed, provides insight into metabolic fuel use. Implants shift energy metabolism toward lean tissue growth, which increases the RQ value due to reduced fat deposition and enhanced protein synthesis (Parr et al., 2011a; Smith & Johnson, 2020).

Intake

Implants stimulate anabolic pathways, increasing protein synthesis and reducing muscle protein degradation (Smith & Johnson, 2020; Parr et al., 2011a). This results in greater dry matter intake (DMI) without compromising feed efficiency. Reichhardt et al. (2021) found that implanted cattle exhibited a 7% increase in DMI compared to controls, with an average intake of 21.4 kg/d. Additionally, feeding behaviors are influenced by implant type and dosage. Bryant et al. (2010) demonstrated that implanted cattle exhibited more consistent feeding patterns, reducing feedlot variability. Such behavior optimizations contribute to improved feed management and overall feedlot productivity.

Economically, implants provide substantial returns by reducing feed costs and increasing carcass yields. USDA APHIS (2013) estimated that implants add $30 to $67 per head in net returns, depending on market conditions. Moreover, longer-lasting implants like Revalor-XS, which do not require reimplantation, save labor costs while maintaining performance (Parr et al., 2011b). Kayser et al. (2022) found that steers implanted with high-dose TBA-E2 combinations produced the highest ADG and HCW, demonstrating a strong return on investment. This economic advantage extends to consumers by ensuring a stable supply of affordable beef while promoting food security (Johnson et al., 2013).

CONCLUSION

Growth-promoting implants in feedlot cattle provide significant benefits across the three pillars of sustainability: environmental, economic, and social. Environmentally, implants have the potential to reduce CH_4 emissions intensity by 12% to 20%, along with decreases in CO_2 and other emissions, thereby contributing to climate change mitigation efforts. These reductions are achieved through improved feed efficiency, enhanced lean tissue growth, and optimized energy utilization, all of which lower the carbon footprint of beef production. Economically, implants increase profitability by enhancing ADG by up to 28% and HCW by 24.9 kg, while reducing feed costs and improving feed conversion efficiency. These gains ensure a more efficient use of resources, reduce production costs, and provide a stable supply of affordable beef for consumers, aligning with economic sustainability goals. Socially, implants support global food security by increasing beef production efficiency and producing leaner, nutrient-rich meat that caters to evolving consumer health preferences.

Despite these advantages, challenges such as reduced marbling scores and consumer acceptance of growth-enhancing technologies remain. To address these concerns and ensure continued progress toward sustainability, future research should explore ways to optimize implant strategies, particularly for balancing CH_4 mitigation with carcass quality and consumer preferences. Additionally, integrating implants with complementary CH_4 reduction strategies, such as dietary interventions (e.g., 3-NOP, ionophores, fat supplementation, and high-concentrate diets), could amplify environmental benefits while maintaining economic viability. Tailoring these strategies to specific feedlot operations will ensure a holistic approach to sustainability, maximizing environmental gains, enhancing profitability, and meeting the needs of consumers and producers alike.

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CHAPTER 2 – EFFECTS OF GROWTH IMPLANTS ON ANIMAL PERFORMANCE, INTAKE, CARCASS CHARACTERISTICS, FEEDING BEHAVIOR, ENTERIC METHANE EMISSIONS, AND ECONOMIC PROFITABILITY OF FINISHING ANGUS STEERS

ABSTRACT

Anabolic growth implants are a useful tool in cattle production to improve their environmental impact by lowering emissions per unit of gain or beef produced and increasing overall feed efficiency. The study's objective was to assess the relationship between animal performance, feed intake, carcass characteristics, feeding behavior, enteric CH_4 emissions, and economic profitability of implanted and nonimplanted finishing Angus steers. Sixty-two cattle were housed at the Climate Smart Research pens at Colorado State University and blocked by body weight into two pens fed for 52 and 80 d.. Each pen was equipped with GreenFeed automated head chambers and SmartFeed feeder for feed intake and behavior measurement (C-Lock, Rapid City, SD). The study was conducted as a randomized complete block design. Animals within each pen were randomly assigned a treatment: implanted with Component TE200 (IMP) (Elanco Animal Health, Greenfield, IN) or not implanted (CON). Body weight (BW) gain, feed intake, and enteric emissions were collected from each individual. Data were analyzed in JMP Pro and significance was declared at $P < 0.05$ with tendencies at $P < 0.1$. IMP animals had a greater final BW (709 kg vs 670 kg) and ADG (2.4 kg/d vs 1.7 kg/d, $P < 0.0001$) compared to CON animals. A greater dry matter intake (DMI) was observed in IMP animals (11.3 kg/d) compared to CON animals (10.9 kg/d, $P = 0.01$). IMP animals had improved feed conversion (F:G) and G:F efficiencies when compared with CON animals ($P < 0.0001$). A difference was observed in hot carcass weight (HCW) between IMP and CON animals (414.8 kg vs 386.5 kg, $P < 0.0001$). Similarly, ribeye area (REA) was larger in IMP animals compared to

CON animals ($P = 0.01$). No differences were observed in marbling score and USDA yield grade (YG) between the two treatments ($P > 0.05$). There was a difference in USDA quality grade (QG), where CON animals graded more frequently in higher grade categories (Choice, Choice+, and Prime) compared to IMP animals ($P = 0.04$). IMP animals tended to have larger session size (SS) (g DM/visit) than CON animals ($P = 0.08$). An interaction was observed where IMP animals fed for 80 d had greater enteric CH_4 emissions compared to CON animals within the same pen (199 g CH_4/d vs 177 g CH_4/d, $P = 0.04$). IMP animals had greater oxygen (O_2) consumption and hydrogen (H_2) emission than CON animals ($P < 0.05$). With animals fed for 52 d, IMP animals had reduced CH_4 emissions intensity (g CH_4/kg ADG) compared to CON animals ($P < 0.05$). Relative profitability was greater than \$0 in both pens with mean differences of \$111.76 and \$143.39 for 52 and 80 DOF, respectively. In summary, anabolic implants improve feedlot animal productivity and efficiency, potentially reducing emissions per unit of beef produced while improving economic profitability.

INTRODUCTION

Methane (CH_4) emissions from livestock production represent an environmental concern, contributing to climate change due to CH_4 high global warming potential (IPCC, 2019). Ruminant animals, such as beef cattle, produce CH_4 primarily through enteric fermentation, a process in which methanogenic archaea convert hydrogen (H_2) and carbon dioxide (CO_2) into CH_4 in the rumen (Beauchemin et al., 2020). Despite its relatively short atmospheric lifespan of approximately 12 years, CH_4 is over 28 times more potent than CO_2 in terms of radiative forcing over a 100-year period, making its mitigation a critical component of reducing the livestock industry's carbon footprint (Shindell et al., 2024). Given that livestock contributes to approximately 40% of agricultural CH_4 emissions globally (O'Connor, 2024), improving efficiency in beef production is a key strategy to reduce CH_4 emissions per unit of output. Reducing CH_4 intensity in livestock systems not only supports climate goals but also enhances food security by enabling more sustainable protein production without increasing resource use.

Growth-promoting implants have long been used in the beef industry to improve average daily gain (ADG), feed efficiency (G:F), feed conversion efficiency (F:G), and hot carcass weights (HCW) without increasing days on feed (DOF) to achieve greater market weights compared to alternative natural production practices (Smith & Johnson, 2020). These implants, consisting of naturally occurring and synthetic steroid hormones such as trenbolone acetate (TBA) and estradiol (E2), enhance anabolic pathways, leading to increased lean muscle growth and improved feed conversion efficiency (Duckett & Owens, 1997; Parr et al., 2011a). The economic benefits of implants are well-documented, with reports indicating increased profitability per head ranging from \$20 to \$75 due to improved growth performance with similar or maintained feed costs (Reichhardt et al., 2021).

Beyond economic gains, implants could also offer environmental advantages by reducing CH_4 emissions per unit of beef produced. Since CH_4 production is closely tied to feed intake and G:F, interventions that improve these aspects can significantly lower CH_4 emissions intensity (Stackhouse et al., 2013). Furthermore, increased lean tissue growth in implanted cattle results in more efficient nutrient utilization, leading to lower CH_4 production per kilogram of HCW (Cooprider et al., 2011; Stackhouse et al., 2013). Although absolute CH_4 emissions may increase in implanted cattle due to higher feed intake, CH_4 emissions per kilogram of gain can be reduced, supporting a more sustainable beef production system with a reduction in GHG emissions per kg HCW (Capper et al., 2021).

The objective of the current study is to evaluate the impact of growth-promoting implants on feedlot performance, carcass characteristics, feeding behavior, emissions, and economic profitability in finishing steers. Specifically, the study assesses the extent to which implants influence CH_4 yield (g CH_4/kg dry matter intake (DMI)) and CH_4 intensity (g CH_4/kg ADG). By investigating the interaction between productivity-enhancing technologies and greenhouse gas emissions (GHG), this research provides critical insights into the role of growth implants in reducing the environmental impact of beef production while maintaining economic viability.

MATERIALS AND METHODS

Ethics Statement

This study was conducted at the Climate Smart Research pens in Fort Collins, CO at Colorado State University. All procedures were approved by the Colorado State University Institutional Animal Care and Use Committee (IACUC #4689)

Animals and Experimental Design

Sixty-two Angus steers from John E. Rouse Beef Improvement Center (Saratoga, WY) were used in a complete randomized block design finishing trial, with individual animals being the experimental unit. Animals were on feed for 32 d prior to being enrolled in the experiment and had not received a growth implant prior to the start of the experiment. At the start of the study, all animals were weighed and blocked by body weight.. To achieve similar final body weights (FBW), heavier animals were observed during the experimental period for 52 consecutive days (n = 32), while lighter animals were observed for 80 consecutive days (n = 30). Cattle were then randomly assigned a treatment of implanted (IMP) or not implanted (CON). Initial body weights (IBW, $\mu \pm$ SD) were collected on days -1 and 0 to attain individual mean starting weights from all animals fed for 52(579 ± 3.6 kg), and 80 d (522 ± 3.7 kg). Animals were then weighed every 21d until the end of trial. All animals were weighed on the given pen's last two DOF to attain individual mean final weights (685 ± 4.2 kg and 693 ± 4.4 kg, respectively). All weighing events were performed on a hydraulic chute and the scale that was calibrated with 227 and 454 kg to determine accuracy before and after each event.

On day 0, all animals were either implanted (IMP) with Component TE-200 (200 mg trenbolone acetate/20 mg estradiol; Elanco Animal Health, Greenfield, IN) or not implanted (CON). Prior to implanting, all animals were exposed to GreenFeed and Smartfeed units (C-Lock Inc., Rapids City, SD) for a 12 d covariate period to determine baseline individual feed intake and gas flux. During the covariate period, GreenFeed systems were equipped with headbox extension boards (wings), and cattle panels were installed during the entirety of the 12d covariate period to ensure one animal could access the GreenFeed at a time. Animals were previously exposed to GreenFeed systems and required no acclimation period. Animal health was monitored daily throughout the experimental period by trained personnel who ensured access to fresh feed and water, and observed feed and water intake, locomotion, and signs of disease. Any animals showing signs of respiratory or locomotive stress were removed from the pen and body weight and rectal temperatures were recorded. Animals appearing to be clinically ill were treated accordingly following veterinarian recommendations and returned to their pen.

Housing, Gas Flux Measurement, and Feed Intake Measurement

The animals were housed in typical feedlot pens (15m × 43m) with partial shade covering the Smartfeed bunks on a concrete pad (15m × 3m). Individual pens were assigned for animals on feed for 52 and 80 d. Each pen was equipped with 5 SmartFeed feeding units and 1 GreenFeed automated head chamber system (C-Lock Inc., South Dakota, USA) to track daily intake, feeding behavior, and gas flux (enteric CH_4, CO_2, O_2, and H_2). All animals were transitioned to the finishing diet 2 weeks prior to the beginning of the covariate period. Animals were blocked from Smartfeed units every morning during feeding and then allowed access to feed *ad libitum*. All animals were fed the same finishing diet for the total duration of the study. The composition of the finishing diet was 65% steam-flaked corn, 20% corn silage, 7% dried distillers grain with solubles (DDGS), 4% PMS liquid supplement, and 4% combination pellet containing monensin sodium and tylosin (Ralco Nutrition Inc., Marshall, MN) (Table 1).. Chemical composition of the total mixed ration (TMR) and alfalfa pellets are reported in Table 1. Smartfeed units were calibrated at the beginning and end of the trial, and every 7d during the experimental period. All Smartfeed units were scraped 3x/week during the entire trial to remove any spoiled feed. The GreenFeed systems were programmed to allow animals to visit up to 6 times a day in at least 4-hour intervals. Each visit to the GreenFeed provided up to 6 drops of suncured alfalfa pellets (~37 g pellets per drop), released in 30 second intervals while the animal's head was present in the headbox. GreenFeeds were filled with pellets and in line air filters were cleaned every other day. Automatic standard calibrations were performed every 3 days to ensure the accuracy of the gas analyzers. Carbon dioxide recoveries were performed monthly by trained personnel to ensure accurate gas flux measurements were being collected. Individual animals were identified to both Smartfeed and GreenFeed systems with Radio Frequency Electronic Identification (RFID) tags located in the animals left ear. Time stamped data was uploaded daily from both systems and accessible through C-Lock Inc.'s online software.

Fresh TMR samples were collected once a day, weekly immediately after feeding throughout the experimental period. Individual samples were collected from each Smartfeed unit and then combined into a singular sample. Weekly samples were weighed directly after collecting, dried for 72 hours at 65C, and then reweighed to determine daily dry matter (DM) of the ration. Dried samples were then stored appropriately until the end of the study completion. A dried composite sample was then sent to Dairy One Forage Laboratory (Ithaca, NY) for nutritive chemical analysis.

Raw gas flux events were filtered based on visit length, airflow, and head proximity and validated by C-Lock Inc. data analysts. The gas emission rates (Q_c) were calculated using the following equation (Huhtanen et al., 2015):

$$Q_c = [C_P \times (Conc - BConc) \times Q_{air}] \div 10^6$$

Here, C_p is the fractional capture rate of air, Conc is the captured gas concentration, BConc is the background gas concentration, and Q_{air} is the volumetric airflow. Therefore, gas flux (Q_m) was calculated using the following equation:

$$Q_m = Q_c \times 273.1 \div (273.15 + T_{air}) \times GD$$

Where, T_{air} is the temperature of the air, and GD is the gas density at 1 atm and 273.5 K. Processed events were additionally filtered by excluding events that were shorter than 2 minutes, longer than 8 minutes, or had an average airflow less than 26L/s (Gunter and Beck, 2018). CO_2, CH_4, and H_2 emission, and O_2 consumption measurements were then averaged by animal during the covariate and experimental period, as well as averaged weekly by animal. Respiratory quotient (RQ) and CH_4 as a percentage of gross energy intake (GEI) were calculated with the following equations:

$$RQ = L/d\ CO_2 \div L/d\ O_2$$

$$CH_4\ as\ \%\ GEI = (MJ\ CH_4\ \div MJ\ GEI) \times 100$$

Raw feeding events recorded via Smartfeed were excluded from analysis if the visit exceeded 3600s or were not a minimum of 5s in duration time, resulted in a mass difference greater than 10 kg, and/or was flagged due to unallocated feed or negative intake. Intakes were then summed by day and averaged by animal to determine daily and weekly TMR DMI. Alfalfa pellets from the GreenFeed were then summed into the TMR DMI by summing total drops received by day to determine total grams received by day of pellets to then determine total DMI. Mean total DMI were calculated for covariate and experimental periods for each animal.

Feeding behavior

Feeding behavior was determined using individual animal visits throughout the duration of the study from the SmartFeed systems. Individual feeding events were adjusted due to lag time between RFID recognition between different Smartfeed bunks. Therefore, if 2 or more visits from an individual animal overlapped the earliest start time and latest end times were utilized, and mass differences were summed from the visits. Time intervals between feeding events were log-transformed, pooled, and then fitted to a Gaussian and two Weibull distributions in SAS (9.4 SAS, Institute Inc.). The intersection of the 2 distributions was determined as the meal duration cutoff time (Yeates et al., 2001; Kelly et al., 2020). The determined meal duration criterion for both IMP and CON animals was 3972 sec. Behavioral traits from Dressler et al. (2023) were determined using the meal criteria. These traits included meal visit (MV, visits/d), session size (SS, g DM/visit), session length (SL, min/visit), session interval (SI, min), and intake rate (IR, g DM/min).

Carcass characteristics

All animals were harvested at Cargill Meat Solutions (Fort Morgan, CO) following the end of the given weight groups experimental period. Animal tag numbers and RFIDs were recorded for each individual in the plant. All processing of animals was overseen by a trained employee of the U.S. Department of Agriculture Food Safety and Inspection Services (USDA FSIS). Once carcasses were processed, they were then quality and yield graded based on USDA standards. Calculated yield grades were classified according to USDA guidelines. Carcass characteristics that were collected include HCW, marbling score, yield grade (YG), fat thickness, ribeye area (REA), liver scores and heart scores. Reported values for carcass value and $/cwt are actual price value for the carcass at time of slaughter. Equivalent shrunk body weight (EQSBW) was calculated for CON animals using the following equation (NRC, 2016):

$$EQSBW(CON) = SBW \times \left(\frac{478}{FSBW}\right)$$

Where, SBW is the average initial shrunk body weight of the animal at the start of the experimental period in kg, 478 kg as the standard reference body weight (NRC, 2016), and

FSBW represents the animal's final shrunk body weight at time of slaughter in kg. Equivalent shrunk body weight was calculated for IMP animals using the following equation (NRC, 2016):

$$EQSBW(IMP) = SBW \times \left(\frac{478}{FSBW + 45}\right)$$

Here, all variables are the same as the previous equation, with the addition of 45 kg to the FSBW based on NRC recommendations (2016). Dressing percentage (DP) was calculated using the following equation:

$$DP = HCW \div average\ final\ live\ weight$$

Where, HCW is the hot carcass weight in kg. Empty body fat percentage (EBF) was calculated using the following equation (Guiroy et al., 2001):

$$\begin{aligned} EBF = 17.76107 + (4.68142 \times FT) + (0.01945 \times HCW) + (0.81855 \times QG) \\ - (0.06754 \times LMA) \end{aligned}$$

Here, FT is the 12th rib fat thickness in cm, HCW is the hot carcass weight in kg, QC is the numerical quality grade, and LMA is the longissimus muscle area in cm^2 (Guiroy et al., 2001).

Economic data

Relative profit differences of IMP and CON animals within each pen were determined using the variables DMI, livestock weights, feeder and fat cattle prices, and feed costs during the respective experimental period. Relative profit differences were defined as the difference between treatments of animals within each pen. All cattle and feed prices were obtained from the Livestock Marketing Information Center (LMIC) (Table 2). Prices were collected from January 2000 to December 2023. All prices were adjusted to 2023 values using the Producer Price Index

(Federal Reserve Economic Data, PPI, All Commodities). Prices were averaged by month to then calculate yearly averages from the months cattle were purchased and sold, as well as the months on feed. For animals fed for 52 d, this included average historical prices of July feeder cattle, feed costs from July-September, and September fat cattle. For animals fed for 80 d, this included average historical prices of July feeder cattle, feed costs from July-October, and October fat cattle. Once historical averages were compiled by year based on the above criteria, the batch fit tool and forecasting were used to produce a Monte Carlo simulation through Crystal Ball (Oracle Corp., Texas) of the relative profitability differences between IMP and CON animals within each weight group. It is to be noted, prices of commodities and cattle were the only stochastic variables in the model, while cattle weights and intake were deterministic based on averages from each treatment from each pen. Relative profitability per hd was calculated using the following equation:

$$Relative\ profitability = FP - TF - I - FC$$

Where, FP is the fat cattle price, TF is the total cost of feed stuffs, I is the cost of an implant if administered, and FC is the feeder cattle cost. Each variable represents the average price or cost of the commodity in a given year during the time of production for each weight group.

Statistical analysis

Animal was considered the experimental unit.. All variables were analyzed using JMP Pro version 16.2.0. For all dependent variables regarding animal weight, growth performance, and carcass characteristics, DOF and treatments, and their interaction were included in each model as fixed effects based on the following equation:

$$Y_{ijk} = \mu + T_i + WDOF_j + (TDOF)_{ij} + \varepsilon_{ijk}$$

Where, T_i is the treatment (IMP or CON), DOF_j is the categorical value for animals on feed for 52 and 80 d, , TDOF is the treatment by DOF interaction, and ε_{ijk} is the random residual effect of each observation. For all dependent variables regarding gas flux and DMI, DOF and treatments, their interaction, and covariate measurements were included in each model as fixed effects based on the following equation:

$$Y_{ijkl} = \mu + T_i + DOF_j + (TDOF)_{ij} + COV_k + \varepsilon_{ijkl}$$

Here, all variables represent the same input as the previous equation, and COV_k is the covariate measurement collected prior to the experimental period of the study. Interactions observed between treatment by DOF effects were further analysis using a mixed effects model for repeated measures analyses on weekly DMI and enteric CH_4 emissions. For all dependent variables, covariate measures, treatments, weeks, and the interaction were included in each model as fixed effects, and individual animals were included as a random effect using the following equation:

$$Y_{ijklmn} = \mu + T_i + DOF_j + (TDOF)_{ij} + COV_k + W_l + A_m + \varepsilon_{ijklmn}$$

Where, again, all variables represent the same input as the previous equation, W_l is the number of weeks an animal was on feed and A_m accounted for the random effect of each animal. Pens were analyzed separately to account for the difference in the number of weeks. A chi-squared test was performed to determine a difference in frequency of quality grading results between IMP and CON animals using the following equation:

$$x^2 = \Sigma \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

Here, O_{ij} represents the observed frequency in the contingency table for the number of cattle in quality grade *i* and treatment group *j*, and E_{ij} is the expected frequency under the assumption of independence. Statistical significance was declared at $P < 0.05$ and a trend at $P < 0.10$.

RESULTS

The following results are all reported in Table 3 unless otherwise noted. There were no differences in initial BW of the animals at the beginning of the study between treatments (551±3.64 kg, $P = 0.88$). IMP animals had heavier final BW ($P < 0.0001$) compared to CON animals. Similar results were observed when evaluating ADG, where IMP animals had a 34% greater ADG ($P < 0.0001$) than CON animals. A difference was observed in final EQSBW with IMP animals having a 9% lower EQSBW than CON animals ($P < 0.0001$). Animals on feed for 80 experienced greater ADG and lower final EQSBW ($P < 0.05$), when compared to animals in the HEAVY weight group. Overall, DMI was greater in IMP animals ($P = 0.01$) compared to CON animals. When evaluated with repeated measures, DMI for animals fed for 52 d was greater during wk 5, 6, and 7 in IMP animals compared to CON animals (Figure 1; $P < 0.05$). Similarly, DMI in the LIGHT weight group was greater during wk 2, 8, 9, 10, and 11 in IMP animals compared to CON animals (Figure 2; $P < 0.05$). An improvement in both F:G and G:F was observed in IMP animals compared to CON animals by 29% and 27%, respectively ($P < 0.0001$).

Also reported in Table 3, a difference was observed in HCW, with IMP having 7% greater HCW ($P < 0.0001$) than CON animals. Similarly, IMP animals had larger REA (92.2 cm^2) when compared to CON animals (85.2 cm^2, $P = 0.001$). Animals in the IMP treatment also had greater carcass values ($P < 0.0001$) than CON animals. Dressing percentage tended to be greater in IMP animals compared to CON animals ($P = 0.054$). No differences were observed ($P > 0.05$)

between treatments in fat thickness, marbling score, value per 100 kg, YG, or EBF. A greater percentage of CON animals graded Prime, Prime-, and Choice+ compared to IMP animals (58% vs 49%, $P = 0.04$).

Feeding behavior results are reported in Table 4. IMP animals tended to have larger SS than CON animals (1778.2 vs 1703.5 g DM/visit, $P = 0.08$). No differences were observed between treatments for MV, SL, SI, or IR ($P > 0.05$). Within pens, animals with DOF of 52 d had more MV than animals on feed for 80 d ($P = 0.049$). Animals fed for 52 d also exhibited longer SI (271.4 min) compared to animals fed for 80 d (255.6 min, $P = 0.009$).

Gas flux results are reported in Table 5. No differences were observed between IMP and CON animals within the pen fed for 52 d for daily enteric CH_4 emissions ($P > 0.05$). Within pen fed for 80 d, IMP animals had 12% greater daily CH_4 emissions of 199 g/d compared to CON animals 177 g/d ($P = 0.04$). When evaluated with repeated measures, CH_4 emissions were not different between treatments during any wk for animals fed for 52 d (Figure 4; $P > 0.05$), however, for animals fed for 80 d, IMP had greater CH_4 emissions during wk 4, 8, 9, 10, and 11 compared to CON animals (Figure 5; $P < 0.05$). Animals with 80 DOF had greater CO_2 emissions and O_2 consumption rates than animals with 52 DOF ($P < 0.05$) by 5% and 12%, respectively. O_2 consumption was greater in animals on feed for 80 d compared to those on feed for 52 d ($P < 0.0001$), and a 3% difference was observed between treatments, where IMP had greater O_2 consumption compared to CON animals ($P = 0.01$). Hydrogen emissions were different between treatments where IMP animals had greater emissions compared to CON animals ($P = 0.003$). Animals fed for 52 d had greater RQ ($P < 0.0001$) than animals fed for 80 d. Methane energy loss as a percentage of GE intake was not different between treatments, between DOF, or their interaction ($P = 0.46$). Methane yield tended to be different between treatments within pens($P = 0.09$). IMP animals fed for 52 d had lower CH_4 intensity (74.9 g CH_4/kg ADG) compared to CON animals (106.7 g CH_4/kg ADG, $P < 0.05$), whereas no differences were observed in animals with 80 DOF.

Within both pens, the difference in relative profit between IMP and CON animals was greater than \$0, with mean differences of \$111.75 and \$143.36 for 52 and 80 DOF, respectively. This in turn resulted in breakeven always being above \$0 100% of the time when using an anabolic implant. Relative profitability with 80 DOF exhibited a wider spread distribution compared to52 DOF. Fat cattle prices contributed to 99.9 and 99.8% of the variance observed in the difference of relative profitability between IMP and CON with 80 and 52 DOF, respectively (Figures 8 and 9).

DISCUSSION

Performance

Implantation with Component TE-200 resulted in notable improvements in growth performance, including increased ADG and G:F compared to non-implanted animals. Increases in performance were expected as anabolic growth implants are a common practice in many feedlot operations to improve economic return (Johnson et al., 2013). Final BW of animals in the current study were greater in IMP animals compared to CON which is consistent with previous studies reporting 2 to 7% increases in final BW (Johnson et al., 1995; Bryant et al., 2010; Stackhouse et al., 2013). Average daily gain differences are also consistent with the results observed by Duckett et al. (1997), who reported ADG improvements of 5% to 20%. Similar growth improvements were also documented by Stackhouse et al. (2013), who found a 24% increase in ADG for steers treated with anabolic implants, aligning with the current study.. However, it should be noted the current study experienced greater ADG compared to other studies due to the limited number of DOF. This decline in response as post implantation time increases is exhibited in Preston (1999) and Kayser et al. (2022). Animals on feed for 52 d gained more rapidly, similar to the trends observed in Johnson et al. (1995). On the other hand, animals fed for 80 d demonstrated a more gradual increase, confirming the notion that lighter animals benefit from longer DOF to achieve comparable gains. However, even though implanted animals gain faster than non-implanted animals, they do not put on fat at the same rate to growth compared to non-implanted animals (Reinhardt et al., 2007).This observation is reflected in the EQSBW difference between treatments of the current study, and adds to why implanted animals predicted EQSBW need additional kg added to their FSBW to reach a similar carcass composition as nonimplanted animals (NRC, 2016). In a review from Guiroy et al. (2002), it was summarized that adjusted FSBW at 28% EBF was increased by implants by 14 to 42 kg. This is again reflected in the current study where EBF was similar between treatments, however IMP animals' final body weights were 39 kg greater than CON animals.

It is typically reported that growth implants increase DMI over a negative control treatment in finishing feedlot animals (Johnson et al., 1995; Duckett et al., 1997; Parr et al., 2011a; Reichhardt et al., 2021). Where, Johnson et al. (1995) and Reichhardt et al. (2021) reported observations of even greater increases in DMI than the current study of 7-9% in implanted animals compared to non-implanted animals. These increases were seen over 115 to 132 d periods, possibly explaining the lesser DMI increases observed between treatments in the current study. Other studies have also reported no differences in DMI between various treatments of implant strategy. Johnson et al. (1995), Bryant et al. (2010), and Parr et al. (2011a) reported no differences in DMI between treatments during the first 40 to 84 d post implantation, contrasting the observed increased DMI of 4% of the current study where animals were implanted for 52 80

d. Interestingly, despite the higher intake rates, implanted steers exhibited more efficient feed conversion, which corresponds with the findings of Perry and Fox (1997) and Stackhouse et al. (2013), who also observed similar G:F increases without corresponding increases in total feed intake. Subsequential to increased growth rates and moderate increases in DMI, growth promoting implants have been shown to enhance F:G and/or G:F. Duckett et al. (1997) reported G:F gains of 5% to 20% for implanted cattle, while Parr et al. (2011a) also reported similar increases in G:F of 21% and 20% over 56 and 84 d timelines, slightly lower than G:F observed in the current study.

Carcass characteristics

Implanted animals in the current study exhibited larger HCW and REA, consistent with findings from Stackhouse et al. (2013), Bryant et al. (2010), and Kayser et al. (2022). These improvements are attributed to the enhanced muscle growth facilitated by anabolic implants. The increase in HCW and REA with no difference in fat thickness is corroborated by Johnson et al. (1995) and Bryant et al. (2010), who also observed similar differences to the current study. The current study observed a tendency in DP between treatments, supported by the findings of Bryant et al. (2010) and Parr et al. (2011a), who observed increased DP in implanted cattle. However, literature has presented inconsistent results on the effects of anabolic implants on DP with some reports of about 1% difference in treatments (Bruns et al., 2005) or no differences in DP between treatments (Johnson et al., 1995). This difference in results could be explained by the use of a single combination implant or reimplantation, dosage of TBA or E_2, as well as the delivery rate of hormones from an implant early versus later in the payout period (Reinhardt et al., 2007). Similar to the results observed by Lundy et al. (2021) and Reichhardt et al. (2021), no differences between treatments in marbling scores was observed in the current study. Similar to results in the current study, Preston et al. (1990) concluded that implanted steers should be finished at a BW 39.5 kg heavier than nonimplanted steers to achieve similar marbling scores. However, while marbling scores did not differ, a lower proportion of implanted carcasses graded as USDA Choice or Prime compared to nonimplanted carcasses. As expected, the implanted carcasses did have numerically lower marbling scores, which may be reflecting the statistical difference observed in quality grading frequency between IMP and CON animals. This represents a possible tradeoff with the use of implants and their impact on mature body composition (NRC, 2016)

Feeding Behavior

Feeding behavior in the current study, aligns with the observations of Reichhardt et al. (2021) and Reichhardt et al. (2023). A tendency was found in SS between treatments in the current study, the previously mentioned studies observed a difference in SS between treatments, where implanted animals with moderate and high doses ate more feed per visit to the bunk. These observations are better explained by the increase in DMI in implanted animals reported in the current and past studies and could explain possible metabolic demand differences between treatments. Understanding these behavioral patterns is important, as they provide insight into how growth promoting implants may influence feeding strategy, potentially affecting feed bunk management, nutrient utilization, and overall performance. Moreover, altered feeding behavior could have downstream effects on rumen fermentation and enteric CH_4 production.

Emissions

Methane is one of the most abundant sources of GHG emissions from livestock agriculture with most of the emissions sourcing from enteric emissions (Johnson & Johnson, 1995). Many studies have been conducted evaluating the impacts of feed additives and other growth promoting technologies (i.e., 3-NOP, ionophores, beta agonists) on CH_4 emissions;

however, few studies have assessed the aspect of anabolic implants on emissions from feedlot cattle. The current study's total CH_4 emissions fall within the expected range for feedlot cattle and are comparable to those reported by McGeough et al. (2010) and Carlson et al. (2023) for cattle on similar finishing diets. However, total CH_4 emissions are lower than other studies (Cooprider et al., 2011; Stackhouse et al., 2013) from feedlot cattle, this variation is most likely due to measurement methods of emissions. The aforementioned studies utilized cattle pen enclosures which may result in greater CH_4 emissions compared to AHCS due to the inclusion emissions of not only enteric fermentation but manure as well. CH_4 yield was unaffected by implant treatment, consistent with Carlson et al. (2023). When evaluating CH_4 emissions, the current study, and others (Cooprider et al., 2011; Stackhouse et al., 2013)) found that implanted steers showed a slight reduction in CH_4 emissions per kilogram of HCW. This reduction is consistent with the literature, which suggests that enhanced G:F in implanted cattle leads to lower emissions per unit of energy intake (Reichhardt et al., 2021; Smith and Johnson, 2020). In the current study, IMP animals reduced CH_4 intensity (g CH_4/kg ADG) by approximately 30% compared to the CON animals with 52 DOF. This is a greater improvement in CH_4 intensity to prior findings by Stackhouse et al. (2013), Cooprider et al. (2011), and Boonstra et al. (2020), where growth-enhancing technologies resulted in reduced CH_4 emissions per unit of production. The observed reduction in CH_4 intensity can be attributed to the enhanced G:F of implanted steers, leading to improved growth performance with only modest increases in DMI. Meanwhile, the observed differences of the current study's intensity and others could be attributed to the length of time the animals experienced an implant before slaughter.

Differences observed in CO_2 emissions and O_2 between DOF or treatments may be attributed to differences in metabolic rate, growth phase, and feed intake dynamics. The observed

CO_2 emissions are consistent with trends reported in Carlson et al. (2023), where CO_2 output scaled with DMI and growth performance. The RQ values were significantly lower in animals fed for 80 d compared to those fed for 52 d, indicating potential differences in substrate oxidation and metabolic efficiency or differences (Proctor et al., 2024) These RQ values agree with findings by Proctor et al. (2024), where RQ fluctuated with diet composition and growth phase. Oxygen consumption is likely reflective of differences in metabolic demands, as lighter cattle tend to be in a more active growth phase requiring greater oxidative metabolism. Similarly, IMP animals may be experiencing greater consumption in O_2 due to the metabolic effects of an anabolic implant. Hydrogen emissions followed a similar pattern to CH_4, with slight increases in IMP animals fed for 80 d, potentially indicating shifts in ruminal fermentation pathways. These findings are comparable to those reported by Vyas et al. (2018), where dietary modifications and additional growth technologies alongside monensin altered H_2 production without significantly affecting CH_4 yield. Methane yield as a percentage of GE intake remained consistent across treatments, aligning with previous reports for high concentrate finishing diets (McGeough et al., 2010). This suggests that the primary effect of the implant was on growth efficiency rather than methanogenesis per unit of energy intake.

Relative Profitability

Growth-promoting implants have been widely utilized in the feedlot industry due to their ability to enhance productivity, improve carcass characteristics, and reduce production costs. Their economic impact is primarily driven by increased ADG, improved G:F, and greater HCW, which collectively contribute to greater profitability for producers (USDA APHIS, 2013). The current study's Monte Carlo simulations further support these findings, demonstrating a clear financial advantage for implanted cattle, particularly across different DOF. The profitability distributions from the Monte Carlo simulations indicate that implanted cattle significantly outperform non-implanted counterparts in terms of economic returns. IMP animals fed for 52 d had a mean difference in profitability of $111.76 per head, while IMP animals fed for 80 d showed an even greater mean difference of $143.39 per head. This suggests that implants are particularly beneficial for lighter-weight cattle, likely due to their longer time on feed and greater G:F improvements. These findings align with previous research indicating that implants can increase ADG and improve G:F, leading to greater economic sustainability (Johnson et al., 2013; Parr et al., 2011a). Sensitivity analysis indicated that fat cattle prices account for over 99% of the variation in the model output, demonstrating that fluctuations in market cattle prices are the primary driver of the observed variability and suggest economic outcomes are influenced by fat cattle price dynamics. Additionally, the wider profitability distribution observed during 80 DOF could be explained by the greater variability seen in historical fat cattle prices during the month of October when the weight group was marketed.

From an environmental perspective, the improved G:F observed in implanted cattle translates to sustainability benefits by reducing total feed consumption per kg of gain (Stackhouse et al., 2013; Kayser et al., 2022). Despite these clear benefits, the use of implants remains limited in some markets due to consumer perception and regulatory restrictions. One of the main concerns among consumers is misconceptions regarding hormone residues in beef, which have contributed to some resistance toward implanted cattle (USDA APHIS, 2013). However, extensive research has confirmed that hormone levels in beef from implanted cattle remain well within safe limits and are negligible compared to naturally occurring hormone levels in other foods, such as soy and dairy products (Reinhardt, 2007; Johnson et al., 2013). Addressing these misconceptions is crucial to increasing acceptance of implants. From a social sustainability perspective, implants contribute to global food security by increasing beef production efficiency, thereby making high-quality protein more accessible and affordable (USDA APHIS, 2013; Johnson et al., 2013).

CONCLUSION

The findings of this study underscore the role of growth promoting implants in improving productivity in feedlot cattle, while contributing to the environmental and economic sustainability in the industry. Implanted animals experienced greater ADG and HCW, improved G:F, and greater economic profitability compared to non-implanted animals. These advantages could benefit the environmental impact of beef production by lowering CH_4 emissions intensity per unit of beef produced. This reduction is critical for sustainable intensification, where maximizing production efficiency can help meet growing global protein demands while minimizing environmental impact. This study highlights the multifaceted benefits and limitations of growth implants in beef production, demonstrating their potential to enhance production efficiency, reduce environmental impacts, and improve economic returns. Future research is needed to explore and expand upon the long-term implications of implant strategies on CH_4 mitigation, consumer acceptance, and sustainability metrics across diverse production systems. As the livestock industry continues to adapt to increasing demands for sustainable protein sources, integrating growth-enhancing technologies with environmentally conscious management practices can help meet both producer and consumer needs.

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Table 1. Diet and chemical compositions of the TMR diet and alfalfa pellets during the experimental periods for all animals

Ingredient	**Inclusion on DM basis, %**	
Steamflaked corn	65.0	
Corn silage	20.0	
DDGS	7.0	
PMS liquid supplement	4.0	
Combination pellet[1]	4.0	
Composition (% of DM)	**TMR**	**Alfalfa Pellets**
Dry matter, % as fed	66.5	95.4
Crude protein	13.7	17.7
Neutral detergent fiber	17.5	49.2
Acid detergent fiber	8.8	39.9
Non-fiber carbohydrates	61.3kg	16.1
Starch	53.8	1.1
Ether extract	3.1	2.3
Ash	4.5	14.7
Gross energy, MJ/kg DM	18.6	18.2

[1] Per veterinary feed directive, concentrations of Tylan (tylosin phosphate) and Rumensin (monensin) (Elanco Animal Health, Greenfield, IN), were fed at 9 mg/kg DM and 45 mg/kg DM, respectively.

Table 2. Source information and justifications for each commodity used in the Monte Carlo simulation

Item	Classification	Sub-Classification	Source	Time Period[1]	Geo Level[2]	Justification
Monthly Weighted Average Slaughter Cattle- Negotiated-Nebraska	Commodity	Fat Cattle	LMIC	2000-2023	State-Nebraska	Consistency with feeder data
Weekly Weighted Average Summary-Nebraska Auctions	Commodity	Feeder Cattle	LMIC	2000-2023	State-Nebraska	Historic data was representative of the starting weight range of these cattle
Corn Distillers Dried Grain 10%	Commodity	DDG	LMIC	2000-2023	State-Nebraska	Consistency with feeder data
Cash Prices #2 Yellow Corn	Commodity	Corn	LMIC	2000-2023	National-United States	Consistency with feeder data
Feed Prices	Commodity	Hay (Other)	LMIC	2000-2023	National-United States	Hay prices were used in conjunction with corn prices to estimate the price of silage using calculations from Carlson et al. (2021). Most granular data for hay that could be publicly acquired

[1] All historical prices were adjusted to 2023 value using PPI (FRED)

[2] Geological level that prices were obtained from.

Table 3. Performance and carcass characteristics of finishing feedlots steers treated with or without the use of growth implants and between weight groups

	Treatment		**Weight Group**			**P value**		
Item	**CON[1]**	**IMP[2]**	**HEAVY**	**LIGHT**	**SEM**	**Treatment**	**Weight Group**	**Treatment x Weight Group**
Performance parameters								
Number of steers	31	31	32	30				
Initial BW, kg	551	551	579	522	3.64	0.88	<0.0001	1.00
Final BW, kg	670	709	685	694	4.36	<0.0001	0.17	0.46
ADG, kg[3]	1.7	2.4	2.0	2.1	0.04	<0.0001	0.003	0.38
Final EQSBW[4], kg	435.3	398.3	427.6	405.9	0.81	<0.0001	<0.0001	0.39
Pellets, kg/d	0.3	0.4	0.4	0.3	0.02	0.46	0.01	0.49
TMR, kg/d	10.6	10.9	10.7	10.8	0.10	0.02	0.80	0.83
Total DMI, kg/d	10.9	11.3	11.1	11.1	0.11	0.01	0.87	0.83
Feed:Gain	6.4	4.8	5.8	5.4	0.17	<.0001	0.11	0.07
Gain:Feed	0.16	0.21	0.18	0.19	0.005	<0.0001	0.13	0.43
Carcass characteristics								
HCW, kg	386.5	414.8	400.4	400.9	3.06	<0.0001	0.93	0.52

Fat thickness, cm	1.5	1.4	1.4	1.6	0.03	0.30	0.16	0.57
REA, cm^2	85.2	92.2	87.6	89.8	1.47	0.001	0.29	0.68
Marbling score[5]	7.4	6.9	7.4	6.9	0.22	0.17	0.13	0.98
Value per 100 kg, $	671.57	669.72	674.42	666.90	1.45	0.68	0.10	0.99
Carcass value, $	2597.30	2778.92	2702.20	2674.01	29.38	<0.0001	0.49	0.66
USDA yield grade	3.4	3.2	3.3	3.3	0.11	0.17	0.82	0.81
Empty fat body %[6]	32.2	31.6	31.7	32.1	0.36	0.30	0.49	0.91
Dressing %	60.0	60.7	60.5	60.2	0.26	0.054	0.37	0.79

[1] CON = no growth implant

[2] IMP = implanted with Component TE200

[3] unshrunk ADG

[4] EQSBW= Equivalent shrunk body weight, 45 kg adjustment for IMP animals

[5] BIF (2022)

[5] Guiroy et al (2001)

Table 4. Feeding behavior of finishing feedlots steers treated with or without the use of growth implants and between weight groups

	Treatment		Weight Group			P value		
Item	**CON[1]**	**IMP[2]**	**HEAVY**	**LIGHT**	**SEM**	**Treatment**	**Weight Group**	**Treatment × Weight Group**
Meal visit, (visits/d)	6.5	6.4	6.6	6.3	0.10	0.38	0.049	0.97
Session size, (g DM/visit)	1703.5	1778.2	1722.8	1758.9	30.1	0.08	0.40	0.81
Session length, (min/visit)	12.5	12.5	12.6	12.3	0.38	0.84	0.58	0.30
Session interval, (min)	260.9	266.0	271.4	255.6	4.2	0.38	0.009	0.98
Intake rate, (g DM/min)	138.3	146.9	139.5	145.7	3.7	0.1	0.24	0.30

[1] CON = no growth implant

[2] IMP = implanted with Component TE200

*meal criteria for variables =

Table 5. Gas fluxes and respiratory quotient of finishing feedlots steers treated with or without the use of growth implants within each weight group

	HEAVY[1]		**LIGHT**[1]			**P value**		
Item	**CON**[2]	**IMP**[3]	**CON**	**IMP**	**SEM**	**Treatment**	**Weight Group**	**Treatment × Weight Group**
GF visits, n	83	93	100	110	8.71	0.25	0.06	0.96
CH_4, g/d	184^{ab}	182^{ab}	177^{a}	199^{b}	5.72	0.06	0.35	0.04
CO_2, g/d	10321^{c}	10455^{bc}	10766^{ab}	11036^{a}	134.10	0.10	0.0003	0.57
O_2, g/d[4]	7036^{b}	7334^{b}	8061^{a}	8186^{a}	87.70	0.01	<0.0001	0.28
H_2, g/d	1.2^{ab}	1.3^{a}	1.0^{b}	1.4^{a}	0.08	0.003	0.33	0.24
RQ[5]	1.05^{a}	1.05^{a}	0.97^{b}	0.98^{b}	0.01	0.76	<0.0001	0.53
CH_4 as a % GE intake	5.1	5.2	5.0	5.3	0.17	0.33	0.95	0.46
CH_4 Yield, g CH_4/kg DMI	16.9	16.4	16.3	17.6	0.55	0.52	0.60	0.09
CH_4 Intensity, g CH_4/kg ADG	106.7^{a}	74.9^{b}	102.6^{a}	90.4^{ab}	6.68	0.0001	0.54	0.07

[1] Animal weight group

[2] CON = no growth implant

[3] IMP = implanted with Component TE200

[4] consumption of O_2

[5] RQ = Respiratory quotient; g/d CO_2/ g/d O_2

[a,b,c] = Within a row, means with different superscripts differ, $P < 0.05$

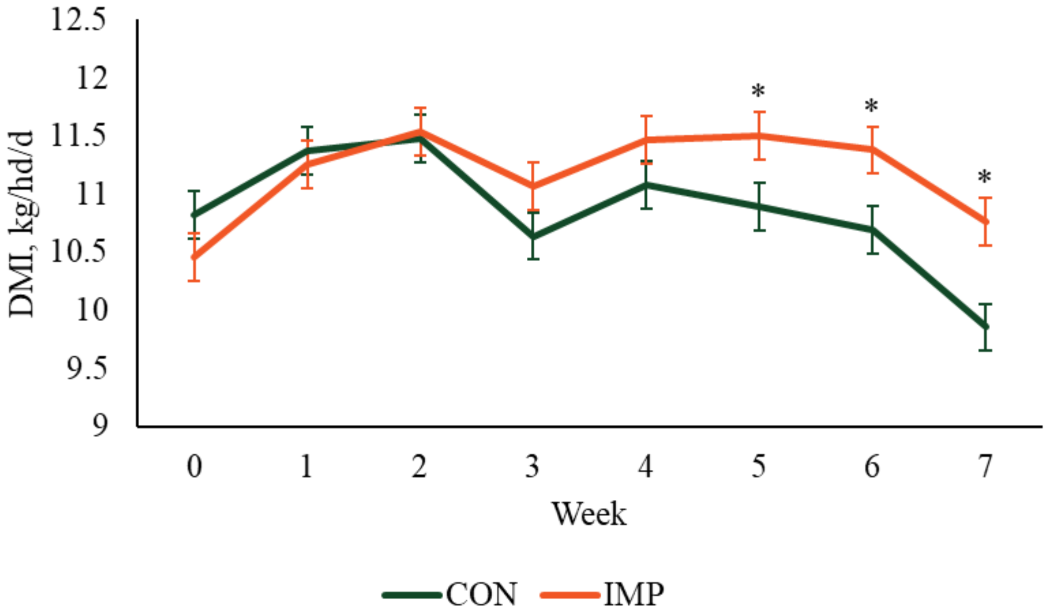

Figure 1. HEAVY weight group's weekly mean DMI of IMP (n=16) and CON (n=16) finishing steers. *$P < 0.05$

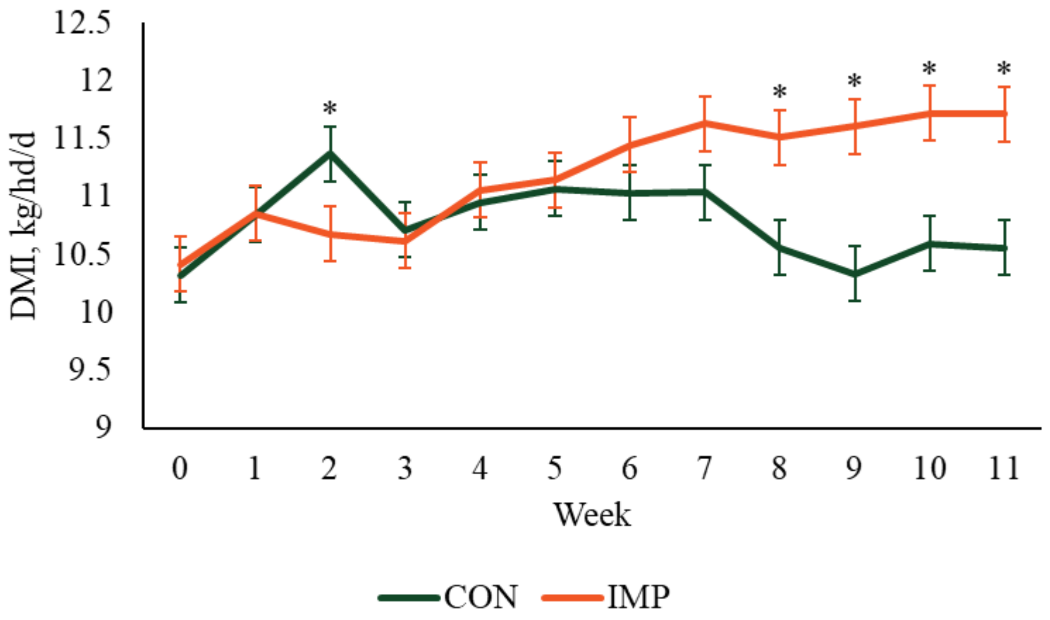

Figure 2. LIGHT weight group's weekly mean DMI of IMP (n=15) and CON (n=15) finishing steers. *$P < 0.05$

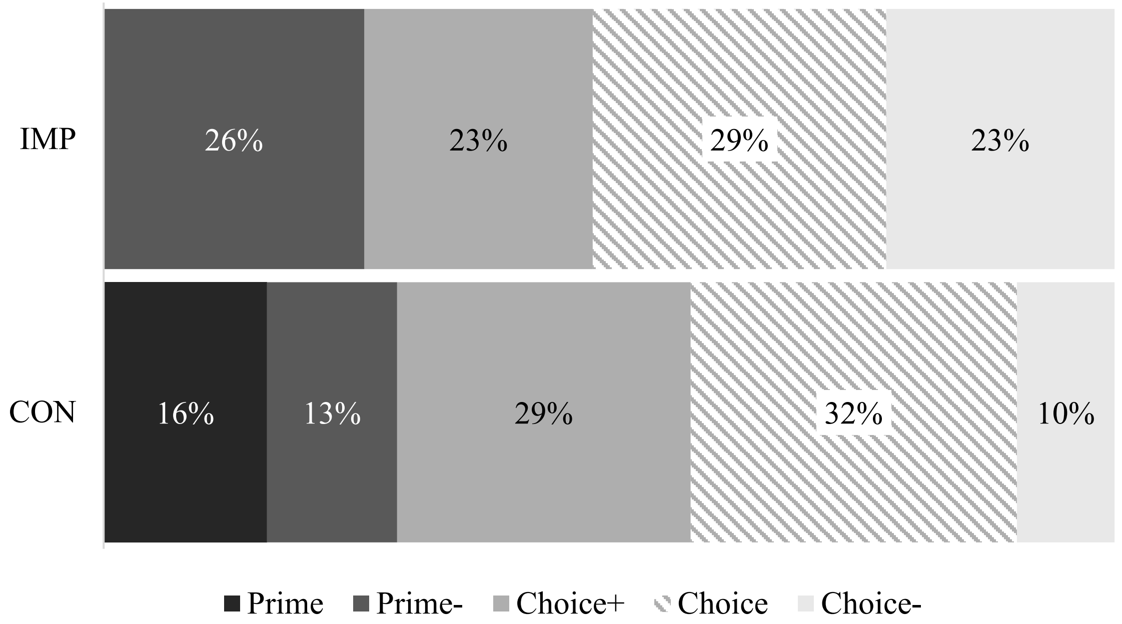

Figure 3. Percentage of animals from each treatment (IMP or CON) who received a USDA quality grade of Prime, Prime, Choice+, Choice, or Choice- at the time of slaughter. *P = 0.04*

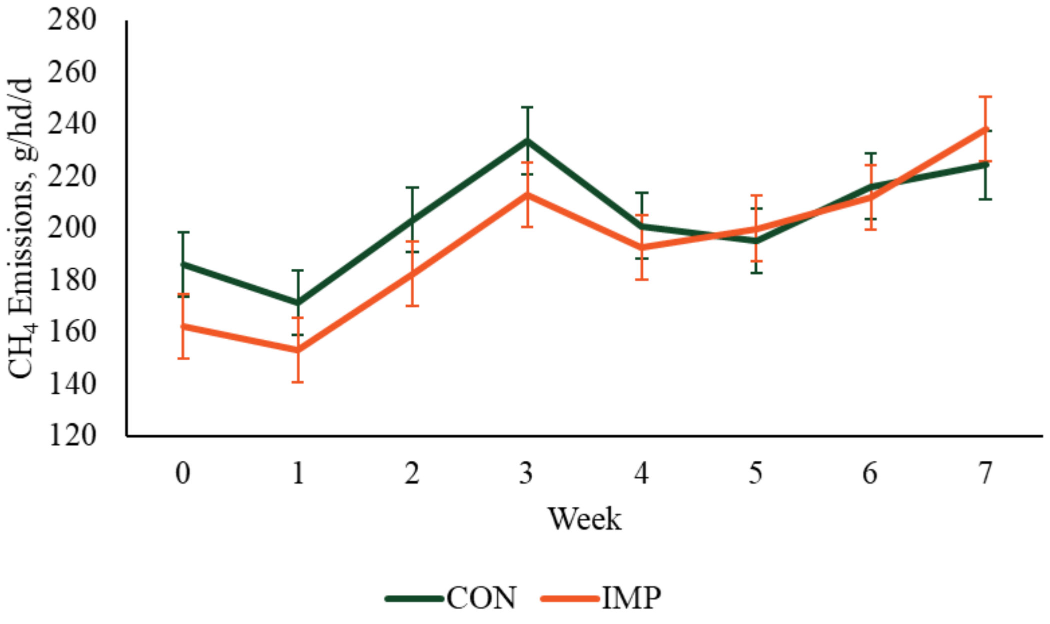

Figure 4. HEAVY weight group's weekly mean CH4 emissions of IMP (n=16) and CON (n=16) finishing steers. *$P < 0.05$

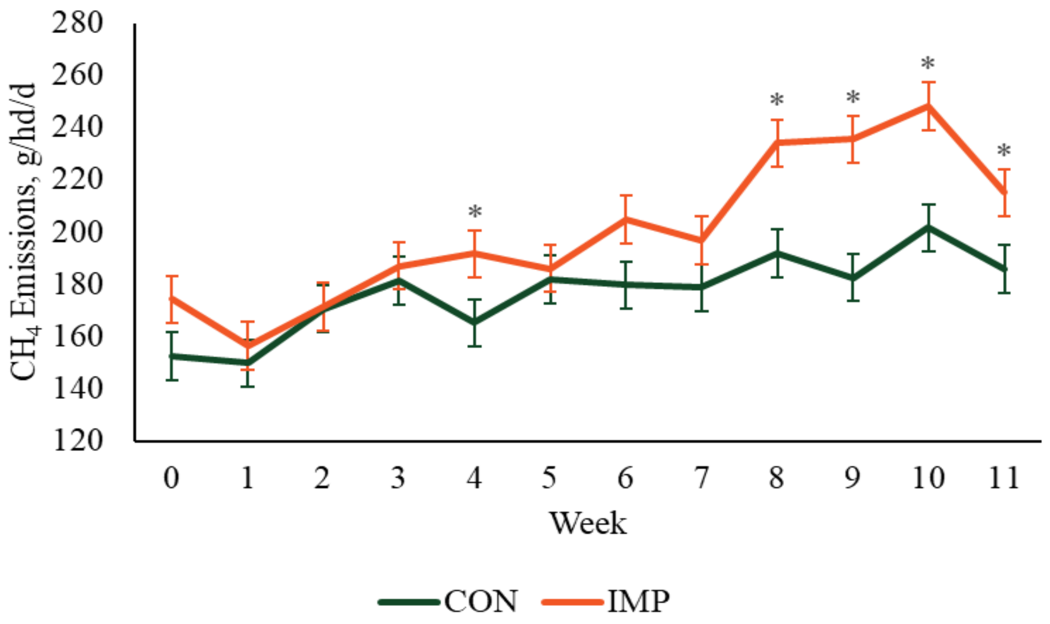

Figure 5. LIGHT weight group’s weekly mean CH4 emissions of IMP (n=15) and CON (n=15) finishing steers. *$P < 0.05$

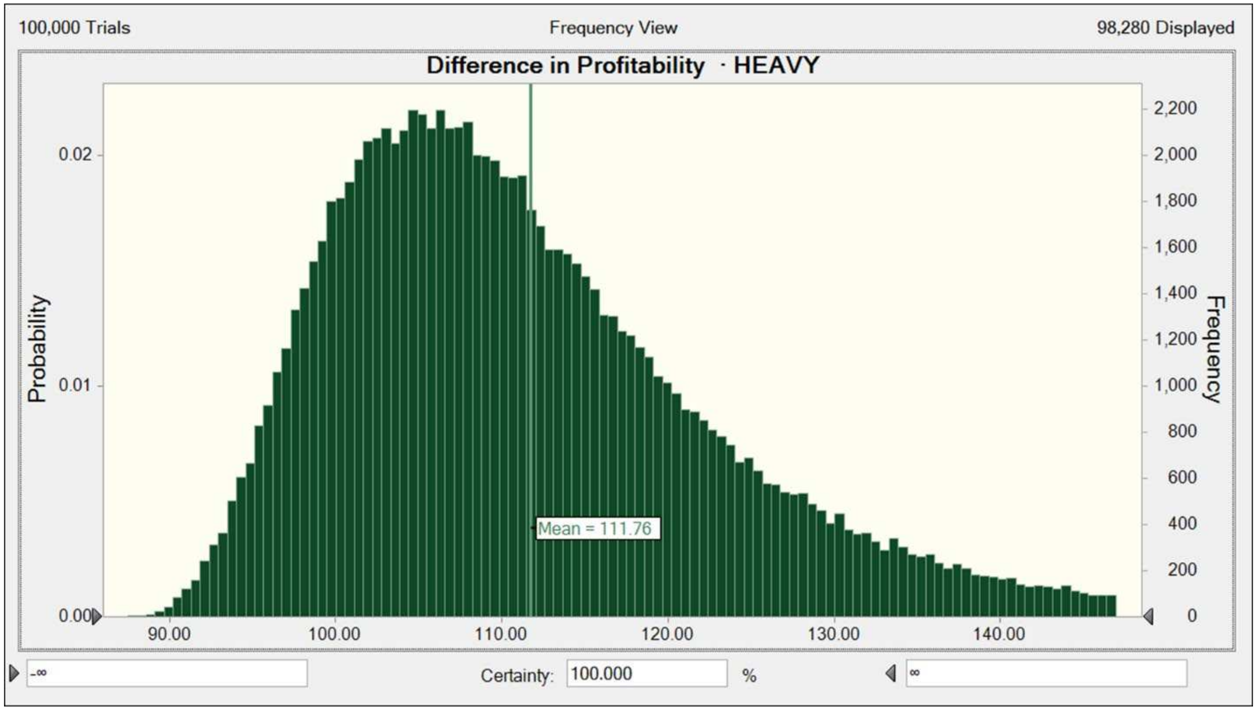

Figure 6. Monte Carlo simulation results of the difference in relative profitability between IMP and CON animals in the HEAVY weight group

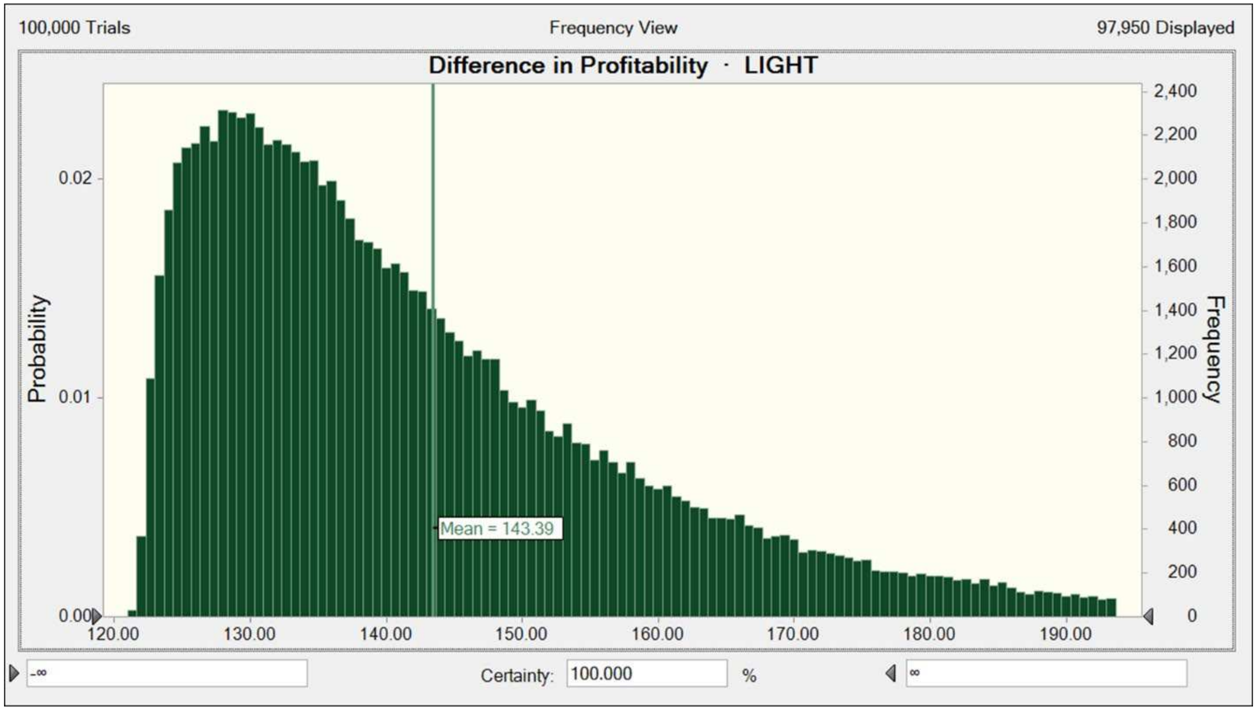

Figure 7. Monte Carlo simulation results of the difference in relative profitability between IMP and CON animals in the LIGHT weight group

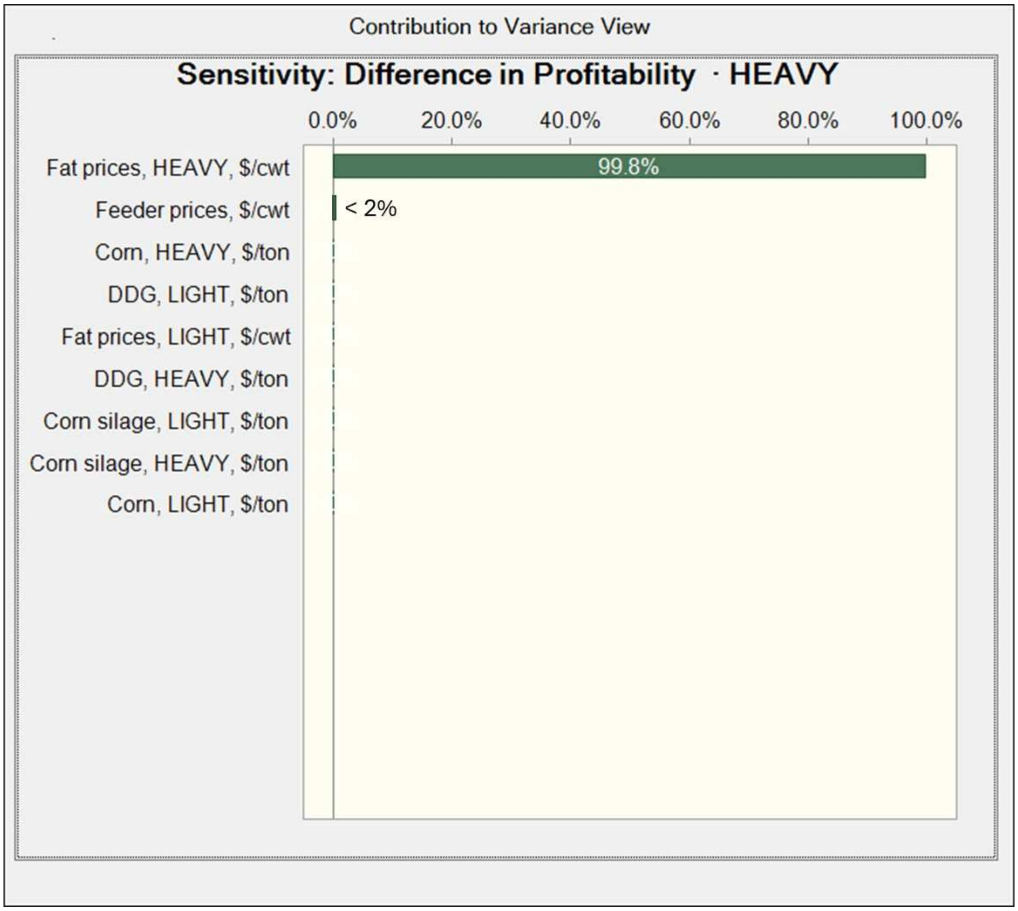

Figure 8. Sensitivity chart representing the contribution of variance to the difference in relative profitability between IMP and CON animals within the HEAVY weight group

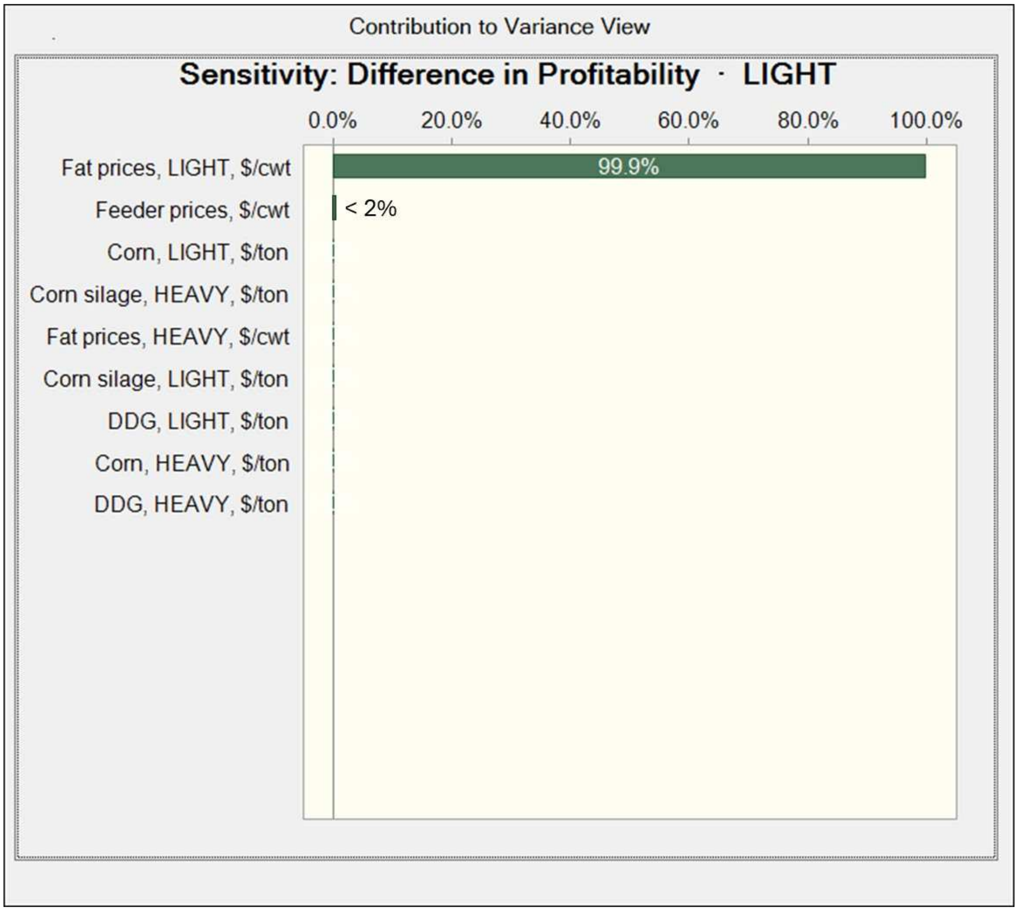

Figure 9. Sensitivity chart representing the contribution of variance to the difference in relative profitability between IMP and CON animals within the LIGHT weight group