

Project Summary

Physiological Mechanisms Regulating the Coordinated Development of Marbling and Muscle in Stocker Cattle

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Background

Marbling, or intramuscular fat, is the primary determinant of quality grades for beef and has a strong relationship with palatability such that improvements in marbling development could enhance consumer demand for beef. Marbling deposition is a lifetime event and pre-feedlot nutrition has a significant impact on marbling deposition, indicating that the stocker phase of production is critical to improving marbling development. In addition, 76% of the yearly calf crop enters a backgrounding/stocker program prior to finishing; thus, there is tremendous opportunity to improve carcass quality attributes by influencing adipose tissue development during the backgrounding/stocker phase of production.

One of the primary objectives of the backgrounding/stocker phase is to enhance muscle development of young calves. Marbling deposits develop in close association with muscle fibers, and marbling score is related to measures of energy metabolism and vascular development in *Longissimus* muscle. Proliferation and differentiation of satellite cells during postnatal muscle growth is regulated by many growth factors such as insulin-like growth factor-I and myostatin, which influence adipocyte differentiation. Thus, muscle growth and metabolism could have a significant influence on marbling development, but little research has evaluated the physiological mechanisms regulating muscle and marbling development.

Objectives

The central hypothesis was that stocker cattle production systems can be manipulated to enhance marbling development through changes in intercellular signaling between muscle and marbling, promoting adipocyte differentiation. The objective of this project was to determine muscle growth and adipose tissue development, changes in gene expression profiles in *Longissimus* muscle and adipose tissue, and muscle fiber type composition in cattle from different stocker production systems.

Methodology

Fall-weaned Angus steer calves were assigned to one of four stocker systems. Stocker systems included: 1) grazing winter wheat pasture at a low stocking density to produce a high rate of gain (**HGW**); 2) grazing winter wheat pasture at a high stocking density to produce a moderate rate of gain (**LGW**); 3) grazing dormant winter native range supplemented with corn/cottonseed meal at followed by short season grazing on summer pasture (**CORN**); and 4) grazing dormant winter native range supplemented with cottonseed meal followed by season-long grazing on summer pasture (**CON**). Steers were not implanted during the stocker phase. Steers continued grazing pasture until the average body weight (BW) of the treatment group reached a common BW of approximately 375 kg, at which time a subset of steers (four steers/treatment) were harvested and remaining steers were transitioned to the finishing phase. During the finishing phase, steers were fed common finishing diet until harvest at a common fat thickness of 1.27 cm. During finishing, steers were implanted with Revalor-S (120 mg trenbolone acetate, 24 mg estradiol). At the end of the finishing phase, four steers per treatment were harvested at the Oklahoma State University to collect final harvest tissue samples and measurements, and the remaining steers were harvested at a commercial abattoir. At the intermediate and final harvest, carcass characteristics were measured, and samples of longissimus muscle, subcutaneous fat over the 12th-rib, and kidney fat collected.

A sample of intact muscle fibers from *Longissimus* muscle was cryopreserved and used to determine fiber type composition, capillary density, fiber area, and nuclei density. The remaining muscle sample was used to measure gene expression of muscle and marbling by dissecting marbling from *Longissimus* muscle samples. Genes related to recruitment of new adipocytes and lipid synthesis were measured in marbling, rib fat, and kidney fat. Genes related to energy metabolism and vascular development were measured in *Longissimus* muscle. Gene expression of growth factors was measured in muscle and expression of growth factor receptors was measured in marbling, rib fat, and kidney fat.

Findings

During the stocker phase, average daily gain (ADG) was greatest for HGW steers, followed by LGW steers, then CORN steers, with CON steers having the lowest ADG. At intermediate harvest, HGW steers had greater 12th rib fat thickness, kidney, pelvic, and heart fat percentage, and marbling score compared with CON steers suggesting that HGW steers had increased intramuscular fat development. However, at final harvest, CON steers tended ($P = 0.12$) to have greater marbling score, lower ($P = 0.14$) 12th rib fat thickness, and significantly lower ($P < 0.05$) yield grade compared to HGW steers. Additionally, ribeye area was smaller for HGW steers than the other treatments at final harvest.

Expression of genes involved in recruitment of new adipocytes in marbling, rib fat, and kidney fat is shown in Figure 1. Expression of these genes was greater in rib fat for HGW steers, but not marbling compared with CON steers. These results indicate that a very rapid rate of gain such as with HGW steers increases recruitment of new adipocytes in rib fat, but not in marbling even though marbling score was greater at intermediate harvest. Thus, rib fat is primed for a very rapid increase in fat deposition during the finishing phase, which causes HGW steers to reach the desired rib fat thickness before muscle growth is maximized.

Interestingly, expression of genes related to energy metabolism and vascular development in *Longissimus* muscle were positively correlated with PPAR γ expression in marbling, but not in rib fat or kidney fat (Figure 2). The transcription factor PPAR γ is the central regulator in conversion of preadipocytes to mature adipocytes and lipid filling. The fact that these genes are correlated with PPAR γ in marbling, but not other fat depots indicates that muscle metabolism and marbling development are coordinated, whereas, muscle metabolism has lesser influence on rib and kidney fat development.

Two of the primary growth factors regulating muscle growth are myostatin and insulin-like growth factor-1 (IGF1). In regard to fat development, insulin-like growth factor-1 is a strong stimulator of preadipocyte conversion to mature adipocytes, whereas, myostatin has been shown to inhibit conversion of preadipocytes to mature adipocytes. In this study, LGW steers had lower expression of myostatin in *Longissimus* muscle than CON and HGW steers (Figure 3), which corresponds to LGW steers having the greatest marbling score at intermediate harvest. In contrast, CORN and HGW steers had greater expression of IGF1 compared with CON steers. Expression of IGF1 does not correspond to differences in marbling score, but may have an important role in regulating marbling versus rib fat development. Expression of IGF1 in longissimus muscle was negatively correlated with expression of IGF1 receptor in marbling, but positively correlated in rib fat. In addition, ADG during the stocker phase was positively correlated ($r = 0.75$) with expression of IGF1 receptor in rib fat, but not correlated with expression in marbling. These results indicate that as growth rate increased expression of IGF1 increased in *Longissimus* muscle, which coincided with

an increase in expression of IGF1 receptor in rib fat; however, the increase in IGF1 in *Longissimus* muscle was related to a decrease in IGF1 receptor in marbling even though IGF1 receptor expression in marbling was not correlated with growth rate.

At the intermediate harvest, LGW steers had greater muscle fiber area and nuclei density than the other treatments, which corresponds to the numerically larger ribeye area for LGW steers. However, muscle fiber type composition, or satellite cell and capillary density, were not influenced by treatment. At final harvest, CON steers tended ($P = 0.12$) to have greater percentage of Type 1 and lower percentage of Type 2 muscle fibers compared with the other treatments. Type 1 fibers are more oxidative fibers that use fat as a primary energy source, which would be expected to promote development of marbling deposits in close proximity. Thus, a larger relative proportion of Type 1 fibers should result in greater number of marbling deposits. In this study, CON steers tended ($P = 0.12$) to have greater marbling score at final harvest than the other treatments.

At final harvest, CON steers had numerically greater capillary density compared to the other treatments, which corresponds to the trend for greater marbling score in CON steers. Marbling develops alongside muscle fibers surrounding blood vessels. An increase in the capillary network in muscle would be expected to promote development of marbling deposits by increasing the blood supply to sustain new adipocytes.

In conclusion, slower rates of gain such as with the CON steers can slow development of rib fat without impacting marbling allowing marbling to fully develop before the animal reaches the desired rib fat thickness. Moreover, slower rates of gain may change muscle characteristics and metabolism to promote development of marbling deposits later in the finishing phase. Collectively, slower rates of gain may change the metabolism of muscle and rib fat to improve marbling score relative to rib fat thickness in beef cattle.

Implications

Marbling is an important attribute of beef that influences palatability and consumer demand. However, methods to improve marbling relative to other fat depots have been difficult to develop. One of the possible reasons for this may be the influence the muscle environment has on marbling, but not on other fat depots. Results from this project indicate that growth and development of muscle can influence marbling development, and that intercellular signaling mechanisms between muscle and fat differ between marbling and rib fat. These results suggest that a new possibility exists to manipulate marbling relative to other fat depots through changes in muscle metabolism. In addition, results demonstrate that cattle from season-long grazing production systems with low rates of gain during winter months will grade similarly if not better than cattle grazing winter wheat pasture when fed to similar rib fat thickness. Thus, these production systems should not be viewed as having a negative effect on carcass quality. However, extensive use of season-long grazing production systems to improve marbling relative to other fat depots is not practical for the beef industry. Further research is needed to better understand the mechanisms coordinating the development of muscle and marbling to allow development of management strategies to enhance marbling.

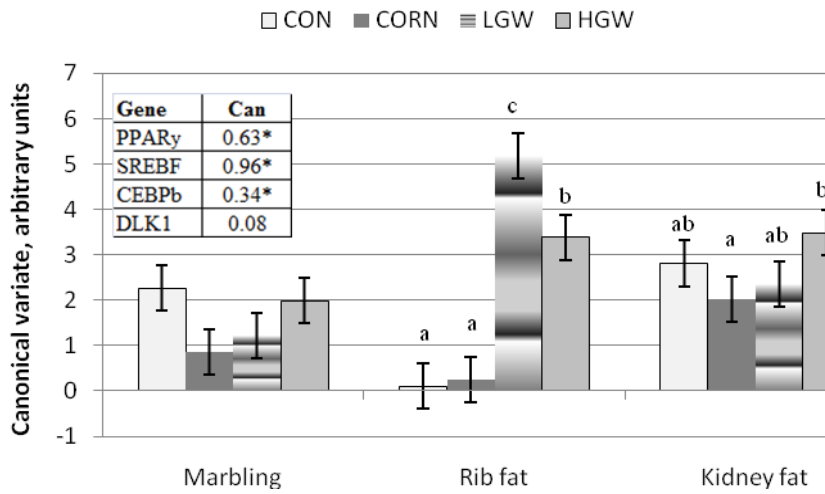


Figure 1. Expression of transcription factors involved in recruitment of new adipocytes in fat depots of stocker cattle from different production systems at intermediate harvest. CON = season-long grazing system; CORN = short-season grazing system; LGW = low-gain wheat pasture system; HGW = high-gain wheat pasture system. ^{abc}Bars within fat depot lacking a common superscript letter differ ($P < 0.05$). Pearson correlation coefficients of adipogenic genes with the canonical variate (Can) are displayed in the inset table. PPAR γ = peroxisome proliferator activated receptor gamma; SREBF = sterol regulatory element binding factor; CEBP β = CCAAT/enhancer binding protein beta; DLK1 = delta-like 1 homolog (preadipocyte factor-1). * $P < 0.05$.

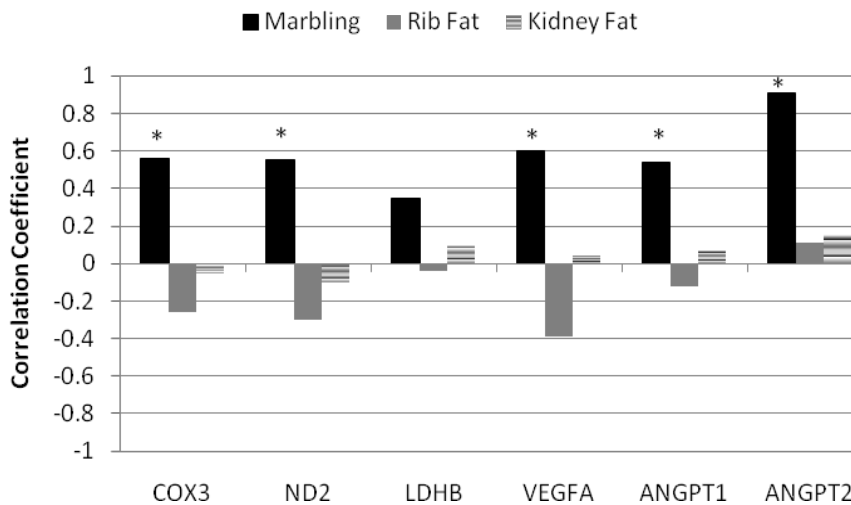


Figure 2. Pearson correlations between expression of energy metabolism and vascular development genes in longissimus muscle and peroxisome proliferator activated receptor gamma (PPAR γ) expression in marbling, rib fat, and kidney fat at intermediate harvest. Energy metabolism genes: COX3 = cytochrome c oxidase subunit III; ND2 = NADH dehydrogenase subunit II; LDHB = lactate dehydrogenase B. Vascular development genes: VEGFA = vascular endothelial growth factor A; ANGPT1 = angiotensin 1; ANGPT2 = angiotensin 2. * $P < 0.05$.

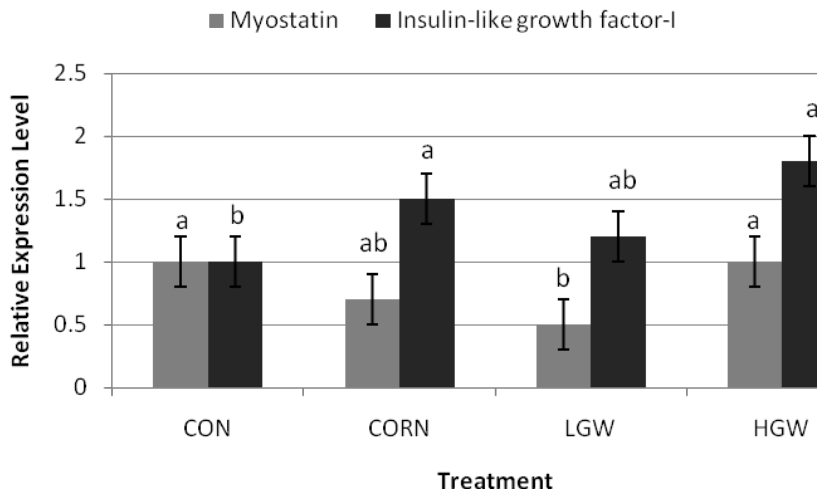


Figure 3. Expression of the growth factors myostatin and insulin-like growth factor-I in longissimus muscle of steers from different production systems at intermediate harvest. CON = season-long grazing system; CORN = short-season grazing system; LGW = low-gain wheat pasture system; HGW = high-gain wheat pasture system. ^{ab}Bars within growth factor lacking a common superscript letter differ ($P < 0.05$).

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