Assessing the sustainability of U.S. beef production: western grass-fed beef production systems and rancher willingness to adopt best management practices

By

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DISSERTATION

Submitted in partial satisfaction of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

Animal Biology

in the

OFFICE OF GRADUATE STUDIES

of the

UNIVERSITY OF CALIFORNIA

DAVIS

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2021

ABSTRACT

Grass-fed beef sales are expected to increase globally by 40 billion U.S. dollars by the year 2025. Increased demand for grass-fed beef raises many producers' and consumers' concerns regarding feasibility, product quality, economic viability, and environmental impacts that have gone unanswered. Therefore, using a holistic approach, we investigated the performance, carcass quality, financial outcomes, environmental impacts, and fatty acid profile of four grass-fed and grain-fed beef systems in California. The treatments included: 1) steers stocked on pasture and feedyard finished for 128 days (CON); 2) steers grass-fed for 20 months (GF20); 3) steers grass-fed for 20 months with a 45-day grain finish (GR45); and 4) steers grass-fed for 25 months (GF25). Final body weight, dressing percentage, and carcass quality varied significantly across all treatments. Animal performance directly affected economic and environmental footprints with grass-fed systems resulting in higher carbon and breakeven than grain-fed treatments. Fatty-acid profiles differed significantly from all treatments with CON systems higher in monounsaturated fatty acids and saturated fatted acids. No difference in total polyunsaturated fatty acids were observed between treatments, but grass-fed treatments where higher in omega-3 fatty acids. The results from these studies indicate that varying grass-fed beef production systems in the western U.S. yield significant differences in both animal performance, carcass quality, fatty acid profile and result in varying environmental and economic impacts. However, before sustainability practices can be achieved they must first be adopted by producers. To gauge insight into rancher's interest and motivations for joining a sustainability program we performed a multistate survey investigating best management practices related to the Beef Quality Assurance (BQA) program. The BQA program is one of the most successful rancher educational program and as such, a great case study to learn about why ranchers would chose to volunteer for an educational program. The survey indicated that that those that joined the BQA program were more likely to perform BQA best management practices, however BQA involvement did not affect a rancher’s willingness to join a sustainability program. Overall, this survey provided an overview for why a rancher would or would not join a BQA program and provided insight on current BQA practices.

ACKNOWLEDGEMENTS

Thank you to my professor at U.C. Davis. Dr. Oltjen without your belief in me and dedication to my teachings I would not be here today. Your encouragement, energy and teaching gave me the time and knowledge needed to find my place. Your mentorship will always mean the world to me.

To my awesome beef best friends whether it was at the feedlot, a conference, or on the couch watching TV after a Friday night Trader Joe’s run, you were always there for me. I am so privileged to know you beautiful, intelligent women and I cannot wait to see where the world takes you. I love you all so much.

I would especially like to thank the California beef community for taking the time to teach me about California beef and what it takes to be a rancher. Your teachings and friendship have made me a stronger scientist and better person.

To the man that that was there for me during the start and the finish of this academic journey, thank you for your love, support, and unshakable belief in my success. I can’t wait to start the next phase of our post-graduate lives together.

Finally, thank you to all the scientists who supported me on this journey. Mom and Dad, if not for your love, nonstop encouragement, and scientific expertise I would not have been able to follow my passion in agricultural sustainability. I will always value you as parents, mentors, and scientists.

DEDICATION

I dedicate this dissertation to the scientists that gave me everything, Dr. Carole Klopatek and Dr. Jeffery Klopatek. AKA, Mom and Dad.

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Beef cattle systems: from grass-fed beef to rancher motivations

A literature review of United States grass-fed beef production and ranchers motivations for adopting best management practices

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Abstract

Based on the literature review, the sustainability of a beef system depends on the integrity of three fundamental principles: product quality and acceptability, land-animal synergy, and economic and rancher feasibility. If one of these three should fail, system sustainability is not achieved. With increasing concerns regarding climate change and human health, consumers now perceive grass-fed beef systems as a sustainable alternative to conventional beef systems. Despite consumer perceptions, the sustainability of beef systems often results in trade-offs rather than absolutes. For example, consumers were willing to pay more for grass-fed beef, yet animals from these systems resulted in substantially lower quality grades, dressing percentages, and harvest weights compared to conventional beef systems. This decrease in grass-fed beef animal performance was shown to negatively affect land-animal synergy with grass-fed systems having higher environmental footprints than grain-fed systems. Although, grass-fed systems resulted in higher ecological footprints, grass-fed beef was found to be higher in omega-3 and C18:1 t11 than conventional beef. In turn, grain-fed systems were higher in saturated fatty acids but also higher in heart healthy monounsaturated fatty acids. Finally, sustainability trade-offs were also observed in the literature in terms of rancher feasibility and conservation practices. For example, surveyed ranchers stated they were willing to accept lower income if they were able to maintain the ranching lifestyle thus maintaining open spaces that could be beneficial for ecosystem health. However, willingness to adopt a new conservation program often depended on financial incentives. Overall, this literature review highlighted the issues with achieving sustainability across multiple beef systems and rancher communities. With continual interest in food sustainability across the country, it is imperative that we answer these beef production questions so that producers, consumers, legislators, and stakeholders across the beef supply chain can make informed production decisions.

Introduction

In the last decade, concern over food animal sustainability has led to a paradigm shift in consumer spending (McCluskey, 2015). Consumers, who once based their food purchasing decisions primarily on taste and price, are now taking into account additional factors such as environmental sustainability, animal welfare, and human health (McCluskey, 2015, Xue et al., 2010). With increasing concerns over conventional beef's environmental impacts, grass-fed beef is now viewed by many consumers as the more sustainable and healthier alternative (McCluskey, 2015; McCluskey et al., 2015; Xue et al., 2010). This evolving consumer ideology has resulted in a steady increase in demand for grass-fed beef, with a 25% to 30% annual growth rate, totaling $272 million in revenue in 2017 (Nielsen Data, 2018). In order to meet these demands many ranchers have begun to utilize a grass-fed beef option into their current production systems. Conversely, unlike conventional beef, grass-fed production systems can vary significantly depending on region and resource availability (Berthiaume et al., 2006; Duckett et al., 2013; Scaglia et al., 2012). With such variation in grass-fed beef systems, grass-fed beef performance, fatty acid profile, and environmental footprints are currently not well understood. Therefore obtaining grass-fed beef production and meat quality data is essential for future environmental and human health policy decisions involving beef cattle production practices.

To ensure the efficacy of these beef cattle policies and practices they need to be adopted by ranchers. Within the supply chain, cow-calf operations, at over 725 thousand strong (USDA-NASS, 2021), are the backbone of the beef industry. Their support, understanding, and adoption of sustainability practices is essential for the success of any sustainability or best management program. Therefore, the purpose of this interdisciplinary literature review was twofold. The first objective was to evaluate current grass-finished beef literature to determine differences in grass-fed beef performance, fatty acid profile and sustainability. The second objective was to evaluate current ranching perspectives and motivations for adoption of best management practices or programs. Grass-fed beef papers were selected on the criteria that cattle within the studies were *Bos Taurus*, raised in either Canada or Mexico, and were fed 100% forage diets throughout their lifetime. Papers selected for the rancher motivation section of this literature included only studies conducted with farmers or ranchers living in the United States or Canada.

Part 1: Grass-fed Beef Performance

Grass-fed beef vs. Conventional beef Systems

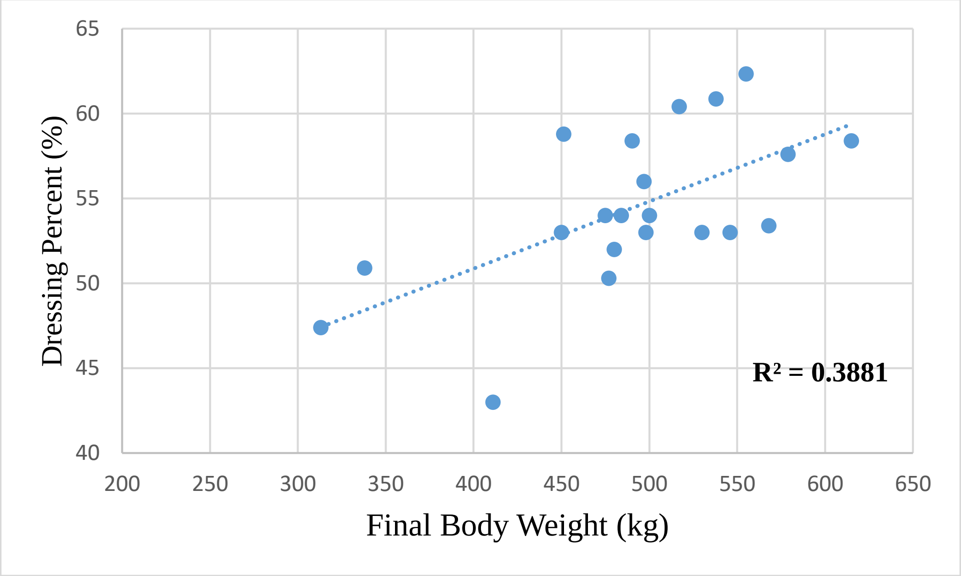
In conventional beef production systems, performance characteristics [i.e. final body weights (FBW; weight at time of harvest), dressing percentage (DP), quality grades, and hot carcass weights (HCW)] are relatively standardized across the production system (Boykin et al., 2017). According to the most recent beef quality audit, 70% of cattle graded choice and HCWs averaged 613 kg (Boykin et al., 2017). Cattle DP in the U.S. averaged 62% (USDA-ERS, 2019, Boykin et al., 2017). This product quality and consistency can be attributed to genetics, system logistics, and nutrition. Although there are managerial nuances between individual operations, the lifecycles of beef cattle raised conventionally are similar across the industry (Capper, 2012; Asem-Hiablie et al., 2019). Typically, after weaning, at 6 to 7 months of age, cattle are stocked on pasture or backgrounded for 4-5 months before being transferred to feedyards. While at the feedyards, animals are finished on a high starch diet, typically consisting of processed corn. In contrast, grass-fed beef lifecycles differ substantially in age of harvest, logistics and diet composition, leading to large variabilities in animal performance and product quality (Schmidt et al., 2013; Scaglia et al., 2012; Roberts et al., 2014). Specifically, FBW, DP and HCW can vary depending on forage type, region of production, and management strategies (Berthiaume et al., 2006; Duckett et al., 2013; Scaglia et al., 2012). To comprehensively evaluate grass-fed beef performance and meat quality over 15 grass-fed beef trials were reviewed and compared. Animals documented in these trials consisted of *Bos taurus* breeds, primarily Angus, with all animals raised and harvested within the U.S. or Canada (Table 1).

Animal Performance

When comparing animal performance, FBW across all studies, excluding the large framed Simmentals study by Steinburg et al. (2009), ranged from 338 kg to 554 kg with an average harvest weight of 528 kg (Table 1). Based on the average weight in these studies grass-fed beef FBW was approximately 85 kg less than conventional beef harvest weights (USDA-ERS, 2012). Dressing percentages across the studies ranged from 43-62%, averaging 54%. As expected, DP was positively correlated with FBW (British breeds only, R=0.38; Figure 1). However, when DP was compared to HCW, a higher correlation was observed (British breeds only, R=0.53; Figure 2). The lower correlation in DP to FBW may be due to the increased variations in gut fill and visceral mass between animals within the studies. Cruz et al. (2013) determined that grass-fed steers resulted in heavier and more varied rumen weights compared to conventionally raised steers.

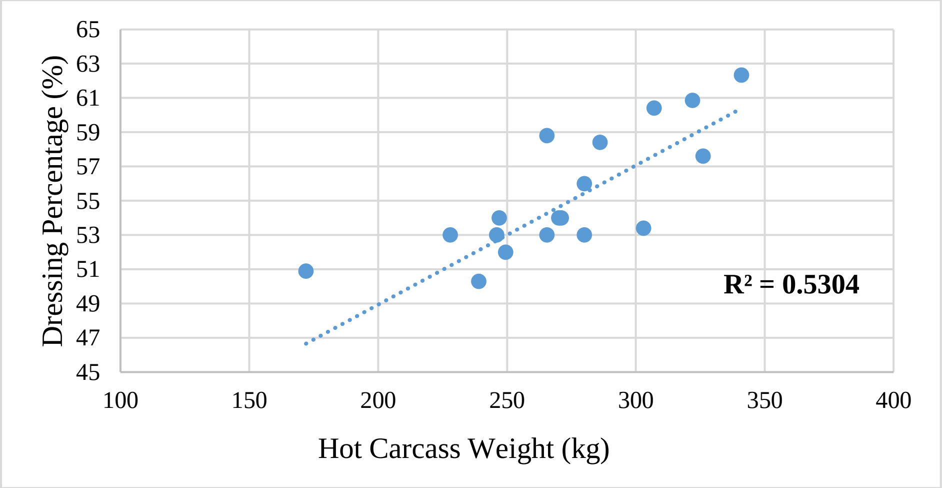
Overall, grass-fed DP were lower than the industry average of 62% (Boykin et al., 2017). The lower DP may be directly related to diet. Both digestibility and passage rates of high fiber diets are slower than concentrates diets which may result in higher gut fills at time of harvest for grass-fed cattle, even with adequate feed withdrawal periods (Demment and Van Soest, 1985). Thereby more fibrous diets with slower rates of digestibility and passage may result in higher weights at times of harvest compared to grass-fed diets higher in digestibility, resulting in a depressed DP.

Figure 1: Dressing percentage vs. final body weight in grass fed British breed steers*



*Based on the 15 studies compared in the literature review.

Figure 2: Dressing percentage vs. hot carcass weight in grass-fed steers*



*Based on the 15 studies compared in the literature review.

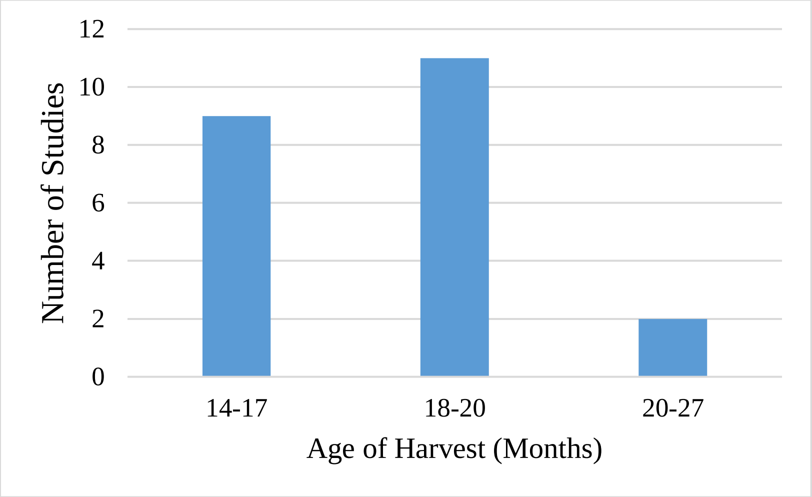
Growth Technologies

For the majority of grass-fed programs, the use of either an ionophore or implant is disallowed. However, substantial research has indicated that the use of these technologies significantly improves animal performance (Duckett et al., 200, Peel, 2003, Thompson et al., 2016). In order to improve stocker cattle and feedlot performance, anabolic steroids, or implants, have been used by producers for decades. Thus far, research has demonstrated the efficacy of anabolic steroids on stocker cattle with an increase in average daily gain (ADG) from 6 to 20% (Duckett et al., 2009, Peel, 2003). Ionophores, which are non-human medically important antimicrobials, are known to increase cattle performance in the feedlot by significantly increasing gain to feed and average daily gain (Thompson et al., 2016). Although many grass-fed certification programs disallow the use of implants or ionophores, there are some pasture raised and grass-finished programs that allow for the use of growth promoting technologies. Therefore, understanding the effect of growth technologies on grass-finished beef performance is critical from both an economic and beef quality prospective. In one study performed in Kapuskasing, Canada, Angus cattle were randomly assigned to either grass-silage only or grass-silage with growth promoters (Berthiaume et al., 2006). Animals fed a diet consisting of only corn-silage finished at a weight of 451.2 kg with a dressing percentage of 58.8%. Cattle fed an identical diet with the inclusion of an ionophore gained 18 kg more than the grass-silage only group and 6.8-22.3 more kg more than the grain finished groups fed without an ionophore. Dressing percentage for both the grass-silage fed cattle averaged 58% which was only 1% less than the grain finished treatments and 3% less than the US conventional beef average (USDA-ERS, 2019). Although several studies have shown that the use of ionophores can reduce marbling, negatively effecting quality grade (Herschler et al., 1995; Roeber et al., 2000), this study did not show any deleterious effects of ionophores on quality grade or meat quality. Overall, the use of ionophores and other grow promoting technologies has the potential to improve grass-fed beef animal performance.

Age of Harvest

With the majority of grass-fed beef diets resulting in lower energy availability than conventional grain diets, grass-fed cattle require a longer time to finish than grain-finished cattle (Capper, 2012). Based on the reviewed grass-fed studies, age of harvest for grass-fed cattle varied from 14 to 27 months. From the studies provided in Table 1, cattle were harvested based on one of two factors; 1) back-fat deposition or 2) forage availability/ nutritional decline (Berthiaume et al., 2006; Duckett et al., 2013; Scaglia et al., 2012). Both approaches are readily used by grass-fed beef producers (Cruz et al., 2013) and depend on rancher preferences and operation type. If a grass-finished producer manages a smaller operation there are benefits to using ultrasound to determine carcass composition when only sending one or two animals to harvest at a time. However, if a large-scale grass-finished producer is harvesting a large group of cattle at a time, using grazing seasons may be a better management technique.

Figure 3: Dressing percentage vs. age of harvest of grass-fed steers*



*Based on the 15 studies compared in the literature review.

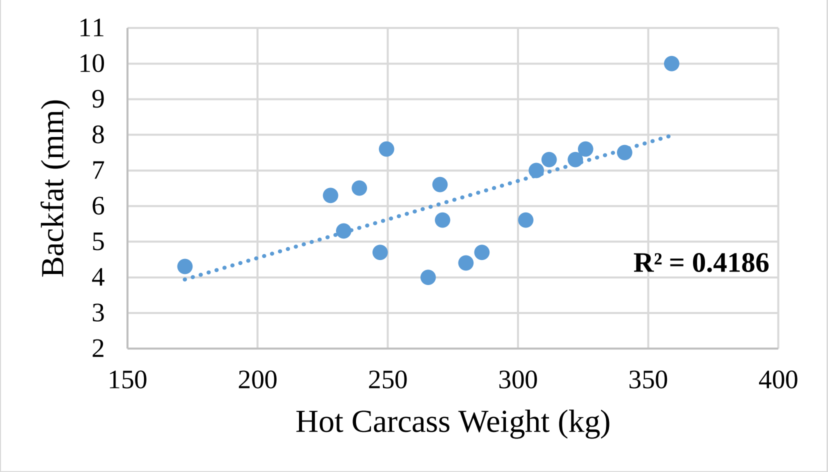
Interestingly, almost all the cattle harvested to the right of the 100th meridian finished before 20 months of age with many studies with cattle harvested between 14-15 months of age (Figure 3).

This is substantially younger than the two studies performed in California where cattle were harvested at least at 20 months of age. This difference in harvest age may be due to climate. In the US, the majority of precipitation occurs in the Midwest, Southeast and Northeast (Statista, 2021). Having heavier more consistent rainfall may allow for higher forage quality and quantity, enabling cattle to finish faster. However, despite the literature depicting a younger harvest age of cattle, survey studies have indicated that ranchers in the eastern United States do harvest cattle well over 20 months of age (Battagliese et al, 2015: Lozier et al., 2005). For instance, in a study that surveyed 17 grass-fed producers in Pennsylvania harvest ages ranged from 24-30 months of age (Battagliese et al, 2015, 2018). The discrepancies in age of harvest between the reviewed papers and the surveyed ranchers may be the time and money constraints placed on research projects. These constraints may not allow researchers to replicate grass-fed cattle systems that are currently performed by ranchers. Overall, more research needs to be performed to understand how region, forage availability, and ranch management practices affect age of harvest.

Back Fat and Ribeye Area

Among grass-fed beef studies, back fat ranged from 4.3 to 10 mm, with back fat averaging 6.1 mm. Although weak, there was a positive linear relationship ($R^2 = 0.42$) between back fat and HCW (Figure 4). Diet type may also have had an effect on back fat deposition. For example, in Schmidt et al. (2013) when animals grazed either alfalfa or bermuda grass, no difference in HCW was observed (322 kg and 326 kg respectively). However, back fat was significantly different between the treatments; alfalfa finished steers had 7.6 mm and bermuda grass finished steers had 5.6 mm of back fat.

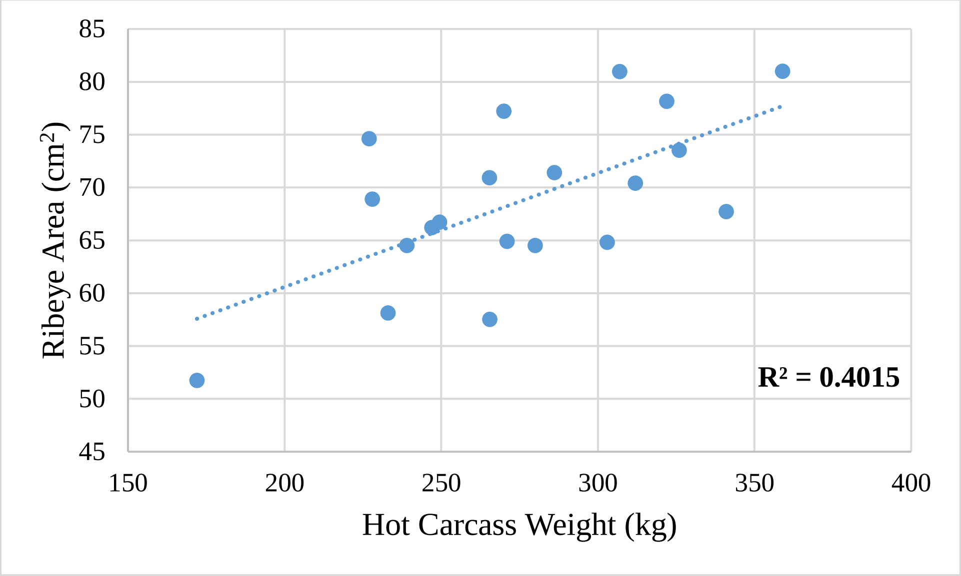
Figure 4: Back fat vs. hot carcass weight of grass-fed steers*



*Based on the 15 studies compared in the literature review.

Ribeye areas ranged from 51 to 81 cm^2 with average ribeye size of 68 cm (Table 1). Not surprisingly, the youngest animals harvested had the smallest ribeye area of 51 cm^2, and the oldest animals harvested had the largest ribeye area of 81 cm^2. Beside age, ribeye area was positively correlated with HCW ($R^2 = 0.40$; Figure 5). However, there was a large amount of variation between ribeye area and HCW suggesting additional factors, such as management strategy, genetics, and diet played a significant role in ribeye area. For example, animals in Berthiaume et al. (2006) and Scaglia et al. (2012) grass-fed trials resulted in an average HCW of 265 kg, but ribeye areas differed greatly. In Berthiaume et al. (2006) when cattle were finished on grass silage, ribeye areas were 70.1 cm^2. In contrast Scaglia et al (2012) finished cattle on tall fescue, and animals had a smaller ribeye area of 57.5 cm^2.

Figure 6: Ribeye area vs. hot carcass weight of grass-fed steers*



*Based on the 15 studies compared in the literature review.

Quality and Yield Grades

With the exception of Kim et al. (2012), cattle grass finished with an average quality grade of either standard or select. Cattle in Kim et al. (2012) finished at a higher quality grade of choice most likely due to the high quality Hawaiian pasture. Cattle in grass-fed trails finished at a lower quality grade compared to conventional grain-fed beef, with 85% of grain-fed cattle finishing choice or above (USDA-Extension, 2019). Although the majority of grass-fed cattle found in the literature finished with low quality grades, some extension studies have demonstrated that cattle can finish high choice given the right forage conditions and management techniques (Filbert, 2019). However, the resources necessary (forage quality/availability and increased days on feed) to finish grass-fed cattle may not be available or financial reasonable for most grass-fed beef operations. Interestingly, in contrast to quality grades, yield grades were similar between conventional and grass-fed beef systems. Across the grass-fed studies yield grades averaged 2.25 which is only slightly lower than the average yield grade for conventional at 2.6 (NBQA, 2016; Table 1).

Table 1: Summary of grass-fed beef performance and carcass quality

Study	Location	Breed/ Sex	Diet Formulation	Age of Harvest (M)	ADG for Finishing Period (kg)	Live Weight (kg)	Carcass Weight (kg)	Dressing Percentage (%)	Quality Grade	Yield Grade	Back Fat (mm)	Ribeye Area (cm^2)	KPH (%)
Berthiaume et al., 2006	Kapuskasing, Canada	Angus/ Steers	Grass Silage	14-15	0.74	451	265	58.8	Standard	__	4.9	70.9	__
Berthiaume et al., 2006	Kapuskasing, Canada	Angus /Steers	Grass Silage + Growth Promoters	14-15	1.08	490	286	58.4	Standard	__	4.7	71.4	__
Mandell et al., 1997	Guelph, Canada	Limousine Cross	Alfalfa Silage +Implant	14-15	1.12	__	312	__	__	__	7.3	70.4	__
Cruz et al., 2013	Central California	Angus/ Steers	Clover Ryegrass Pasture +Alfalfa Hay	21-27	0.73	615	359	58.4	Select	3.0	10	81.0	1.7
Scaglia et al., 2012	Virginia	Angus, Angus Cross /Steers	Tall Fescue Pasture	20	0.98	498	267	0.53	Standard	2.0	4.0	57.5	1.8
Scaglia et al., 2012	Virginia	Angus, Angus Cross /Steers	Alfalfa Pasture	20	0.93	480	250	0.52	Standard	2.1	7.6	66.7	2.0
Neel et al., 2007	West Virginia	Angus	Mixed pasture (Bluegrass, Orchard grass, Tall Fescue, Alfalfa)	18	0.85	475	247	0.54	Select	1.6	4.7	66.2	1.6
Schmidt et al., 2013	South Carolina	Angus-Cross/ Steers	Alfalfa (*Medicago sativa*) Pasture	>20	1.28	538	322	60.9	Select-	2.5	7.3	78.2	1.8
Schmidt et al., 2013	South Carolina	Angus-Cross/ Steers	Bermuda Pasture	>20	0.76	579	326	57.6	Select-	2.2	5.6	79.1	1.8
Schmidt et al., 2013	South Carolina	Angus-Cross/ Steers	Cowpea (*Cichorium intybus*) Pasture	>20	1.13	517	307	60.4	Select-	2.6	7.6	73.53	1.9
Schmidt et al., 2013	South Carolina	Angus-Cross/ Steers	Pearl Millet (*Pennisetum Glaucum*) Pasture	>20	0.88	555	341	62.3	Select+	2.4	7.0	81.0	1.8
Kerth et al., 2007	Georgia	Angus	Ryegrass	15-16	__	>554	227	___	Select-	2.3	7.5	67.7	1.5
Roberts et al., 2014	Georgia	Angus Crossbred/ Steers	Ryegrass	__	1.04	497	280	56.0	__	2.1	__	74.6	2.2
Stanley et al., 2018	Michigan	Red Angus	Irrigated Pasture/ Alfalfa Hay	14-15	0.91	530	280	53	__	___	__	__	__

Klopatek et al., 2020	Central California	Angus, Angus Cross/ Steers	Rangeland	20	__	477	239	50	Standard/ Select	1.5	4.4	64.5	1.1
Klopatek et al., 2020	Central California	Angus, Angus Cross/ Steers	Irrigated Pasture	25	__	568	303	53	Select	2.1	6.5	64.5	1.3
Scaglia et al., 2014	Louisiana	Gelvieh, Red Angus, ¼ Brahman/ Steers	Bermuda and Rye Pasture and Hay	>20	0.67	500	271	54	Select	2.4	5.6	64.8	1.6
Duckett et al., 2013	Virginia	Angus Cross/ Steers	Pasture (Legume last 40 days)	14-16	1.30 (Last 40 days)	484	270	54	Select	__	5.6	64.9	1.6
Kim et al., 2012	Hawaii	Angus Cross/ Steers	Kikuyu Pasture	19	0.88	546	228	53	Low Choice	__	6.6	77.2	__
Steinburg et al., 2009	Pennsylvania	Angus Simmental Cross/ Steers and heifers	Grass and Legume Pasture	17-18	0.69	1109	554	50	Select	2.5	6.3	68.9	__
Brown et al., 2009	Kentucky	Angus/ Steers	Low toxic fescue with mixed pasture	__	__	338	172	51	__	__	__		__
Realini et al., 2005	Georgia	Herford/ Steers	Tall Fescue+ Wild Type Endophyte	>14	0.28	411	233	43	Standard/ Select	2.4	4.3	51.8	___
Realini et al., 2005	Georgia	Herford/ Steers	Tall Fescue+ Novel Type Endophyte	>14	0.65	450	246	53	Standard/ Select	2.4	5.3	58.1	___

Part 2: Grass-fed Beef Fatty Acid Profile

Mainstream diets including Keto and Paleo have advertised grass-fed beef as a healthier alternative to grain-fed beef, principally due to higher omega-3 content in grass-fed beef (Grass-fed Farms, 2021). As a result, many consumers now view grass-fed beef as a healthier alternative than conventional grain-fed beef (McCluskey, 2015; McCluskey et al., 2005; Xue et al., 2010). Although numerous studies have confirmed grass-fed beef to be greater in omega-3 (Daley et al., 2010; Duckett et al. 2013; Noci et al., 2015), grain-fed beef contains greater levels of heart healthy monounsaturated fatty acids (Smith et al., 2020). Consequently, multiple fatty acids need to be compared to determine if one beef system is superior or "healthier" to another.

Saturated Fatty Acids

In general, it is thought that saturated fatty acids (SFA), particularly palmitic acid (C16:0), are harmful in the human diet. The unhealthy reputation of SFA is primarily due to its' positive correlation with low-density lipoproteins (LDL) or "bad" cholesterol (Siri-Tarino et al., 2010). However, recent studies have also shown a positive correlation between SFA and high-density lipoproteins (HDL) or "good" cholesterol (Siri-Tarino et al., 2010). As such, the full effects of SFA acids on human health are still not fully understood. In terms of beef's SFA content, the effect of diet on SFA concentration vary greatly. On a percentage basis, Leheska et al. (2008) and Lorenzen et al. (2007) found grass-fed beef to be higher in SFA compared to grain-finished beef. In contrast, French et al. (2000) determined beef's SFA percentage decreased as the forage to concentrate ratio increased. However, Duckett el al. (2009) and Duckett et al. (2013), found no difference in SFA percentage from grass-fed or grain-fed beef.

Although the health effects of total saturated fatty acids on the human diet are still debated, palmitic acid (16:0) has been designated as a harmful saturated fatty acid (Siri-Tarino et al., 2010). Previous studies have found no difference between grass-fed and grain-fed diets onpalmitic acid concentrations (Leheska et al., 2008; Duckett et al., 2013). In contrast to palmitic acid, stearic acid (C18:0) has been shown to decrease both cardiovascular and cancer risk (Kelly et al., 2001; Hunter et al., 2010). In addition, stearic has been identified as an important dietary metabolite that aids in mitochondria function (Senyilmaz-Tiebe et al., 2018). Multiple studies have found grass-fed beef to be greater in stearic acid than grain-fed beef (Duckett et al, 2009; Duckett et al., 2013; Leheska et al., 2008).

Monounsaturated Fatty Acid

In the United States, beef is the primary source of monounsaturated fatty acid (MUFA, Zong et al., 2018). In contrast to SFA, MUFAs have been shown to reduce LDL without lowering HDL (Degirolamo et al., 2009). Furthermore, multiple epidemiological studies comparing disease rates in different countries have suggested an inverse association between MUFA intake and mortality rates to cardiovascular disease (Schwingshackl et al., 2014). In beef, the most common MUFA is oleic acid (18:1 n-9). Oleic acid is found to increase in beef as fat cells in marbling begin to differentiate (Van Elswyk and McNeill, 2014). Thereby, the higher marbled grain-finished beef has been found to be higher in oleic acid than lower marbled grass-fed beef (Duckett et al., 2009; Ducket et al., 2013).

Although grain-fed beef has consistently produced higher concentrations of MUFA's compared to grass-fed beef, several studies have shown grass-fed beef to be higher in C18:1 *t*11 (TVA) concentration (Daley, 2010). The fatty acid TVA is an essential MUFA needed for the de novo synthesis of anti-carcinogen conjugated linoleic acid (CLA: C18:2 *c*-9, *t*-11; Bauman, 2006). In regard to effect of type of grazing system on TVA, Duckett et al. (2013) found no effect of grazing system type on TVA concentration in beef.

Conjugated linoleic acid

Conjugated linoleic acid (CLA) is known to have both anti-carcinogenic and weight loss properties (den Hartigh, 2018; Park et al., 1997). Although CLA is a trans-fat, the USDA classifies CLA as a general recognized as safe (GRAS) due to the aforementioned benefits. Ruminant fats are known for some of the highest concentrations of CLA isomers of all food sources (French et al., 2000). This is principally due to the ruminal biohydrogenation of linoleic and linolenic acids into stearic acids by *Butyrivibrio fibrisolvens* that produces CLA as an intermediate (Kepler et al., 1966). Previous studies have found CLA to be higher in grass-fed beef than grain-fed beef (Alfaia, et al., 2009; Leheska, et al., 2008; Garcia et al., 2008). Although linoleic acid is typically higher in feedlot rations than forage diets (Duckett et al., 2013), *Butyrivibrio fibrisolvens*, known for fiber digestion, prefers a more neutral pH. Grain consumption decreases the rumen pH, thus reducing the abundance of the key rumen bacteria linoleic acid isomerase activity (Bessa et al., 2000). Thereby it is most likely that the grass-fed beef diets result in higher *Butyrivibrio fibrisolvens* biohydrogenation activity, resulting in higher CLA concentrations compared to grain-fed beef.

Polyunsaturated Fatty Acids

Polyunsaturated fatty acids (PUFA) are critical for cardiovascular health (Ander et al., 2003) and brain function and development (Lauritzen et al., 2016). In comparison to fish, beef is not a large source of PUFA, with PUFA concentrations in grain-fed beef averaging only 5% of the total fat produced (Scollan et al., 2006). However, in countries where fish consumption is low, such as Australia or Kurdistan, beef and meat from small ruminants can contribute up to a third of omega-3 fatty acids (n-3) fatty acid consumption (Howe et al., 2006). As such, beef's PUFA profile has garnered a great deal of interest. In comparison to grain-fed beef, grass-fed beef has been shown to produce higher PUFA concentrations, averaging 25% higher than grain-fed beef (Daley et al., 2010). Furthermore, PUFA concentrations were shown to increase as cattle increased the number of days being grazed (Noci et al., 2005), suggesting that different grazing systems can have a significant effect on PUFA concentrations.

Dietary n-3 fatty acids have been shown to decrease the incidence of heart disease, aid in brain development, decrease inflammation, and have even been suggested to decrease the onset of behavioral disorders (Conner, 2000). However, despite the positive health effects of n-3, within the United States, dietary intake of n-3, particularly eicosatetraenoic acid (20:5 n-3; EPA) and docosahexaenoic acid (22:6 n-3; DHA) are limited (Cave et al., 2020). In fact, many adults and most American children are unable to meet the recommended n-3 requirements (Sheppard and Cheatham, 2018). Therefore, increasing dietary n-3 has become a mainstream human health interest. Thus far, several studies, have found grass-fed beef to be higher in n-3 compared to conventional grain-fed beef (Duckett et al., 2009; Duckett et al., 2013; Leheska et al., 2008). The leading long chain n-3 fatty acids (lc-n-3) in beef are eicosapentaenoic acid (20:5 n-3; EPA) and docosapentaenoic acid (DPA; 22:5 n-3), docosahexaenoic acid (22:6 n-3; DHA). Previous studies (Ponnampalam et al., 2006; Nuernberg et al., 2005) found grass-fed to be higher in both DPA and EPA. However, there is conflicting results on the effect of diet on beefs DHA levels (Duckett et al., 2013; Ponnampalam et al., 2006). Ultimately, more research needs to be performed to better understand how type of feeding system affects the n-3 profile.

Like n-3, omega-6 fatty acids (n-6) are essential to the human diet. Currently, the effects of n-6 in the human diet are still not fully understood. Increased dietary n-6 has been linked to an increase in the pro-inflammatory response in rodents (Innes and Calder, 2018). However, when increased n-6 was increased in the healthy adult human diet no effect on the inflammatory response was observed (Innes and Calder, 2018). In beef, grain-fed diets were found to have greater levels of n-6 compared to grass-fed beef (Duckett et al., 2009; Leheska et al., 2008). In addition to n-3 and n-6 total intake, the ratio of intake is critical to human health (Husted and Bouzinova, 2003). High levels of dietary n-6 to n-3 ratios have been shown to increase the rate of pathogenesis of depression (Husted and Bouzinova, 2003), while higher intake ratios of n-3 to n-6 have been shown to aid human health including decreasing the risk of breast cancer (Simopoulos, 2002). Conventional grain-fed beef systems have been shown to have higher levels of n-6 to n-3 ratio (Duckett et al. 2009; Duckett et al, 2013). However, the ratio was still under the suggested intake of n-6 to n-3 ratio of 6:1 (Weijedran and Hayes, 2003).

Part 3: Grass-fed Beef and Environmental Sustainability

Beef sustainability is an incredibly complex and highly contested topic. Over the last decade scientists, producers, and consumers have debated the ecological, sociological, and economic sustainability of the beef system. In the face of this discourse, organizations across the globe have formulated their own sustainability and beef sustainability definitions, often in contradiction with one another (Capper, 2012, Gwin et al., 2009, Willits-Smith et al., 2020). With inconsistent beef sustainability definitions and lack of societal acumen, consumers now view grass-fed beef as a more sustainable choice than conventional beef. In fact, in a recent survey over 60% of participants believed grass-fed beef was a more sustainable option compared to conventional beef (Gwin et al., 2012). With continued scrutiny of beef sustainability, there is an increasing need to evaluate both grass-fed and conventional beef systems using a multi-dimensional approach. In order to determine the sustainability of beef production analysis needs to be performed to better understand sustainability of scales, system resilience, and utilizing and assessing environmental metrics.

Sustainability of Scale

Before the sustainability of a beef system can be assessed, the scale of the system must be properly defined. It is important to distinguish the differences between scales of production, for without accurate system boundaries, sustainability interpretations can become inaccurate (Belk et al, 1992). Beef sustainability assessments can evaluate beef production on a global, national, regional, or individual producer scale. Grass-fed beef production systems are often assessed on a national scale (Capper, 2012; Hayek and Garret, 2018). In 2018, Hayek and Garrett of Harvard determined that if the U.S. beef supply chain converted to 100% grass-fed beef, current grass resources could only support 27% of the current beef supply (Hayek and Garrett, 2018). In addition, grass-fed beef systems would produce higher carbon and water footprints compared to conventional beef production (Hayek and Garrett, 2018; Capper, 2012). Overall, if the U.S. were only to produce beef from grass-fed systems, then total beef production would be drastically reduced, causing large scale food scarcity and economic issues (Hayek and Garrett, 2018, Capper 2012). However, although converting 100% of all beef to grass-fed beef would be unsustainable, when evaluating beef production on smaller scale, grass-fed beef systems have the potential to be sustainable systems (Stanley et al., 2018). For example, if an individual rancher producing grass-fed beef has an adaptive grazing management strategy, has long-term access to natural resources and labor, and has a steady market to sell the grass-fed product, then this system has potential for sustainability.

System Resilience

For a system to be sustainable it must have resilience. System resilience is an ability of the system to withstand severe disruptions within a set of degradation boundaries, and to recover from the disturbance within an acceptable time parameter (Kröger, 2019). Multiple factors affect a systems resilience such as diversity, efficiency, and adaptability (Fiksel, 2003). For a beef system to be sustainable, including grass-fed and conventional production, the system must be resilient to a multitude of economic, biological, and sociological factors. Several organizations such as the US Roundtable for Sustainable Beef and livestock grazing societies have recognized system resilience as an essential part of beef cattle sustainably. In 2014, a multidisciplinary study set up a framework to identify vulnerabilities within the grazing sector in order to determine how this sector responded to a disturbance (Steiner et al., 2014). Some of the biggest vulnerabilities identified on a micro scale were socioeconomic issues, specifically rancher knowledge and ranchers' ability to invest and adapt to changing technologies. When the resilience of the beef industry was evaluated on a macro scale, more vulnerabilities became apparent. One major vulnerability to the beef industry is the increasing rate of disturbances to rangelands. Disturbances to rangelands can be readily seen across the country and especially in California where available pastures and rangelands are disappearing rapidly (Cameron, 2014). In fact, from1984 to 2008, more than 195,000 hectares of California rangeland habitats were converted, primarily for commercial development or agricultural intensification (Cameron, 2014). Not only are rangeland areas being reduced, climate change research suggests rangelands will undergo unprecedented changes uncovering multiple vulnerabilities within the beef system (de Groot et al., 2013; An et al., 2015). Climate change has resulted in increased rates and intensities of drought and fire (de Groot et al., 2013; An et al., 2015), and a continuing increase in atmospheric carbon has shown to negatively affect rangeland health (Adler et al., 2009; Toledo et al., 2014) and nutrition (Augustine et al., 2018; Dumont et al., 2015). This subsequent decrease in nutrition could have significant negative effects on all beef production system by increasing land area and additional supplementation needed to produce beef. Although all cattle require range or pastureland during at least one stage of production, grass-fed beef production systems require greater land area than conventional beef systems and may be less resilient to land use and forage production changes (Capper, 2012).

Grass-fed beef systems are also particularly vulnerable to cattle harvesting capabilities. Since 1967, the number of packing houses in the U.S. has dramatically declined from over 10,000 to less than 3,000 (USDA-FSIS, 2010). With the number of packing houses decreasing and the distance from cattle operations to packing houses increasing, many operations find that harvesting and packaging grass-fed beef has become infeasible, both logistically and financially. Without increasing the number of packing houses or increasing the harvesting capacity, grass-fed beef will continue to face harvesting difficulties.

Vulnerabilities within the conventional beef systems have also come to light in recent years. In 2019, a packing house in Holcomb, Kansas, caught on fire. The Holcomb plant was only one of seven US plants with the ability to harvest 6,000 cattle per day and after the fire occurred cash prices sharply lowered and the USDA 5-area average prices severely decreased. Although prices within the industry recovered within a month, the severe disturbance to the packing house brought into question the short-term resilience of the beef supply chain.

Environmental Sustainability and Life Cycle Assessment

To consumers, the term sustainability is most often associated with environment well-being (Vanhonacker, 2013). Beef, having a high environmental footprint (when compared to alternative proteins) has given rise to the consumer perception that beef is a less sustainable protein source (Vanhonacker, 2013; Verbeke at al., 2010). Although studies have demonstrated that consumer’s sustainability viewpoint weakly correlates with their meat buying habits (Verbeke et al., 2010), with continual regulatory interest and increasing competition from alternative protein products the interest in understanding and improving beefs environmental footprints have never been greater. In order to comprehensively evaluate the environmental sustainability of a food system, multiple environmental metrics are used. Commonly used environmental metrics include global warming potential, ozone depletion, water scarcity, and acidification potential. The tool most used to evaluate and compare environmental metrics of multiple food systems, including beef, is known as Life Cycle Assessment.

A life-cycle assessment (LCA) is an environmental accounting tool used to determine environmental impacts related to the manufacturing of a product, material, process, or activity from the time of inception to termination (Curran, 2016). LCA's consider all aspects of the production process including, but not limited to, transportation, development, mining resources, packaging, and final disposal. An LCA evaluates the environmental sustainability of a food system by evaluating system inputs, such as water and energy usage, and system outputs such as greenhouse gases. In order to compare multiple system to one another, system inputs and outputs are formulated into impact categories. There are over ten impact categories, with the impact categories of Global Warming Potential (GWP) and absolute water usage (AWU) garnering the most public and academic attention. Using these impact categories food LCA's have determined that beef production is highest in almost all impact categories (de Vries, M and de Boer, 2010; Clune et al., 2017). However, beef is one of the most complicated and diverse food systems and interpretations of these LCA's can vary depending on the LCA model and the type of beef production system examined.

Beef Lifecycle and LCA Designs

Beef LCA can vary in goal and scope. The goal and scope of a LCA is defined by how the model is computed and interpreted. In order to both compute and interpret an LCA, a functional unit needs to be selected. Common functional units for Beef LCA's include kg of live animal weight, kg of hot carcass weight, and kg of beef (Stackhouse at al., 2012; Beauchimin et al, 2010; Stanley et al., 2018). The functional unit live weight represents the weight of the animal prior to harvest. This value can be useful when computing an LCA, however using live animal weight as a functional unit can be misrepresentative when comparing animals from different production practices. For example, culled cows and steers can both be harvested at weights 550 kg, but since their dressing percentages are significantly different, 50% for cows and 62% for steers, the meat produced from these scenarios would be substantially different. Therefore, most beef LCAs incorporate DP into the assessment by using the functional unit of HCW or kg of beef.

Scope of beef cattle LCA differ in what production phases are added to the model. In cradle to gate LCA inputs and outputs to the system include all live animal production processes up until the point of harvest. In a recent cradle to gate LCA, the cow-calf phase of production represented 80% of the GWP and feedlots represented only 20% of the GWP (Beuchemin et al., 2010) signifying the importance of incorporating the cow-calf phase into beef LCAs. Cradle to harvest LCA include all the inputs of production from birth through harvest but excludes retail. The most inclusive beef LCA is cradle to grave. In cradle to grave LCA the entire system inputs and outputs are considered from the time of birth, to harvesting, to food retail. In 2019, a report by Battagliese et al determined retail, restaurants, and consumer impact accounted for less than 10% of the GWP, less than 1% of the water used and were less than 2% for all other impact categories. What was highlighted on the retail, restaurant and consumer side was the high rate of food waste. Specifically, from harvesting to human consumption, at least 10% of the beef product was wasted. Although post-harvest activities accounted for a far smaller percentage of the total beef footprint, incorporating post-harvest impacts such as food waste highlight important sustainability issues that would have otherwise not have been accounted for in a cradle to gate LCA.

Global Warming Potential

With livestock production representing 2% of total United States GHG emissions and 14.5% of the world's GHG emissions, beef production's global warming potential has become one of beef's most scrutinized impact categories (Gerber et al., 2013; U.S. E.P.A, 2019). In fact, in a recent literature review evaluating GWP in a food LCA, GWP was included in 98% of livestock LCA publications and one-third of livestock LCA publications exclusively evaluated GWP (McCelland et al., 2016). When evaluating these LCA's on a cradle to grave basis, beef cattle GWPs ranged from 10.75 to 109 per kg of boneless beef, or 7.47 to 75.8 per kg of HCW (Clune et al., 2017). For North American beef production GWP averaged 26.61 per kg of boneless beef or 18.5 per kg of HCW (Clune et al, 2017). Overall, when comparing multiple food LCA's on a cradle to grave basis, beef cattle maintained the highest GWP compared to all the food sources (Clune et al., 2017).

In a recent cradle to gate LCA examining the GWP of Canadian beef, the GWP was 22.0 kg CO_2 eq. per kg of HCW (Beauchemin et al., 2010). In another LCA examining the GWP of beef in the U.S. Northern Great Plains, GWP was very similar to the Canadian LCA with a GWP value of 23.0 kg CO2 eq. per kg of carcass weight (Lupo et al., 2014). Lupo may have produced a higher GWP than Beauchemin by using a DP of 55% compared to Beauchemin who used 62%. In contrast, an LCA performed by Pelletier et al., 2010 determined that beef's footprint in the Midwestern US was higher than both Beauchemin or Lupo studies estimates, with a GWP of

24.3 kg CO2 eq (Pelletier et al., 2010). Differences in GWP may be due to differences in goal and scope of the LCA design.

Grass-fed vs. Grain-fed Beef's Global Warming Potential

In 2012, environmental footprints of grass-finished, all natural, and conventional beef were modeled (Capper, 2012). The model concluded conventional beef required 56.3% fewer animals, 24.8% less water, 55.3% less land and 71.4% less fossil fuel energy compared to grass-finished systems (Capper, 2012). In addition, the carbon footprint for grass-finished beef systems was calculated to be 167% greater than conventional beef systems (Capper, 2012). The principal reason for the higher carbon footprint for the grass-finished beef was due to the increased enteric methane production. The amount of enteric methane produced (eructated methane from ruminal fermentation) in a cow's lifetime is dictated by feed type, feed intake, and days on feed (IPCC, 2014). According to the IPCC (2014) cattle consuming forage diets lose almost twice as much methane from gross energy, 6%, compared to grain-finished cattle at, 3.5% (IPCC, 2014). Although feed intake was higher for feedlot animals, the combination of increased days on feed (639 compared to 440) and a high forage diet resulted in the increase of enteric methane production for grass-finished cattle compared to conventional cattle (Capper, 2012).

In a contrasting study by Stanley et al (2018), using live animal performance and soil carbon data, grass-finished cattle had a similar carbon footprint compared to grain finished cattle at 6.65 kg CO2-e kg carcass weight $(CW)^{-1}$, compared to 6.12 kg CO2-e kg CW for grain finished animals. In the study, animal performance was based on a five-year grazing trial. Grass-finished cattle were harvested at 14.5 months of age, weighing 530 kg. Grain fed cattle did not go through a backgrounding or stocking phase and were harvested at 654 kg at 12-13 months of age. The LCA input values used for the Stanley study were substantially different then the values used by Capper. In the Capper LCA, conventional cattle were harvested at 14.5 months at 571 kg and grass-fed cattle were harvested at 22 months of age at 440 kg. Average daily gain for the Stanley study was similar to those found in the grass-finished beef literature for cattle finished in the eastern part of the United States (Table 1) with gains of 0.91 per day. In contrast, Cappers ADG of 0.61 kg was similar to the findings in the California grass-finished studies. Furthermore, the largest difference between the LCA's was the incorporation of the greenhouse gas sinks and emissions from both soil sequestration and soil erosion in the Stanley study. The study determined that by utilizing adaptive multi-paddock grazing, soil carbon levels where sequestered, increasing soil carbon by 3.59 Mg C ha−1yr-1 which substantially offset grass-feds enteric methane emissions. If soil sequestration was not taken into consideration, cattle greenhouse footprints would be 9.62 Global Warming Potential for grass-finished beef.

Water Usage and Water Footprint Impact Category

In LCA, water footprint and water usage are not interchangeable terms. According to ISO 14046 regulations, the water footprint is defined as a "metric(s) that quantifies the potential environmental impacts related to water" (Pfiser et al, 2018). Unlike water usage, water footprint (i.e. absolute water usage, AWU) incorporates an additional factor known as water quality degradation (Pfiser et al, 2018). In order to determine water footprint, the water usage is multiplied by a damage factor known as a water stress index. In the LCA computed by Asem-Hiabli et al. (2019), conventional beef's water usage was 2,558 L per kg of edible beef. Using the water stress index of 0.49, the AWU, or water footprint, was 5,126 L per kg of beef. The LCA determined that 98% of the consumptive water was attributed to feed production. These results where similar to Beckett and Oltjen (1993). Using a stochastic model, Beckett and Oltjen determined that one kg of beef water usage was 3,682 L of water from birth through harvest. In the model, 96% of the water used resulted from feed production. Direct water consumption by animals and the harvesting of cattle resulted in a small portion of the water used, approximately 3.0% and 0.3% respectively. In another LCA determining the differences between AWC for different beef systems, AWC was only 55 L per kg of beef (Battagliese et al., 2015). It is important to note that this LCA was representative of Eastern U.S. grass-fed beef systems where little to no irrigation water is required for pasture. This is in contrast to the Western U.S. where irrigation water is regularly administered for pasture production.

Part 4: Ranch Management Adoption Practices

Cattle and sheep production have been the most extensive form of land use and type of agriculture in the western United States (Fleischner, 1994). However, urban sprawl has resulted in the rapid conversion of rangelands (Swette and Lambin, 2021). As such, livestock producers and conservationists alike have sought to continue ranching efforts to preserve open land spaces in the Western United States (Brunson and Huntsinger, 2008). Understanding rancher goals, perceptions, and management practices is principal to maintaining rangelands and ensuring a synergistic relationship between producers, conservationists, and policy makers.

Current Rancher Perspectives related to the Environment and Animal Health

According to a survey conducted by the Wyoming Stockgrowers Association, livestock production followed by forage production were survey respondents’ top two goals (Kachergis et al., 2013). Similar results were observed in a survey administered to California ranchers where respondents identified livestock and forage production as their number one priority (Roche et al., 2015). Although these surveys found livestock production to be the top priority of ranchers, the survey data also highlighted the interest and dedication ranchers had in ensuring the health and wellness of the environment. In California, 97% percent of survey respondents agreed with the statement, “Whenever possible, I try to conserve natural resources” and 47% of respondents disagreed with the statement “My landowner rights allow me the absolute right to do whatever I want with my land” (Roche et al., 2015). In Wyoming, a majority of survey respondents (70% on private land, 60% on public or state land) stated they monitored vegetation and vegetation health regardless of their participation in programs that require monitoring. Furthermore, ranchers in Wyoming ranked riparian and/or meadow health and soil health the highest ecosystem priorities. However, level of ecosystem consciousness may vary depending on region and type of ranching operation. For example, in a survey administered in Missouri and Iowa, livestock producer’s general attitudes regarding the environment were not important by themselves (Gedikoglu and McCann, 2012.). However, ranchers did have heightened interest in natural resource conservation when there was a possibility of financial incentive.

Dissemination of Ranching Information

Access to information on Best Management Practices (BMP) or specific conservation programs is critical for the adoption of the practice or program (Liu et al., 2018). Therefore, conservation or rancher educational program leaders need to know how ranchers access their information and on what platform. Ranching information platforms include internet, word of mouth, and print publications. Interestingly, despite the increase in access to internet across the country, 69% of participants in a 2012 Wyoming survey preferred to learn about ranching practices through print publication as opposed to the internet (Kachergis et al, 2013). Similar results were found in California where the top preferred source of communication was print publications at 55%, followed by in-person interactions at 42%, and e-mail and other electronic sources last at 25% (Roche et al., 2015). Although internet does not appear to be a large information source for ranchers, it is unclear how the Covid-19 pandemic changed ranchers’ reliance on the internet. In terms of who ranchers go to for information on ranching, other ranchers and extension or farm agents were often the most trusted and the most sought-after sources (Kachergis et al., 2013; Liu et al., 2018; Roche et al., 2015; Tamini, 2011).

Adoption of Conservation Practices

The decision by ranchers to adopt new agricultural practices are influenced by a variety of environmental, political, societal, and economic factors (Smit and Skinner 2002; Young et al., 2015). Environmental stressors such as drought, disease, and flood can influence a producer to change current management strategies and adopt new practices. During times of drought ranchers have been known to adopt a variety of short- and long-term strategies. For the short term, ranchers have resorted to reactive strategies to keep the cattle business operational, such as buying hay, leasing additional land, or selling off yearlings and cow-calf pairs (Macon et al., 2015; Young et al., 2015). However, with persistent droughts and a need to be resilient, there has been an increase in ranchers adopting more long term or proactive BMP (Macon et al., 2015). Such practices have included increasing diversity of the operation, decreasing input costs, decreasing stocking densities, and improving current water systems and grazing management strategies (Macon et al., 2015; Shrum et al., 2018; Wilmer et al., 2016). These conservation BMP are adopted by ranchers as a way to conserve resources, thereby increasing the likelihood of maintaining livestock production. However, it is unknown how willing a ranching operation would be to adopt a conservation practice even if it provided neutral benefits for the ranching operation. For livestock producers in the East, surveyed producers stated they would not adopt a practice simply for conservation reasons (Gedikoglu and McCann, 2012). However, there was an adoption of BMP at the nexus of environment- and profit-oriented practices. For example, livestock producers were more likely to adopt Roundup Ready soybeans into their production schemes when there were both perceived environmental and profitability benefits (Gedikoglu and McCann, 2012).

Ranching is a lifestyle, and the combination of economic and environmental challenges has hindered many producers from maintaining this lifestyle not only for themselves but also for their families. Therefore, if adopting a BMP is perceived to increases the longevity of the operation (i.e., allows for succession) and can help maintain the ranching lifestyle there is a greater change for that practice to be adopted (Rowe et al., 2001). In a survey by Roche et al. (2015) the majority of respondents, 63%, agreed that the “ranching lifestyle was more important than economic return”. This study is consistent with Grigsby (1980) who found ranchers will trade profit for lifestyle maintenance, and Didier et al. (2004) who found ranchers would not diversify operations if it decreased their ability to maintain a ranching lifestyle even if diversification would increase profitability.

In addition to maintain lifestyle, level of income, capital, and access to labor has also been suggested to be a positive factor on wether a producer would adopt a new practice (Kara et al., 2008, Lamba et al., 2009; Rowan and White, 1994). In a ranching survey conducted in Texas the level of dependence on ranching income was directly correlated with the decision to invest in improvements and adopt new BMP (Rowan and White 1994). Currently it is hypothesized that the larger the scale of production (i.e., the larger in land, profitability, and number of acres operated), the more likely a rancher is to adopt or try new ranching practices due to economically viable and lower economic risk (Lubell et al., 2013; Thurow et al., 2000; Kreuter et al. 2004).

In terms of regulation, with low trust in the federal government (Roche et al. 2015; Lubell et al., 2013), there are relatively few federal environmental regulations that influence a voluntary adoption of agricultural practices in the U.S. (Kara et al., 2008). In fact, public policy regulations were cited as the second most important reason ranchers decided to sell their ranch (Bartlett et al., 1989). However, when utilized correctly, public policies can harmoniously be adopted by ranchers. Lubell and Fulton (2007) determined when agricultural producers' were exposed to local policy networks, the likelihood of adopting a conservation BMP increased. Thereby federal policies may have an effect on adoption of BMP if the policies are disseminated and supported within local policy networks. Unlike federal organizations, the Cooperative Extension System exhibits a high level of trust in the ranching community (Roche et al., 2015). Not only are extension agents (including farm advisors) a principal source for ranching information (Lubell et al., 2013) rancher proximately to advisors has shown to increase the rate of adoption of BMP (Rezvanfar et al., 2009). However, one study showed that the scale of operation was a predisposing factor in whether or not ranchers utilized Extension services, with larger scale operators more likely to utilize Extension agents or technical advisors than smaller ranch operators (Coppock and Birkenfeld, 1999).

Adoption of Animal Health Programs

In regard to adoption of animal health BMP, limited data is available. Of the animal health programs available, the Beef Quality Assurance (BQA) program is the most ubiquitous and has been implemented and adopted within all 50 states. Despite the notoriety and success of the BQA program there is a dearth of sociology research investigating the reasons for the success of this program. A survey conducted in Montana demonstrated that ranchers in the BQA program were more likely to administer shots in the BMP designated site of the neck than those that did not participate in the BQA program (Duffey et al., 2008). However, this study did not investigate why ranchers chose to be a part of the BQA program. Future research needs to be performed on BQA adoption practices; the knowledge obtained could aid future rancher educational and conservation programs.

Conclusion

In conclusion, grass-fed beef production differs greatly in management, animal performance, and product quality. These differences in production practices and animal performance directly impact beef's fatty acid profile and environmental footprint. Therefore, systems research needs to be performed on a regional basis to understand how varying production practices effect the sustainability of specific grass-fed beef system. In addition, although a variety of ranching studies have addressed BMP adoption, no study has investigated the adoption practices of the highly successful BQA program. Research investigating BQA adopting practices is needed in order to improve the integrity and adoptability of future rancher educational and conservation programs.

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Chapter II

Assessing the Sustainability of Multiple Grass-fed Beef and Grain-fed Beef Production Systems in the Western United States[1]

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[1] **ACKNOWLEDGEMENT:** This research was made possible by the James Beard Scholarship Program.

Abstract

Grass-fed beef sales are expected to increase globally by 40 U.S. billion dollars by the year 2025. Increased demand for grass-fed beef raises many producers' and consumers' concerns regarding product quality, economic viability, and environmental impacts that have gone unanswered. Therefore, using a holistic approach, we investigated the performance, carcass quality, financial outcomes, and environmental impacts of four grass-fed and grain-fed beef systems in Western United States. The treatments included: 1) steers stocked on pasture and feedyard finished for 128 days (CON); 2) steers grass-fed for 20 months (GF20); 3) steers grass-fed for 20 months with a 45-day grain finish (GR45); and 4) steers grass-fed for 25 months (GF25). Using carcass and performance data from these beef production systems, a weaning-to-harvest life cycle assessment (LCA) was developed in the Scalable, Process-based, Agronomically Responsive Cropping Systems LCA (SPARCS-LCA) model framework, with the goal of determining global warming potential (GWP), consumable water usage, energy, smog, and land occupation footprints. Final body weight varied significantly between treatments (P <0.001) with the CON cattle finishing at 632 kg, followed by GF25 at 570 kg, GR45 at 551 kg, and GF20 478 kg. Dressing percentage (DP) differed significantly between all treatments ($P < 0.001$). The DP was 61.8% for CON followed by GR45 at 57.5%, GF25 at 53.4%, and GF20 had the lowest DP of 50.3%. Marbling scores were significantly greater for CON compared to all other treatments ($P < 0.001$) with CON marbling score averaging 421 (low-choice ≥ 400). Breakeven costs with harvesting and marketing for the CON, GF20, GR45, and GF25 were \$6.01, \$8.98, \$8.02, and \$8.33 per kg hot carcass weight (HCW), respectively. The GWP for the CON, GF20, GR45, and GF25 were 4.79, 6.74, 6.65 and 8.31 CO_2e/kg HCW, respectively. Water consumptive use for CON, GF20, GR45, and GF25 were 933, 465, 678 and 1245 L /kg HCW, respectively. Energy use for CON, GF20, GR45, and GF25 were 18.69, 7.65, 13.84 and 8.85 MJ /kg HCW, respectively. The results from this study indicate that varying grass-fed beef production systems in the Western U.S. yield significant differences in both animal performance and carcass quality resulting in environmental and economic tradeoffs between systems rather than grass-fed or grain-fed beef absolute system superiority.

Key Words: Beef Sustainability, Life Cycle Assessment, Grass-fed beef, Carcass Quality, beef systems, Greenhouse Gases

Introduction

With increasing concerns over the environmental impacts of conventional beef (beef that is finished in a feedyard for over 60 days), grass-fed beef (beef that has been fed grass for the entirety of its lifecycle as per USDA definition; USDA, 2019) is now viewed by many consumers as a more sustainable alternative (McCluskey, 2015; McCluskey et al., 2005; Xue et al., 2010). This evolving consumer ideology has resulted in a steady increase in demand for grass-fed beef, with retail sales of labeled fresh grass-fed beef in the U.S. growing from $17 million in 2012 to $272 million in 2016 (Nielsen Retail Measurement Services, 2017). To meet these demands, producers have begun to utilize a grass-fed beef option in their current production systems. However, unlike conventional beef production that produces a consistent product, grass-fed beef performance and carcass quality varies significantly depending on region, resource availability, and forage quality (Berthiaume et al., 2006; Duckett et al., 2013; Scaglia et al., 2012). The different production systems lead to variations in quality grade, weight, and dressing percentage (Kim et al., 2012; Neel et al., 2007; Schmidt et al., 2013) that result in varying economic and environmental impacts (Cruz et al., 2013; Pelletier et al., 2010; Stanley et al., 2018). Therefore, to accurately address the economic outcomes and environmental impacts of grass-fed beef, animal performance and carcass quality parameters need to be empirically evaluated on a regional basis.

One of the most effective ways to determine a production system's environmental impact is to use life cycle assessment (LCA; Notarnicola et al., 2017; Tedeschi et al., 2015). Despite continued interest in grass-fed beef's environmental impacts, only a few grass-fed beef LCA have been completed. Moreover, no LCA has modeled grass-fed beef production in the western U.S. In an LCA performed in Michigan that modeled the finishing phases of conventional beef and intensely managed grass-fed beef, grass-fed beef's global warming potential (GWP) on a per kilogram basis was 57% greater (excluding soil carbon sequestration) than conventional beef (Stanley et al., 2018). Similarly, in an LCA that modeled beef production in the Midwest, the GWP per kilogram for grass-fed beef production was 30% greater than that of conventional beef (Pelletier et al., 2010). Although these LCAs provide insight into grass-fed beef production and environmental impacts, the management practices and input parameters modeled in these studies are substantially different from those associated with grass-fed beef systems in the Western U.S. (Cruz et al., 2013). Furthermore, these studies included relatively few environmental impact categories, limiting the scope of analysis as well as the opportunity to assess potential trade-offs between various impacts.

California, with a Mediterranean climate, more than 39 million people, the highest number of farmer's markets (USDA, 2012) and the 4th largest cattle industry in the country (NCBA, 2020) is set to become a leader both in grass-fed beef production and demand. Therefore, there is a pressing need to evaluate the performance and economic characteristics of grass-fed production systems currently being utilized by ranchers in the Western U.S. Only by using a whole systems approach can we understand the relationship between economic feasibility, product quality and environmental impacts of western grass-fed beef production. In order to address consumer, producer, and other scientific concerns, the present study sought to 1) determine the performance, carcass qualities, and economic returns of four grass-fed and conventional beef systems currently being utilized by Western ranchers; and 2) combine the live animal performance (from weaning to harvest) along with carcass data to build the first-ever empirically derived, multi-impact factor LCA for grass-fed beef production systems in the Western U.S.

Materials and Methods:

Animal Protocol

The weaning, animal health protocol, and study design for this project were approved by the Institutional Animal Care and Use Committee at the University of California-Davis (UCD; protocol #20560). In June 2018, cows and calves at the University of California Sierra Foothill Research and Extension Center (Browns Valley, CA) were fenceline weaned for 45 days to minimize animal stress and to monitor calf health as described by Price et al. (2003). At weaning, Angus and Angus-Herford cross steer calves were allocated to one of four treatments: 1) steers stocked on pasture then finished in a feedyard (CON), 2) steers grass-fed for 20 months (GF20), 3) steers grass-fed for 20 months with a 45-day grain finish (GR45), and 4) steers grass-fed for 25 months (GF25; Figure 1). All treatments were designed based on current beef production systems in California. After being fenceline weaned, steer calves were stratified by weight (average initial body weight was 284 SD 27.57 kg) and randomly assigned to treatments. In the beginning of the trial, there were 22 steers per treatment, but these numbers were reduced over time due to pinkeye infection that were treated with antibiotics as per IACUC protocols. Antibiotic-treated cattle were removed from the study as per natural program agreements. After pinkeye animals were treated, the number of cattle remaining in each treatment were: 21 cattle in CON, 18 in GF20, 13 in GR45, and 16 in GF25. After weaning, steers were transported to summer flood irrigated pasture located in Maxwell, CA, that were irrigated bimonthly beginning the second week of July through the second week of November. Steers were rotated between two pastures throughout the grazing season. Irrigated pasture included a mix of annual grasses (predominantly *Cynodon dactylon*, *Sorghum halepense*), and clover (25-30% *Medicago* and *Trifolium*). After the summer-fall grazing season ended in late November, steers were transported to their designated feeding locations. Steers in the CON treatment were taken to the feedyard of UCD located at Davis, CA where they were housed in a group pen. At the feedyard animals were fed a starter ration for 14 days, followed by an intermediate ration for 14 days and finished on a high-energy corn-based ration for 100 days (Table 1). Steers in the GF20, GR45, and GF25 treatments were shipped from Maxwell, CA, to the Sierra Field Research Station Browns Valley, CA, to graze winter-spring foothill rangeland. Cattle were rotated between three large-scale paddocks once every month. Rangeland forage species composition was typical of California rangelands consisting of a mixture of grasses (e.g. *Bromus, Avena* spp.) and forbs (e.g, *Erodium, Medicago, Trifolium* spp). At the end of the winter-spring grazing season cattle in the GF20 treatment were harvested. Steers in the GR45 treatment were taken to the feedyard at UCD. While in the feedyard steers were fed a starter ration for 7 days, intermediate ration for 10 days, and finished on a high-energy corn diet for duration of the 45-day grain period (Table 1). Steers in the GF25 treatment were transported to irrigated University of California-Davis owned, flood irrigated pasture in Davis, CA. The pasture at UCD consisted of a 50:50 mixture of perennial grasses (*Cynodon dactylon* and *Sorghum halepense*), and clover (25-30% *Medicago polymorpha* and *Trifolium dubium.*). Cattle were rotated between two paddocks every two weeks. Cattle land occupation values (head/hector/month) for all the systems are listed in the Supplemental Material. Cattle in the GF20 and GF25 treatments followed USDA Food Safety and Inspection Services labeling guidelines (USDA 2019). Cattle in the CON and GR45 treatments were harvested at a large scale commercial packing house in Fresno, CA and steers in the GF20 and GF25 systems were harvested at a natural and organic beef packing house in Merced, CA. To adhere to natural standards none of the steers were implanted. Steers in the CON and GR45 treatment were fed an ionophore to replicate commercial feeding systems in CA.

Performance and Carcass Quality Analysis

The average daily gain was determined for each animal as the slope of the linear regression of body weight by days of age. At the end of the feeding period, steers were weighed after 18 h of feed withdrawal and then transported to slaughter. All carcasses were chilled for 48 h and separated between the 12th and 13th ribs. The USDA Quality and Yield Grades were assigned to each carcass by trained personnel. Carcass characteristics were evaluated as follows: hot carcass weight (HCW), percentage of kidney, pelvic, and heart fat (KPH), *longissimus dorsi* muscle area at the 12th to 13th rib (REA), body fat depth at ¾ of the width of the *longissimus dorsi* (LD) muscle, and marbling score. Dressing percentage (DP), yield grade, and quality grade were calculated using standard equations (Boggs et al., 1998). Strip loins (LDM, Institute Meat Purchasing Specification number 180) from the right sides of each of 12 carcasses were collected, vacuum packaged and stored under dark conditions at 4ºC for 14 days

Feed Analysis

To collect pasture/ rangeland samples, a quarter meter square (50cm x 50cm) of PVC pipe was randomly thrown into the pasture. Forage samples were collected from the square by cutting the plant matter on the ground. This process was repeated 30 to 100 times along the cross-section of the given pasture. Pasture/ rangeland samples were taken every 30 days for the duration of the project. Feedyard samples were collected from the mixer wagon every 14 days. After each collection, feed samples were combined and sub-sampled in triplicate and frozen at -35°C. Samples were thawed and dry matter was determined by oven drying at 100°C for 12h. For composition analysis, feed samples were ground to pass a 1-mm screen (Wiley mill, Arthur Gill Thomas Co., Swedesboro, NJ) and dried at 55°C for 15 h before undergoing proximate analysis. Dietary ME values were calculated using equations published by the National Academy of Sciences, Engineering, and Medicine (2016).

Cost of Production

Cost analysis was based on UC Davis input costs, livestock advisor estimates, and UC Extension Costs studies (Table. 2). The purchase price of steers was based on Shasta Livestock Auction (Cottonwood, CA) prices for the month of June over a 3-year consecutive period (2016-2018). Pasture/rangeland rental costs were determined based on negotiated prices between UC Davis and landowners. Maxwell pasture was leased for $0.20 per kg of gain and UC land price was based on $30 animal unit monthy (AUM). Although none of the steers during the trial experienced mortality, to be consistent with other UC extension cost studies death loss was considered to be 2% of initial purchase price. Feed costs and markup were based on 2019 market conditions for central CA feedyards. Transportation, management, and harvest costs were based on UC Agriculture and Natural Resource cost studies. Time needed to haul, gather, feed, check and move cattle to new pastures were considered individual owner expenses and were not included in costs. Water charges, fertilizer, irrigation and fence repair were included in the pasture rental costs. Interest on operating costs was calculated on cash costs (weaning cattle purchased) and was calculated at 5.0% annual interest amortized over a 2.5-year period. All harvesting and marketing costs were based on the University of California Agriculture and Natural Resource (UCANR) cost and return study (Forero et al., 2017). To calculate cost per head, each treatment maintained the same number of animals. An account for each treatment are presented in Table 2.

Statistical Analysis

All statistical analyses were performed in R. The study was a completely randomized design with individual animals treated as the experimental unit. Performance data and carcass components were analyzed in a GLM procedure with model containing treatment as the fixed effect. Differences between treatments were determined by Tukey Honest Significance Difference using an α-level of 0.05.

Life Cycle Assessment Assumptions and System Boundaries

In order to determine the environmental impacts of each of the beef production systems, an attributional cradle-to-gate Life Cycle Assessment (LCA) was performed using a Scalable, Process-based, Agronomically Responsive Cropping Systems LCA (SPARCS-LCA) model framework (Marvinney and Kendall, 2020). This is a deterministic LCA model framework constructed in Microsoft Excel. System boundaries included the stocker and finishing (pasture, rangeland, and feedyard) phases. Animal performance, herd management practices, transportation, feed inputs, and machinery usage were empirically based. Figure 2 shows the schematic of the main components of the life cycle assessment for the four different beef systems examined. This LCA was produced following International Organization for Standardization

(ISO) 14040 standards. Because harvest and post-harvest operations typically contribute a minimal percentage of total water, GHG, and energy use to the life cycle environmental footprint of beef production (Asem-Hiablie et al., 2018), these operations and impacts were excluded from this analysis. Emissions from equipment manufacture, infrastructure and other long-term capital investments are also generally excluded from LCA system boundaries (due to their minor footprint) and so were not included (Lupo et al., 2013).

For this application, SPARCS-LCA model was parameterized with input quantities specific to each phase of the California beef production life cycle on a per head cattle per month basis to generate an input table. Each item in this table was assigned one or more reference inventories obtained from Ecoinvent and U.S. professional databases via GaBi ts v6 software (PE International, 2019), and the input quantity multiplied by the environmental flow values from the LCI. These values were multiplied by characterization factors obtained from TRACI v3.1 (USEPA, 2017) for particular environmental impacts to produce reference impacts by life cycle phase on a per head per month basis (see supplementary material). Impact categories were calculated on a per head basis each month for each system and subsequently divided by the total time the animal spent in each system (stocker, range, irrigated pasture, feedyard) to determine total environmental impact per steer. Although the mortality rate in this trial was zero, to accurately represent the four beef systems, mortality was set at 2% for the stocking phase and 2% for the finishing phase (Stackhouse-Lawson et al., 2012). The total for each phase was adjusted by the mortality of the succeeding phases to obtain the total for the production system per finished animal. After impact per steer and mortality rate were incorporated, per steer impact was divided by steer hot carcass weight to determine environmental impact per kg of hot carcass weight produced.

The following impact categories were reported: Global warming potential on a 100 year time horizon (GWP), freshwater use, energy use, smog formation potential, and land occupation, based on characterization factors obtained from TRACI 3.1 (USEPA, 2017). We accounted for greenhouse gas production (e.g. methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O)) from enteric ruminal fermentation, manure storage and handling, feed production, transportation and on-farm energy use. In order to more easily compare results to previous and future beef LCAs, the functional unit of reporting was set as 1 kg of hot carcass weight (HCW).

Enteric CH_4, manure CH_4 and N_2O emission

Carbon dioxide, methane, and nitrous oxide emissions from transportation and on-site manure, enteric, and fuel combustion as well as upstream industrial processes (for which sulfur hexafluoride and PFC emissions were also considered) were accounted for in calculation of GHG impacts. Biogenic carbon dioxide from soil and livestock respiration was treated as carbon neutral in GHG impact calculation, while methane from manure and enteric emission was treated separately from non-biogenic methane as per IPCC guidelines (IPCC, 2014). Greenhouse gases were converted to CO_2 equivalents (CO_2eq) using 100-year global warming potentials: $CO_2 = 1$, $CH_4 = 34$, $N_2O = 298$ (IPCC, 2014).

Enteric fermentation was based on IPCC 2006, Tier 2 methodology (IPCC, 2014). Gross energies (bomb calorimeter-derived total heat of combustion energy contents) were calculated using feed ingredients and animal characteristics from on-farm data for all four systems. Dry matter intake (DMI, kg d^{-1}) was calculated using NASEM (2016). The DMI required for maintenance was determined by the NEm requirement divided by the NEm content of the diet and the DMI required for BW gain was the NE required to meet the ADG goal divided by the NEg content of the diet. Both NEm and NEg were determined by the shrunk weight of the animal and the rate of gain as reported by NASEM (2016). Default CH_4 conversion factors (Ym) of 3.0% of gross energy intake were used for grain-systems and 6.5% gross energy intake for grass systems were consistent with other cattle LCA analysis (Stackhouse-Lawson et al., 2012; Stanley et al., 2018).

Manure CH_4 and N_2O emissions were calculated using the Agriculture module of the State Inventory Tool produced by the US Environmental Protection Agency (USDA, 2019). All formulas in the tool were based on IPCC (2014) Tier 2 methodology. The Agriculture module calculated CH_4 emissions for manure management by first calculating total volatile solids (VS; Mg animal mass^{-1} day^{-1}) produced by the state's livestock. For cattle, animal population was multiplied by the VS rate (kg head^{-1} year^{-1}) for total VS produced. For calves and all other livestock, animal population was multiplied by the typical animal mass (kg) by the VS rate, and number of days per year to obtain the total annual VS produced. This value was multiplied by maximum potential methane emissions, and the weighted CH_4 conversion factor, resulting in m3 CH_4. The total volume (m^3) CH_4 emitted was converted into CO_2 equivalents by multiplying by density of CH_4 (0.678 kg m^{-3} CH_4) and GWP of CH_4 (34). To estimate N_2O emissions from manure management, the Ag module first calculated the total K-nitrogen excreted. For cattle, animal population was multiplied by the K-nitrogen excretion rate (kg head^{-1} year^{-1}) for total K-nitrogen excreted. Next total K-nitrogen was separated into dry and liquid systems and multiplied by the corresponding emission factor. For this trial all cattle in the system were housed and drylots so the drylot emission factor of 0.2 kg N_2O-N kg N^{-1} was used. Finally, total kg N_2O emissions are converted to million MT on a CO_2 equivalence by multiplying by the GWP of N_2O (IPCC, 2014).

Stored manure from the scraping of feedyard pens was composted and sold to farmers, primarily orchard growers. Since the compost was not used for cattle feed we did not allocate the emissions from the manure compost to any of the beef systems. Soil N emissions from feed production (i.e. synthetic fertilizer) were accounted for in feed emissions. This trial utilized established CA pastures and no synthetic fertilizer or manure was applied to any of the rangelands or pasturelands used in this study. Pastures in this study had been used for cattle production for the last 50 years with little change in management practices over that time. Animals in this study were not intensively managed and minimal rotational grazing occurred. With no change in grazing management practices and little to no local carbon sequestration grazing research, soil carbon sequestration was not considered in this assessment.

Emissions from freight transport of feed and mineral inputs as well as the movement of cattle between locations were calculated based on transport distance and total mass and referenced with truck freight transport inventory data obtained from the Ecoinvent LCI database via GaBi ts v6 (PE International, 2019). Transport distances were calculated based on specific source location data where available, and based on spatially-weighted mean distances where specific source locations were not available (e.g., local alfalfa production). Emissions from feed production were calculated using the SPARCS-LCA model parametrized with input data from UCANR cost and return studies for alfalfa produced in the Sacramento Valley growing region; and obtained from the US Professional LCI database via GaBi ts v6 (PE International, 2019) in the case of other feed components including corn, tallow, CDS, and DDGs. Fuel consumption was based on empirical data where available and calculated based on vehicle operation time using vehicle type-specific data from the California Air Resources Board (CARB) OFFROAD model (CARB, 2007). Emissions from on-farm vehicle use were calculated from fuel-specific

LCI data for agricultural equipment operation taken from the EcoInvent LCI database via GaBi ts v6 (PE International, 2019).

Water and Energy Use

Consumptive water use included animal water intake, irrigation of crops and pastures, and feedyard water use. Based on Beckett and Oltjen (1993) consumptive water included only water that had the potential to be developed and/or diverted for human use. Therefore, rainfall was not included in this assessment. Water intake for all cattle was based on weight, temperature, and stage of production (NASEM, 2016) California feedyard managers provided total feedyard water usage for cattle in the feedyard treatments. Pasture irrigation demand was obtained from University of California cooperative extension economic cost and return analysis (Stewart and Macon, 2020).

Feedyard mill water and energy use was obtained from (Wiedemann et al., 2017). Fuel and energy use for pasture and feed crop management as well as transportation was calculated from Cost and Return studies (Long et al., 2015; Stewart and Macon, 2020), empirical data, and LCI (Life Cycle Inventory) data (see supplementary material) obtained from GaBi ts v 6.0 (PE International, 2019). Energy use for irrigation pumping was calculated after Marvinney and Kendall (2020), based on pump efficiency and energy use data from industry sources (Goulds Water Technology, 2019).

Smog and Land Occupation Calculations

Smog formation potential was calculated using TRACI 3.1 characterization factors (USEPA, 2017). Land occupation was calculated as ***area* × *occupation time*,** and reported in units of m^2 year, as per Ecoinvent and US Professional LCI databases accessed via GaBi TS v6 (PE International, 2019).

Results

1. Cattle performance and Carcass Characteristics

1.1 Cattle Performance

While stocked on irrigated pasture in Maxwell, CA, from July to November, all steers gained 0.40 kg d^{-1} (SD 0.07). When the grass-fed treatments (GF20, GR45, and GF25) were moved to Browns Valley, CA, rangeland, steers gained on average 0.61 kg d^{-1} (SD 0.10) from late November to mid-June. However, between the months of December to March there was limited rainfall and persistent cloud cover. During this period rangeland forage species remained dormant and stocked steers (GF20, GR45, and GF25) lost 18 kg (SD 5.0). During spring, forage quantity improved and cattle on grass (GF20, GR45, and GF25) rebounded and gained 1.95 kg d^{-1} (SD 0.12) for the duration of the grazing season (late Marth though early June). Cattle in the GF25 treatment gained 0.79 kg d^{-1} (SD 0.13) while on irrigated pasture in Davis, CA. Overall, forage nutritive value was greater for the Davis irrigated pasture compared to the irrigated pasture in Maxwell (Table 3). While in the feedyard, CON cattle gained 2.02 kg d^{-1} (SD 0.19) and GR45 gained 1.60 kg d^{-1} (SD 0.35).

Steer final weights varied across treatments ($P > 0.001$, Table 4). The CON steers finished with the highest final body weight (FBW) at 632 kg (SD 44) and GF20 finished with the lowest FBW of 283 kg (SD 26). There was no difference for FBW between GR45 and GF25 treatments ($P=0.38$) with FBWs of 551 (SD 39) and 570 kg (SD 29), respectively. Hip height of animals at harvest did not differ across treatments ($P=0.41$), as such frame size was not considered a factor for differences in FBW.

1.2 Carcass Characteristics

Hot carcass weight (HCW) followed the same pattern as FBW with CON having the heaviest HCW of 372 kg (SD 25), weighing 69 to 142 kg heavier than other treatments (Table 4; $P<0.05$). The GF20 treatment finished with the lowest HCW ($P<0.05$), with carcasses weighing 230 kg (SD 14). There was no difference between GF25 and GR45 treatments in HCW (551±16 versus 570 kg±22, respectively; $P>0.05$). Dressing percentage (DP) differed between all treatments ($P <0.001$). For the CON treatment DP was 61.8%, followed by the GR45 (57.5%), then GF25 (53.4%), and GF20 having the lowest DP (50.3%). Kidney pelvic heart fat (KPH) differed between CON and all other treatments ($P<0.05$) with the highest KPH of 2.89% and GF20 having the lowest KPH of 0.65%. Between GF25 and GR45 KPH did not differ ($P>0.05$), with KPHs valued at 1.3% and 1.65%, respectively.

As expected, back fat was greater for the CON treatment (11.7 mm) than all other treatments ($P<0.05$). Back fat was lowest for GF20 at 4.4 mm ($P<0.05$) but was not different between GF25 and GR45 (6.6 versus 7.4 mm, respectively; $P>0.05$). Marbling scores and quality grade were greater for CON compared to all other treatments ($P<0.05$) with a marbling score of 421 and quality grade of 7.04. Cattle in the GR20 had the lowest marbling score ($P<0.05$) and quality grade ($P<0.05$) when compared to all other treatments with a marbling score of 285 and a quality grade of 3.95. The GR45 finished with a marbling score of 341 and a quality grade of 5.30 and the GF25 finished with a marbling score of 333 and a quality grade of 8.81. There was no difference in marbling score ($P>0.05$) or quality grade ($P>0.05$) when comparing the GF25 and GR45.

Yield grade (YG) did not differ between CON and GR45 treatments ($P>0.05$) with yield grades of 2.86 and 2.78, respectively. Yield grade for the GF20 was lower compared to all other treatments ($P<0.05$) with an YG value of 1.45. Yield grade for GF25 was different from all other treatments at 2.14 ($P<0.05$). Longissimus Muscle (LM) area was different for CON compared to all other treatments ($P<0.05$) with an LM area of 79.7 cm^2. No difference in LM area was observed between GF20, GR45, and GF25 ($P<0.05$) with LM areas ranging from 65.0 to 68.4cm^2. When evaluating the shape of the LM using the length to depth (L:D) ratio a significant difference was observed for the grain-fed steers (CON and GR45) compared to the grass-fed only treatments (GF20 and GF25) with grain-finished treatments having a smaller L:D ratio ($P<0.05$). Grass-finished treatments with a greater L:D ratio demonstrates that the LM were more oblong in shape than grain-finished treatments.

2. Financial Analysis

Without marketing or processing costs (i.e. cut and wrap and harvesting) the CON produced both the lowest cost per steer and lowest breakeven of $4.00 per kg of HCW (Table 5). When marketing and harvesting costs were included cost per steer for the CON treatment increased to a breakeven of $6.01 per kg of HCW. The cost per steer was lowest for the GF20 with and without harvesting and marketing costs. However, with the lowest harvest weight and the lowest dressing percentage, the breakeven prices were highest for the GF20 treatment at $6.11 per kg of HCW without and $8.98 per kg of HCW with marketing and processing. Compared to the CON treatment the breakeven per steer without and with marketing and harvesting costs were greater for both the GR45 treatment and the GF25. Breakeven prices for the GR45 and GF25 treatments were greater than the CON, but less than the GF20. The breakeven without processing and marketing for the GR45 was $5.29 and with processing and marking $8.02. The breakeven without processing and marketing for the GF25 was $5.60 and with processing and marking $8.33.

3. Life Cycle Assessment

3.1 Energy

The energy footprint was largest for CON at 18.69 MJ kg HCW^{-1}, followed by GR45 at 13.84 MJ kg HCW^{-1}, then GF25 at 8.85 MJ kg HCW^{-1}, and GF20 with the lowest energy footprint at 7.65 MJ kg HCW^{-1} (Table 6). The energy footprints for the CON and GR45 treatments were greater than the grass-fed treatments due to increased transportation and farming inputs needed to produce and deliver their feedyard rations. The GF25 system produced a slightly greater energy value compared to GF20 due to the increased energy demands for irrigating pasture. Breaking down the energy use for each system, in the CON treatment feed and mineral constituted 45% of the total energy, followed by transportation at 38%, and on farm energy at 17% (Figure 3). For the GR45 system, 30% of the energy required stemmed from feed and mineral production, 45% from on farm, and 25% from transportation. For the GF25 system on farm energy use was 98% of the total energy footprint, feed and mineral was 2%, and transportation made up 1% of total energy. Within the GF20 system, 98% of the energy required was on farm, 1% from feed and mineral, and 1% for transportation.

3.2 Smog Formation

The smog formation potential was highest for the CON (0.15 O_3 eq kg HCW^{-1}) followed by GR45 (0.08 O_3 eq kg HCW^{-1}), with the GF20 (0.01 O_3 eq kg HCW^{-1}) and GF25 (0.01 O_3 eq kg HCW^{-1}) resulting in substantially smaller smog formation impacts (Table 6). The lower smog footprint of the 100% grass-fed system was expected due to lower transportation and production inputs (i.e. feed production) compared to the conventional system. In the CON system 56% of the smog formation was from transportation, 24% from feed and mineral production, 19% from on farm use, and less than 1% from enteric and manure emissions (Figure 4). In the GR45 system 53% of smog emissions were from transportation, 25% from feed and mineral production, 19% from on farm production, and 4% from enteric and manure production. For the GF25 system 33% of smog formation was due to enteric and manure production, 32% from feed and mineral production, 27% from on farm and 7% from transportation. The GF20 system resulted in 32% of emissions from feed and mineral, 32% from enteric and manure production, 28% from on farm, and 7% from transportation (Figure 4).

3.3 Consumptive Water Use

The GF25 treatment resulted in the largest water footprint of 1,214 L kg HCW^{-1}, followed by CON with a water footprint of 910 L kg HCW^{-1}, then GR45 at 664 L kg HCW^{-1}, and finally GF20 with the lowest water footprint of 465 L kg HCW^{-1}. Within the CON system, water for feed and mineral constituted the largest portion of consumptive water at 78%, followed by pasture irrigation water at 18%, animal drinking water at 3.5%, and on farm water use at less than 0.3% (Figure 5). For the GF20 system, irrigated pasture (from the stocking phase) was the largest contributor to the water footprint at 80%, next was drinking water use at 18%, and on farm water use and feed and mineral water were both under one percent of the total consumptive water use. For the GR45 treatment, feed and mineral water resulted in 56% of the water usage, followed by irrigated water for pasture at 34%, then animal drinking water at 9%, and on farm water use at less than 1%. With the GF25 utilizing irrigated pasture during both the stocking and finishing phases, irrigated pasture represented the largest portion of consumptive water used at 88%. Drinking water consisted of 11% of consumptive water use and both feed and mineral and on farm water used less than 1% of consumptive water. Overall, the type of grass-fed system greatly affected consumptive water usage with GF20 requiring 50% less consumable water compared to the CON system, and the GF25 system, that required irrigated pasture during two phases of production, required 33% more water compared to the CON system.

3.4 Global Warming Potential

The CON beef systems resulted in the lowest GWP of 4.79 CO_2eq kg HCW^{-1} (Table 6). Within this system enteric methane accounted for 54% of emissions, followed by feed and mineral emissions at 14% and on farm energy and total transportation and manure emissions all at 11% (Figure 6). When compared to the CON system the GWP for GF20 was 40% greater at 6.74 CO_2eq kg HCW^{-1} (Table 6). The GWP value was greater for the GF20 system principally due to the increase in enteric methane production and decreased harvest weight and dressing percentage. Specifically, within GF20 system enteric fermentation accounted 95% of GWP, manure at 3%, and feed and mineral, transportation, and on-farm at 1% or less. The GR45 treatment (6.65 CO_2eq kg HCW^{-1}) resulted in slightly lower GWP than GF20, but was 39% greater than CON. The GF25 treatment had the highest GWP that was 74% greater than CON with a value of 8.31 CO_2eq kg HCW^{-1}. Within the GR45 treatment, enteric fermentation accounted for 81% of emissions, manure emissions at 6%, feed and mineral at 5%, transportation and on farm emissions at 1%. The stocker phase accounted for 17% emissions in CON, 15% in the GF25 treatment, 5% in the GF20 and 10% in the GF25.

3.5 Land Occupation Rate

Land occupation rate was lowest for the CON system at 1.28 m^2 year kg HCW^{-1} (Table 6). In comparison, due to the large amount of rangeland required, the GF20 required the greatest land occupation rate at 11.25 m^2 year kg HCW^{-1}, followed by GF25 at 9.82 m^2 year kg HCW^{-1}, then GR45 at 9.64 m^2 year kg HCW^{-1}. For a more comprehensive view on land occupation rate, land occupation was subdivided into irrigated pasture, rangeland, and farmland and mining

(Table 7). When comparing irrigated pasture, land occupation for GF25 was 0.08 m^2year kg HCW^{-1}. This was 400% greater than the CON system at 0.02 m^2 year kg HCW^{-1}. The GF20 had the largest rangeland land occupation rate of 10.48 m^2 year kg HCW^{-1} followed by the GF25 at 8.25 m^2 year kg HCW^{-1} and the GR45 at 7.95 m^2 year kg HCW^{-1} (Table 7). As expected, the CON and GR45 systems required considerably more farmland and mining land compared to the grass-fed systems due to commodity production at 0.81 m^2 year kg HCW^{-1} and 1.10 m^2 year kg HCW^{-1}, respectively. The GR45 system had a slightly greater farmland and mining land occupation rate compared to the CON system due to the greater in weights of the cattle and the lower gain to feed ratio.

Discussion

1. Cattle Performance and Carcass Quality

1.1 Final Body Weight, Dressing Percentage, and Yield and Quality Grade

In the present study, GF20 and GF25 finished weights (478 and 570 kg, respectively), were similar in performance to previous grass-fed studies completed in the Eastern U.S., where animals finished between 400-559 kg (Brown et al., 2009; Scaglia et al., 2012; Scaglia et al., 2014; Schmidt et al., 2013). In comparison to a grass-fed beef study performed in California by Cruz et al. (2013), the GF25 finished weight was 45 kg lower. Although breed, age of harvest, and location were similar between the two Californian grass-fed beef studies, weather and nutritional logistics were different. In the California Mediterranean climate, the majority of rainfall occurs during the late fall-winter to early spring, with high forage nutrition available on rangelands between February-May (George et al., 2001). In Cruz et al. (2013), despite the ample rainfall in December (NOAA, 2013), to avoid a decrease in nutritional plane during the winter, steers on rangeland were supplemented with alfalfa hay for a 40-day period. In our study, due to delayed rains and persistent overcast, rangeland nutrition remained poor throughout the entire winter resulting in an 18 kg weight loss for grass-fed steers between the months of November-March.

The discrepancies between previous and the present studies reveal a number of potential vulnerabilities and resilience issues associated with grass-fed beef systems. In the West where droughts and fire continue to be an issue, inclement weather could damage pasture or rangeland, jeopardizing a rancher's ability to steadily produce grass-fed beef. One option for ranchers is to harvest grass-fed cattle early. When steers were harvested at an early age of 20 months, FBW was less than other treatments at 478 kg, but still heavier than other grass-fed beef systems in the East (Brown et al., 2009). If harvesting cattle early is not feasible, a combined grass-fed and short term grain-finished program may be a possible alternative. When 20 month grass-fed steers were placed in the feedyard for a 45 day period, cattle gained 73 kg (1.62 kg d^{-1}). The total weight gain resulted in similar harvest weights compared to cattle that were finished on grass for an additional 5 months in the GF25 treatment ($P=0.38$). The ability to move cattle off rangeland into a confined feeding operation, even for a short period of time, may help add resilience to niche market/ farmers market beef programs.

Studies have shown grass-fed beef DP range from 49% to 60%, (Brown et al., 2009; Scaglia et al., 2012; Scaglia et al., 2014; Schmidt et al., 2013; Stanley et al., 2018) with one study producing a dressing percentage of 62% (Schmidt et al., 2013). Although some grass-fed cattle have produced dressing percentages over 60%, most studies have shown cattle that are 100% grass-fed yield lower dressing percentages compared to conventional cattle (Brown et al., 2009; Kim et al., 2012; Scaglia et al., 2012). Our study was no exception, with all grass-fed treatments resulting in lower dressing percentage compared to CON ($P>0.05$). Increasing days on feed improved grass-fed cattle DP, with cattle in the GF25 treatment dressing 3% units greater compared to GF20 at 53%, (*P>0.05*). Interestingly, although animals in the GF25 and GR45 treatments were fasted for the same amount of time and finished at similar weights, GR45 had a 4% units greater dressing percentage (*P<0.05*). This suggests that differences in dressing percentages may be a result of diet and the subsequent effects on muscle and organ development. Cruz et al. (2013) determined that grass-fed steers resulted in heavier rumen weights compared to conventional steers (*P<0.05*) likely linked to increased ruminal papillae length (most noted in calf development in dairy) which would result in reduced dressing percentage. In addition, digestibility is lower and particulate passage rates of high fiber diets are slower than those of concentrate diets which results in greater gut fill at the time of harvest for grass-fed cattle, even with adequate feed withdrawal periods (Demment and Van Soest, 1985). Thereby, more fibrous diets with slower rates of digestibility and passage may result in an inflated live weight at times of harvest as compared to grain-finished animals, and this is reflected in the lower dressing percentage of these cattle.

Consistent with other studies (Brown et al., 2009; Scaglia et al., 2014; Schmidt et al., 2013), the grass-fed treatments resulted in lower quality grades and marbling scores compared to the CON treatment (P<0.05). Although marbling score is an indicator of carcass quality, a greater marbling score does not necessarily correlate with greater consumer satisfaction (Platter et al., 2003), especially with consumers who prefer grass-fed beef (Miller, 2020). In one study when consumers were asked to choose a steak based on marbling, more consumers in Chicago preferred low marbling steaks compared to consumers residing in San Francisco, suggesting consumer perception for marbling is depended on region (Killinger et al., 2004). In addition, studies have shown that grass-fed beef consumers prefer grass-fed beef compared to conventional beef because they believe grass-fed beef is healthier partially due to its lower fat content (McCluskey et al., 2005; Xue et al., 2010). Therefore, it remains to be determined if the grass-fed beef with lower quality grade negatively affects the marketability of the product or sustainability of the system.

1.2 Ribeye Size and Shape

Consumers prefer larger ribeye size, with larger ribeye steaks selling faster than smaller ribeye steaks (Leick et al., 2011; Sweeter et al., 2005), indicating that ribeye size affects consumer purchasing decisions. Conventionally fed beef had the largest LM area of 79.71 cm^2 ($P<0.05$). No difference in LM size was observed for the GF20, GR45, and GF25 treatments (64.95 cm^2 – 68.43 cm^2; $P>0.05$). Several researchers observed smaller LM areas for grass-fed animals as compared to grain fed animals (Berthiaume et al., 2006; Cruz et al., 2013; Kerth et al., 2007; Roberts et al., 2009); however, no study has yet to report differences in LM shape. The present study demonstrated that the CON treatment had a lower length to width ratio, a rounder shape, compared to the GF20 and GF25 treatments. Interestingly, although the GR45 treatment had been on pasture for 20 months, after 45 days on grain in a feedyard setting the LM shapes were not statistically different than the CON ($P>0.05$), and were different from the 100% grass-fed treatments ($P<0.05$). Currently, it is unknown if consumers would evaluate ribeye shape when making purchasing decisions. However, with continued consumer interest in grass-fed beef production (McCluskey, 2015), ribeye shape may be a factor in purchasing decisions in the years to come.

2. Financial durability

Treatment breakeven costs were 40-50% greater for all grass-fed and GR45 treatments as compared to conventional beef production (Table 5). Despite the greater costs of production, grass-fed treatment breakevens with processing costs were still 40-50% less than the 2019 USDA national average direct to consumer whole carcasses prices (\$15.93 kg HCW^{-1}, USDA-AMS, 2019). In terms of total net return, breakeven multiplied by kg of beef produced was far greater for the GF25 and GR45 compared to the GF20, therefore both the GF25 and GR45 in this trial were more profitable treatment compared to the GF20. Although all three non-conventional beef systems had the potential to be profitable, during the trial we encountered several obstacles that could hinder long-term financial successes for our grass-fed beef production systems.

Representing current California grass-fed beef production systems, both GF20 and GF25 steers were 100% naturally raised. In order to stay compliant with the natural program, animals were never given hormones or antibiotics throughout the animal's lifecycle. Unfortunately, during the fall of 2018, 20 steers in the present study were infected with pinkeye in one or both eyes. Pinkeye can have devastating losses on any type of beef operation, with cattle producers regarding pinkeye as one of the most troubling disease affecting their cattle (George, 1990). Following veterinary animal protocols steers were treated with antibiotics to reduce animal discomfort and prevent blindness, then removed from the 100% grass-fed treatments. The removal of these animals from the natural program was not accounted for in our financial analysis, however removing animals from a natural beef program would have profound financial implications for producers, especially if the producer did not have the ability to continue to raise and market non-natural cattle simultaneously.

Since 1967, the number of abattoirs (packing houses) in the U.S. has dramatically declined from over 10,000 to less than 3,000 packing houses in 2010 (USDA, 2011). During the project there were only two packing houses located within 1,000 miles that had the capacity and certification to harvest 10-20 natural grass-fed animals in a single lot. With the number of packing houses decreasing and the distance between cattle operations to packing houses increasing, small-scale and niche market producers will continue to face harvesting issues unless the number of packing houses increases. Despite these obstacles, on a national scale the grass-fed beef market is expected to grow globally by 40 billion U.S. dollars between the years of 2020-2024, suggesting a strong future for grass-fed beef (Technavio, 2020). Furthermore, California producers have a large local market for their beef, with the largest number of farmers markets (827) in the country (USDA, 2012).

3. Life Cycle Assessment

3.1 Energy

Similar to other LCAs, in the present study feed and mineral production was the largest contributor to energy demand for conventional beef production (Asem-Hiablie et al., 2018; Pelletier et al., 2010; Rotz et al., 2015). However, in contrast to these LCAs, our beef system required the transportation of feedstuffs (i.e. corn) from the Midwest to California. This high transportation energy input resulted in a greater energy input for the CON cattle (16.6 MJ kg HCW^{-1}, feedyard only) compared to LCAs performed in the Midwest and Panhandle (Rotz et al., 2015; 13.7 MJ kg HCW^{-1}).

Less energy was required to produce grass-fed steers (7.65 MJ kg HCW^{-1} for GF20 and 8.58 MJ kg HCW^{-1} for GF25) compared to treatments finished in the feedyard (18.69 MJ kg HCW^{-1} for CON and 13.84 MJ kg HCW^{-1} for GR45). Similarly, Pimentel and Pimentel (1996) and Koknaroglu et al. (2007) determined that solar powered grass-fed systems were less energy-intensive compared to the fossil fuel demanding conventional beef systems. However, Pelletier et al. (2010) demonstrated that grass-fed production in the Midwest (33.8 MJ kg HCW^{-1}; assuming 53% DP) was more energy-intensive than conventional beef production (19.5 MJ kg HCW^{-1};

assuming 62% DP). Unlike the present study, cattle were intensively managed on fertilized pastures and required large amounts of hay during winter, resulting in a high energy footprint (Pelletier et al. 2010,). Our results highlight regional disparities between grass-fed beef production systems, and illustrate how grass-fed beef systems are not necessarily directly comparable due to local conditions and logistics.

3.2 Smog Formation Potential

Of the top ten cities in the country with the worst air quality, six are Californian (American Lung Association, 2020). Agricultural activities are a major source of California NO_x emissions (a major component of smog formation) (Almaraz et al., 2018), and the smog formation potential impact is an important metric to evaluate California beef sustainability. Our model determined the GF20, GF25, and the GR45 produced 93%, 92%, and 50% fewer smog emissions than did the CON system (Table 6). However, as most of the grain used was grown elsewhere and transported to California, most of the smog-forming potential occurred outside the state. If our study had utilized nitrogen application on pastures, NO_x emissions would have been substantially higher, resulting in greater local smog formation potential. Although smog has not commonly been examined in prior beef LCA work, an LCA comparing photochemical ozone creation potential (POCP), a precursor to smog, determined that grass-fed systems produced lower POCP values compared to the conventional system (Battagliese et al., 2015). The greater POCP emissions for the conventional beef system was due to greater feed inputs (i.e. corn and corn silage) compared to the grass-fed system.

3.3 Consumptive Water Use

Grass-feeding for 25 months (GF25) had the highest water footprint requiring 1,254 L/ kg HCW for the stocker and finishing phase, 150% greater than the CON system. This result was similar to those of Capper (2012) who used a deterministic model to determine that grass-fed beef systems required 132% more water than did conventional beef systems. In our present study, the water footprint of CON was within range of those found previously, where conventional beef's water footprint for the stocker and finishing phases ranged from 683-5,341 L kg CW^{-1} (based upon on Rotz assessment that cow-calf was responsible for 30% of the conventional beef water footprint; Rotz et al., 2015). Feed (i.e. pasture, mineral, and feedyard rations) was responsible for 96% of total water consumption, and drinking water was responsible for 3% of water consumption for the CON steers. This proportion of water consumption for the CON system was nearly identical to Beckett and Oltjen (1993) who determined for the entire conventional beef lifecycle, including cow-calf production.

In contrast to the GF25 system, the GF20 system (465 L kg HCW^{-1}) did not utilize irrigated pasture during the finishing phase, resulting in a water footprint 50% lower than the CON system and 63% lower than the GF25 system. This finding was consistent with Battagliese et al. (2015) who determined that conventional beef production used more water compared to non-irrigated, grass-fed beef operations. Although the GF20 system produced the lowest water footprint, the system also resulted in the lowest harvest weight and quality grade. In order to improve quality grade without compromising water footprint, placing cattle in the feedyard for 45 days (GR45), improved quality grade ($P<0.05$) while only slightly increasing the consumptive water use (678 L kg HCW^{-1}).

3.4 Global Warming Potential

In this study, GWP for the CON system was 4.91 kg CO_2eq kg HCW^{-1} which were similar to Stackhouse-Lawson et al. (2012) who modeled California Angus conventional beef systems, resulting in a GWP of 4.95 kg CO2eq kg HCW^{-1} (for stocker and finishing phases only). Our CON GWP value was also similar to conventional beef production systems where the GWP for the stocker and finishing phases of beef production was 4.40 kg CO2e kg HCW^{-1} (Beauchemin et al., 2010) The greater GWP values for California beef production systems compared to the Alberta system may be due to increased transportation and feed input emissions associated with producing beef in California. However, it is important to note both the Beauchemin et al. (2010) and Stackhouse-Lawson et al. (2012) studies used the 4th edition IPCC greenhouse gas equivalent of 25 for CH_4 which is lower than the 5th edition IPCC CH4 equivalent value of 34 that was used in the present study.

The GF25 system GWP was 174% greater at 8.53 CO_2eq kg HCW^{-1} compared to CON (Figure 3), similar to results that found that grass-fed beef systems resulted in a carbon footprint over 167% greater than conventional beef systems (Capper, 2012). The principal reason for greater GWP in grass-fed beef was due to increased enteric methane production from the high forage diets and increased days on feed. Though the GF20 cattle GWP was still greater than the CON system at 6.90 CO_2eq kg HCW^{-1}, the GWP was 30% less than the GF25 system (Figure 2). Despite the GF25 system producing a greater dressing percentage and heavier harvest weight, these factors did not offset the increased methane emissions from increased days on feed. Interestingly, compared to the GF20 system, when cattle were moved to the feedyard in the GR45 treatment, GWP decreased slightly, producing a GWP of 6.87 CO_2eq kg HCW^{-1}. The present study is the first to demonstrate that finishing cattle on grain for a short period of time after being grass-fed for an extended period of time results in not only increased carcass quality, but also a lower carbon footprint.

Even though our grass-fed systems resulted in greater carbon footprints compared to our grain-finished systems, some studies have shown the ability for grass-fed beef systems to sequester carbon, offsetting grass-fed beef cattle's GHG enteric methane production (Stanley et al., 2018; Pelletier et al., 2010). In Stanley et al., (2018) when conventional and grass-fed finishing phases were compared and carbon sequestration was not considered, the grass-finished system GWP was 158% greater than the conventional beef systems. In contrast, when carbon sequestration was factored into the model, the grass-fed system produced a net negative GWP of -6.65 CO_2eq kg HCW^{-1} (Stanley et al., 2018). Similarly, using soil organic carbon sequestration rates for US pastures undergoing improvement or transition to management intensive grazing systems (Phetteplace et al., 2001), Pelletier et al., (2010) determined that grass-fed beef systems in the Midwest produced 15% fewer emissions compared to conventional beef. Despite both studies factoring in soil sequestration, no previous study has accounted for decreasing soil organic carbon sequestration rates over time, therefore it is unknown how long each of these grass-fed systems would be able to continue to sequester carbon. In regards to potential soil sequestration in the California Rangelands, studies have observed either no change or a continual decrease in soil organic carbon (Ryals et al., 2015). It has been hypothesized that the soils have slowly released carbon as they transitioned from perennial to annual grasslands over multi-decadal timescale (Ryals et al., 2015). Overall, without real time soil carbon measurements, we cannot infer that the grass-fed systems in our study either contributed to soil carbon loss or gain.

3.5 Land Occupation Rate

Previous LCAs have determined that grass-fed systems require greater land space compared to conventional beef systems (Stanley et al., 2018; Tichenor et al., 2016; Pelletier et al., 2010). Our studies were consistent with these findings with GF20 and GF25 systems requiring substantially greater land, 11.25 m^2 year kg HCW^{-1} and 9.82 m^2 year kg HCW^{-1}, respectively, compared to CON, 1.28 m^2 year kg HCW^{-1}. However, the grass-fed systems in our study required an even greater amount of land compared to previous grass-fed beef LCA's (Stanley et al., 2018; Pelletier et al., 2010). This greater demand for land occupation required by the GF20, GF25, and GR45 was principally due to cattle management strategy and the type of land they utilized. Unlike Stanley et al. (2018) who utilized high quality pasture throughout the finishing phase for grass-fed beef, the present study utilized rangeland. Rangeland is an essential part of cattle's lifecycle in the west, but due to lower nutritive value rangeland requires lower stocking rates compared to pastureland (George et al., 2001). For reference, in the present study, when cattle were on rangeland (GF20, GR45, GF25) they required approximately 0.41 ha/ month. In comparison, when the GF25 cattle were moved to irrigated pasture, land occupation was decreased to 0.07 ha/ month. By moving cattle from rangeland to either irrigated pasture (GF25) or to the feedyard (GR45) the total land footprint decreased (Table 6), demonstrating that finishing cattle on irrigated pasture or feedyards resulted in more beef production with fewer land resources. However, unlike pastureland or cropland, that can be utilized to produce a variety of food sources, rangeland cannot be used to grow crops and is most efficiently used by ruminants. When land footprint was evaluated by type of land, CON had the greatest farmland and mineral footprint at 0.81 m^2 year kg HCW^{-1} and the GF20 had the lowest footprint at 0.01 m^2 year kg HCW^{-1} (Table 7). In contrast, GF20 had the highest rangeland footprint at 10.5 m^2 year kg HCW^{-1}, while CON had a 0 m^2 year kg HCW^{-1} footprint. These disparities in land footprints demonstrate the importance of incorporating land type into environmental assessments because not all land can be utilized in the same manner. However, despite the type of land occupation, grass-fed beef's large land footprint does present an issue. If the U.S. beef supply chain converted to 100% grass-fed beef, current grass resources could only support 27% of the current beef supply (Hayek and Garrett, 2018). Therefore, to maintain food security while meeting consumer demands there needs to be a balance between conventional and grass-fed beef systems.

Conclusion

Our study illustrated the complexities underpinning environmental sustainability, for no beef system resulted in an absolutely lower environmental footprint. Instead the varying grass-fed and grain-beef production systems resulted in systematic and proportional trade-offs. In the CON system, despite having the lowest GHG footprint, it had the highest energy and smog footprints. Water use in the GF20 system was substantially lower compared to GF25, but the GF20 cattle had the lowest quality grade, lowest HCW, and highest breakeven costs. Trade-offs were also observed for land occupation, with the GF20 system resulting in the highest land footprint (due to the large amount of rangeland required) but required minimal cropland. In terms of animal performance compared to the CON all systems (GF20, GF45, and GF25) resulted in lower dressing percentages, lower HCWs and lower quality grades. This decrease in performance illuminates one of the greatest impediments of producing grass-fed beef. The increased days on feed and decreased HCW resulted in higher costs per kg of hot carcass weight for the GF45 and grass-fed systems. However, with the continuing increase in demand for niche market beef, producers may be able to overcome this financial obstacle.

In conclusion, our study demonstrated that nuances of grass-fed and grain-fed beef production result in varying economic, animal performance, and environmental trade-offs rather than being system absolutes. Furthermore, we underscored the importance of obtaining system specific performance data to accurately depict environmental impacts of beef production. For example, in the GF20 system if an average grass-fed dressing percentage of 55% (Schweihofer, 2013) was used instead of our empirically derived 50.2%, the GWP for GF20 would have decreased by 10%, resulting in an inaccurate GWP. Therefore, grass-fed beef systems are not interchangeable and to accurately assess the performance and environmental impacts of these systems, they should be evaluated on a regional and management strategy basis. In the future we plan to further investigate the sustainability and productivity of these grass-fed and grain-fed beef systems by evaluating palatability, food safety, and beef nutrition.

DISCLOSURES

Conflict of Interest: Authors declare no conflict of interest.

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Figure 1

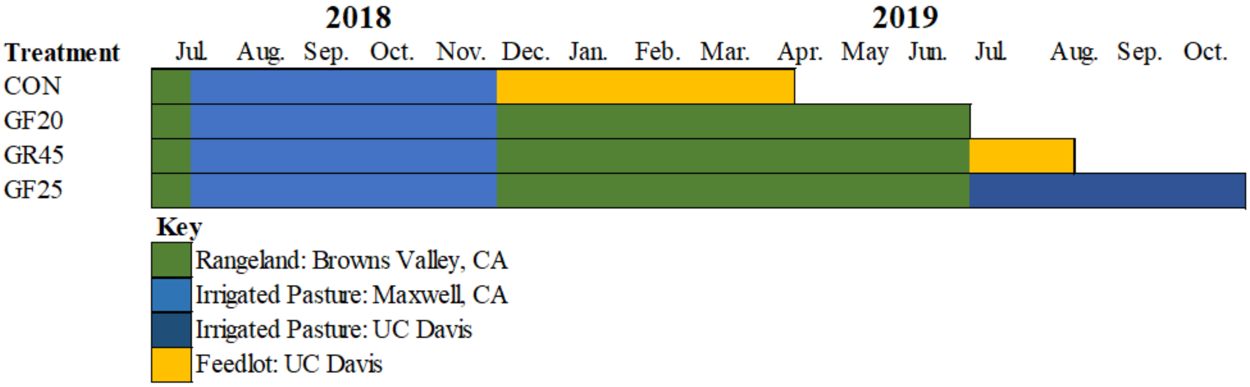


Figure 2

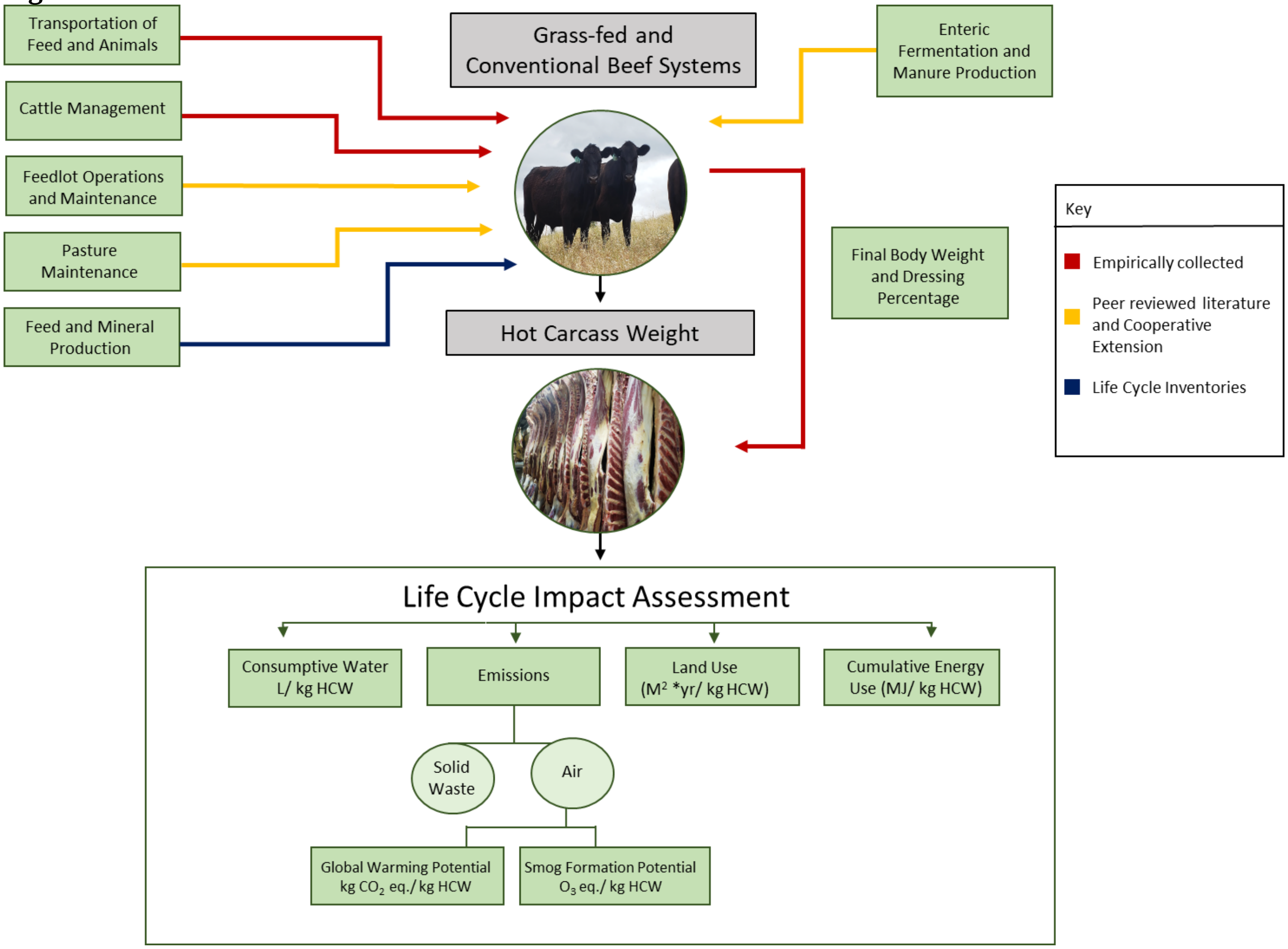


Figure 3

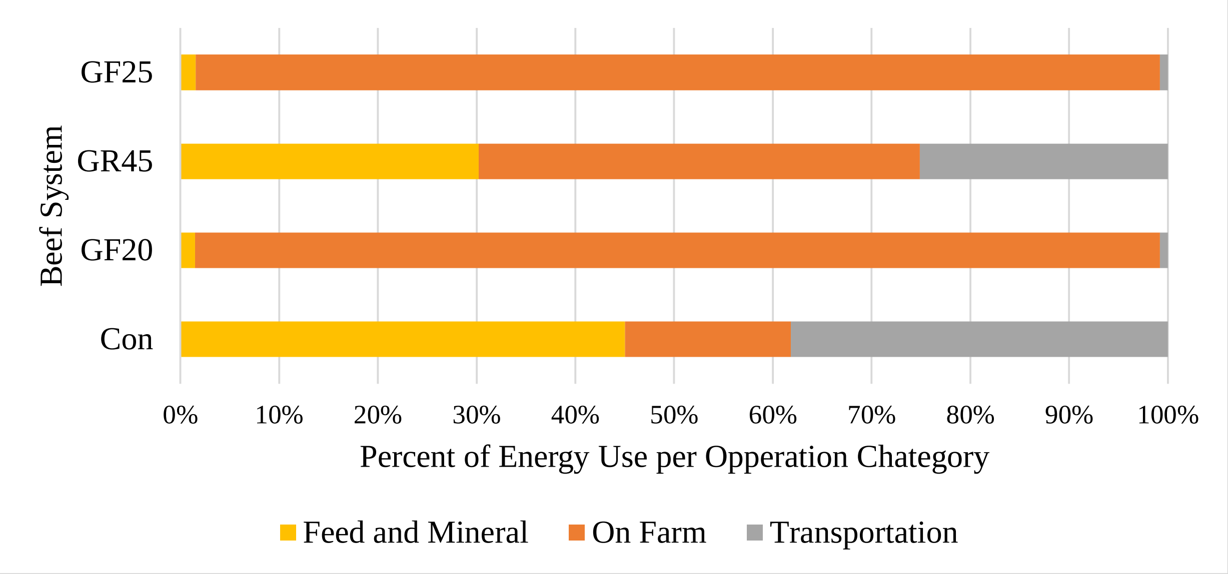


Figure 4

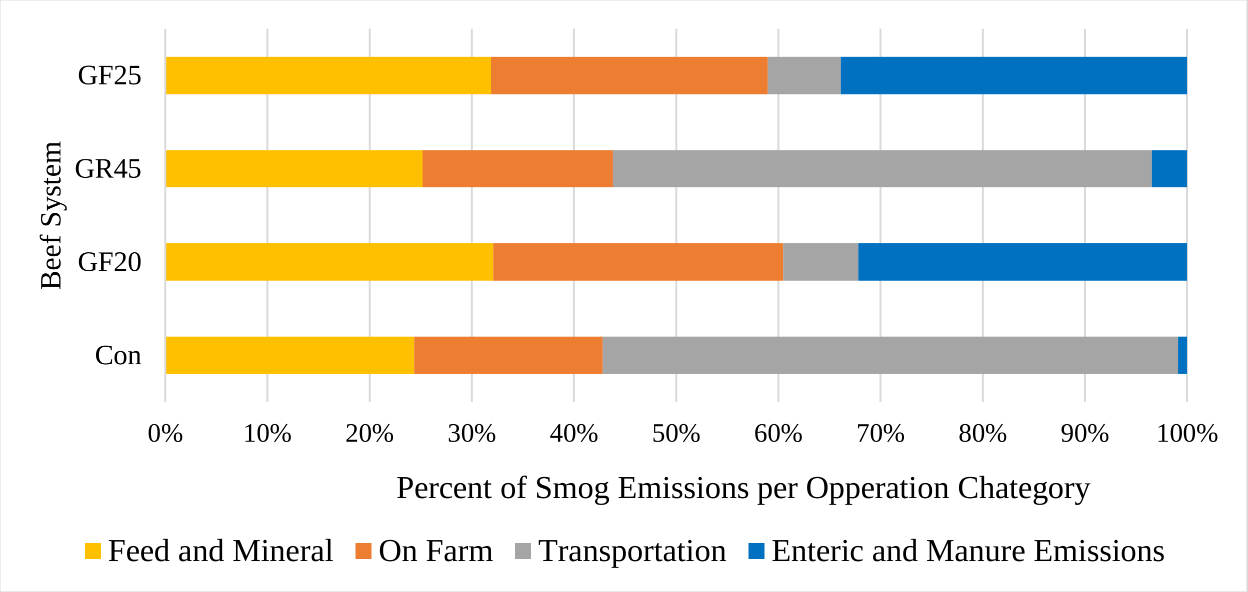


Figure 5

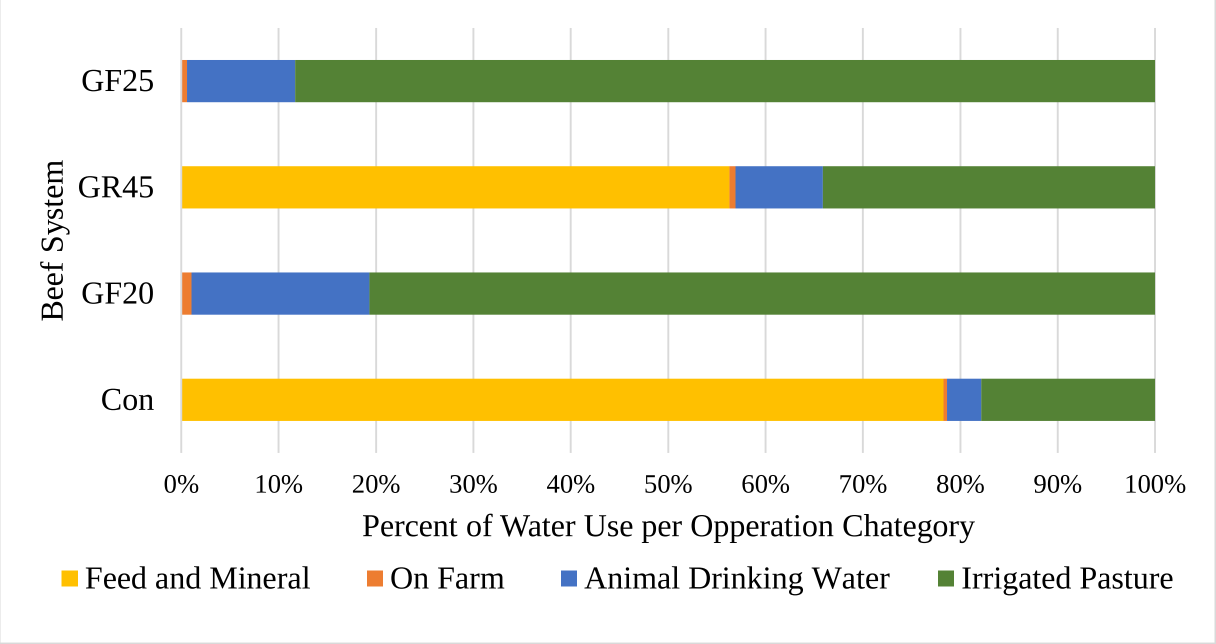
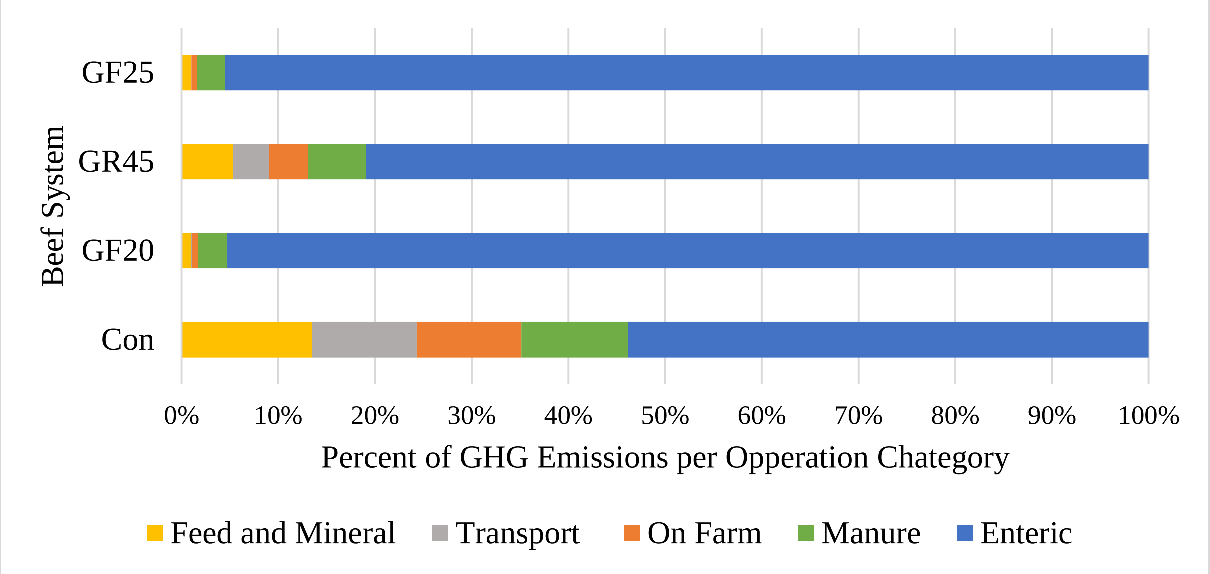


Figure 6



List of Tables

Table 1

Item	Receiving	Intermediate	Finishing
Ingredient		% Dry Matter Basis	
Rolled Corn	41.0	51.1	72.0
Distillers Grains	20.0	20.0	6.00
Fat	1.50	2.0	3.00
Molasses	8.00	7.00	3.00
Alfalfa Hay	15.0	10.0	5.00
Wheat Hay	12.0	8.00	6.00
Calcium Carbonate	0.82	1.15	1.80
Urea (45 N)	0.35	0.40	1.40
Magnesium Oxide	0.00	0.00	0.20
Rumensin	0.02	0.02	0.50
Beef Trace Salt	0.32	0.32	0.32

[1] CON - steers stocked on pasture then finished in a feedyard for 128 days, GR45 - steers grass-fed for 20 months with a 45-day grain-finish

Table 2

Item	CON	GF20	GR45	GF25
	Treatment[1][2]			
Purchase Price, $/hd	845	845	845	845
Operating Inputs, $/hd				
Irrigated Pasture	61	61	61	161
Rangeland	-	150	150	150
Salt/Mineral	-	12.5	12.5	17.5
Veterinary/Medical	16.90	12.68	13.5	14.37
Death Loss (2% of Purchase Price)	1.25	16.90	16.90	16.90
Brand Inspection	1	1.25	1.25	1.25
Checkoff	-	1	1	1
Harvest Costs	-	100	100	100
Cut and Wrap	-	525	695	662
Marketing Costs	-	35	35	35
Stock Trailer	2.4	24	24	36
1-ton Pickup Truck	80.25	185	207	257
ATV	5.25	13.65	13.65	18.9
Feedlot Yardage	469.56	-	154.8	-
Feed Costs	40.3	-	13.95	-
Net Operating Costs, $/hd	655	1138	1499	1471
Cash Overhead Costs, $/hd				
Interest on Operating Loan	21.17	60	65	94.58
Insurance (Liability)	22	22	22	22
Total Cash Overheads, $/hd	43.17	82	87	116.6

[1] Assuming 20 animals in each treatment

[2] CON - steers stocked on pasture then finished in a feedyard for 128 days, GF20 - steers grass-fed for 20 months, GR45 - steers grass-fed for 20 months with a 45-day grain finish, GF25 - steers grass-fed for 25 month.

Table 3

	Grass diets			Grain diets	
Item	Irrigated Pasture Maxwell, CA	Rangeland Browns Valley, CA	Irrigated Pasture, Davis, CA	Feedyard Ration, CON	Feedyard Ration, GR45
Days in System	201	151	134	128	45
Analyzed composition, %					
DM	34.52	35.53	27.94	86.26	88.27
CP	10.65	9.13	12.70	14.8	15.95
NDF	60.45	59.45	53.20	26.65	29.50
ADF	39.25	40.98	35.96	17.41	19.48
Ash	10.73	10.26	11.20	6.24	6.17
EE	2.67	2.83	2.25	6.83	6.74
Ca	0.47	0.43	0.55	0.68	0.63
P	0.23	0.19	0.19	0.31	0.39
Mg	0.25	0.13	0.43	0.25	0.21
K	1.90	1.15	1.85	0.90	0.92
S	0.29	0.10	0.27	0.16	0.23
Calculated energy, Mcal kg DM[1]					
ME	2.38	2.26	2.52	3.33	3.37
NEm	1.50	1.39	1.62	2.30	2.33
NEg	0.90	0.81	1.02	1.60	1.62

[1] Dietary metabolizable energy (ME), net energy maintenance (NEm), and net energy gain (Neg) values were calculated using the NRC (1996) equation.

Table 4

	Treatment[1,2]								
Item	CON	SD	GF20	SD	GR45	SD	GF25	SD	P-value
Final Hip Height, cm	133	3.41	132	2.92	133	3.38	133	3.67	0.48
Initial Body Weight, kg	283	26.4	283	25.9	287	30.9	283	30.4	0.97
Final Body Weight[3], kg	632_c	43.5	478_a	26.2	551_b	39.6	570_b	25.1	<0.0001
Average Total Gain, kg	343_c	27.5	195_a	20.0	286_b	38.6	263_b	28.5	<0.0001
Hot Carcass Weight, kg	372_c	25.0	230_a	13.8	303_b	22.1	292_b	15.9	<0.0001
Dressing percent, %	61.8_d	1.20	50.2_a	1.12	57.5_c	2.08	53.4_b	1.57	<0.0001
KPH[4], %	2.89_c	0.07	1.06_a	0.16	1.65_b	0.25	1.30_b	0.18	<0.0001
Back fat, cm	1.17_c	0.27	0.44_a	0.06	0.74_b	0.16	0.66_b	0.11	<0.0001
LM[5] area, cm	79.7_b	7.13	65.0_a	6.73	68.4_a	6.99	65.0_a	5.99	<0.0001
LM Length. cm	13.3_b	0.21	12.9_a	0.21	13.1_b	0.20	14.2_a	0.23	<0.0001
LM Depth, cm	7.06_c	0.59	6.03_a	0.63	6.41_{ba}	0.60	6.08_a	0.56	<0.0001
LM Length: Depth Ratio	1.89_a	0.21	2.32_b	0.20	2.05_a	0.20	2.35_b	0.23	<0.0001
Marbling Score[6]	421_c	45.8	285_a	49.9	341_b	45.9	333_b	61.4	<0.0001
Yield Grade	2.86_c	0.52	1.45_a	0.28	2.37_b	0.41	2.14_b	0.34	<0.0001
Quality Grade[7]	7.04_c	0.57	3.94_a	1.39	5.30_b	0.75	4.81_b	0.91	<0.0001

[1] CON - steers stocked on pasture then finished in a feedyard, GF20 - steers grass-fed for 20 months, GR45 - steers grass-fed for 20 months with a 45-day grain finish, GF25 - steers grass-fed for 25 month.

[2] Means with different subscripts indicate differences within treatments, determined by Tukey HSD.

[3] Final Body Weight does not include 4% shrink

[4] Kidney, Pelvic, and Heart Fat

[5] Loin Muscle

[6] 100 = Practically devoid^{00}; 300 = Slight^{00}; 400 = Small^{00}; 500 = Modest^{00}; 700 = Slightly Abundant^{00}; 900 = Abundant^{00} (USDA, 2016)

[7] Standard (−, 0, and +)—1, 2, and 3; Select (−, 0, and +)—4, 5, and 6; Choice (−, 0, and +)—7, 8, and 9; Prime (−, 0, and +)—10, 11, and 12.

Table 5

Treatment[1]	Per head cost, without processing and marketing, \$steer^{-1}	Per head cost, with processing and marketing costs, \$steer^{-1}	Breakeven without processing and marketing costs, \$ kg^{-1} of hot carcass weight	Breakeven with processing and marketing costs, \$ kg^{-1} of hot carcass weight
CON	1,543	2,320	4.00	6.01
GF20	1,405	2,066	6.11	8.98
GR45	1,601	2,431	5.29	8.02
GF25	1,635	2,432	5.60	8.33

[1] CON - steers stocked on pasture then finished in a feedyard, GF20 - steers grass-fed for 20 months, GR45 - steers grass-fed for 20 months with a 45-day grain finish, GF25 - steers grass-fed for 25 month.

Table 6

	Treatment[2]			
Impact factor[3]	CON	GF20	GR45	GF25
GWP,CO_2 eq.[4]	4.91	6.90	6.82	8.53
Consumptive Water, L	933	465	678	1245
Land Occupation Rate, m^2 year	1.28	11.25	9.64	9.82
Energy, MJ	18.69	7.65	13.84	8.85
Smog Formation, O_3 eq.[5]	0.15	0.01	0.08	0.01

[1] Envionmental impacts based from weaning to harvest.

[2] CON - steers stocked on pasture then finished in a feedyard, GF20 - steers grass-fed for 20 months, GR45 - steers grass-fed for 20 months with a 45-day grain finish, GF25 - steers grass-fed for 25 month.

[3] All impact factors based on the functional unit kg Hot Carcass Weight^{-1}

[4] Global Warming Potential, carbon dioxide equivalent

[5] Ozone equivalent

Table 7

	Cattle Land Occupation, m^2 year kg Hot Carcass Weight^{-1}		
Treatment[2]	Irrigated Pasture	Rangeland	Farmland and Land for Mining
CON	0.02	0.00	0.81
GF20	0.04	10.5	0.01
GR45	0.03	7.95	1.10
GF25	0.08	8.25	0.01

[1] Land occupation measured using the standard ISO 14040 LCA functional unit

[2] CON - steers stocked on pasture then finished in a feedyard, GF20 - steers grass-fed for 20 months, GR45 - steers grass-fed for 20 months with a 45-day grain finish, GF25 - steers grass-fed for 25 month.

Effects of multiple grass-fed and grain-fed production systems on beef mineral and fatty acid contents[1]

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[1] **Acknowledgement:** This research was made possible by the James Beard Scholarship Program.

Abstract

Globally, the market of grass-fed beef is expected to increase by 40 billion U.S. dollars in the next decade. The objective of this study was to compare the fatty acid composition of grass and conventionally finished beef raised using production practices typical for the western United States. Treatments included: 1) steers stocked on irrigated pasture to one year old, then finished in a feedyard on a concentrate-based diet (CON), 2) steers stocked on irrigated pasture to one year old, then on native annual rangeland to 20 months of age (GF20), 3) steers stocked on irrigated pasture to one year old, then on native annual rangeland to 20 months of age, and finished for 45-days on grain (45GR), and 4) steers stocked on irrigated pasture to one year old, then on native annual rangeland to 20 months of age, and then on irrigated pasture to an age of 25 months (GF25). Final body weight varied significantly between treatments ($P < 0.05$) with CON finishing at 632 kg, followed by GF25 at 570 kg, 45GR at 551 kg, and GF20 478 kg. *Longissimus thoracis* saturated fatty acid (SFA) concentrations were significantly different across treatments ($P<0.05$) with GF20 having the lowest SFA of 1.4 g and CON having the highest SFA at 2.8 g. *Cis*-monounsaturated fatty acids (*c*-MUFA) particularly oleic acid, which is known as a heart healthy fatty acid, were highest for CON at 2.8 g and lowest for GF20 at 1.2 g (P<0.05). In terms of trans-fat grass-fed treatments resulted in t10-18:1: t11-18-1 ratios 15 to 24 time's lower compared to CON. For conjugated linoleic acid (CLA) no difference was observed between grass-fed treatments and CON (P>0.05). Grass-fed treatments where higher in n-3 PUFA (0.11 g GF20 and 0.11 g GF25) compared to CON (0.05 g; $P<0.05$), while feeding grain for a short period of time did not decrease n-3 PUFA concentrations to the CON level (GF45 0.09 g; $P<0.05$). In conclusion, our findings show that beef from grain-fed beef management systems are higher in *c*-MUFA, while grass-fed systems resulted in higher in

bioactive fatty acids including CLnA and branched chain fatty acids. Additional studies are required to find out if the differences in the fatty acid profiles between grass-fed and grain-fed beef would result in different health outcomes for the consumers.

Introduction

Retail sales of labeled fresh grass-fed beef in the U.S. have grown from $17 million in 2012 to $272 million in 2016 (Nielsen Retail Measurement Services, 2017). A primary reason for the increase in demand is the consumer perception and pervasive marketing claim that grass-fed beef (as per USDA definition, grass-fed is defined as cattle fed 100% forage from weaning to harvest; USDA-FSIS, 2019) is healthier than conventional beef (beef that is finished in a feedyard for over 60 days; McCluskey, 2015; McCluskey et al., 2005; Xue et al., 2010). Information, however, appears to be lacking in terms of how current grass finishing production practices compare to conventional finishing, particularly in terms of fatty acid and mineral content.

Grass-fed beef has been found to be higher in healthy fatty acids including CLA (rumenic acid), and omega-3 (n-3) fatty acids, than conventional grain-finished beef (Leheska et al., 2008; Melton et al., 1982; Noci et al., 2005). However, grain-fed beef has consistently been reported to have higher concentrations of monounsaturated fatty acids (MUFA; Smith et al., 2020; Duckett et al., 2009; Melton et al., 1982), a type of healthy fatty acid that has been shown to decrease the risk of cardiovascular disease (FDA, 2016). There is, however, limited information on effects of commercially utilized grass-fed beef systems on beef fatty acids profile. Unlike conventionally finished beef that is relatively uniform, grass-fed beef production systems are dynamic and can vary significantly depending on region, resource availability, and forage quality (Berthiaume et al., 2006; Duckett et al., 2013; Scaglia et al., 2012). For example, in contrast to the Midwest and

South, in the Western U.S. almost all grass-fed production systems rely on rangeland (native land that is lower in forage quantity and nutritive value compared to irrigated pasture; George, 1989). This dependence on rangeland results in older harvest ages compared to cattle in the east, with many cattle being harvested at 20-30 months of age. In addition, to adapt to marketing conditions and to increase beef quality, many producers are now finishing their "grass-fed" cattle for short intervals on grain (30 to 45 days). Despite the abundance of these types of systems in the grass-fed beef market, there is little to no information available on how these production systems effect beef fatty acid profiles. Previous work has evaluated some aspects of different forms of grazing (French et al., 2000; Duckett et al., 2013), but have not looked at effects of short durational grain-finish or extending beef grazing for an additional season on fatty acid profiles. Furthermore, many grass-fed vs. grain-fed beef studies performed to date have not been directly comparable, as cattle were not from genetically similar herds.

In terms of mineral composition, beef contains some of the greatest concentrations of bioavailable iron (NIH, 2021a) and high level of bioavailable zinc (Maares and Haase, 2020). With many Americans at risk for mineral deficiency (Bird et al., 2017) there has been a resurgence of interest in effect of animal diet on meats mineral content. Despite the growing interest in niche market beef production, and effects on human health, there is currently a dearth of research available determining the effect of production system on beef's iron and zinc contents.

Ultimately, with the increased demand for grass-fed beef and increased diversity in grass-fed beef production systems, there is an immediate need to understand how fatty acid and mineral profiles are affected by commercially utilized grass-fed production systems. Therefore, to address consumer, producer and scientific concerns, the objective of the present study was to comprehensively analyze fatty acid and mineral profiles from beef originating from a genetically similar heard produced in four different grass-fed and grain-fed systems currently used by ranchers in the western United States.

Materials and Methods

Animal Protocol

The weaning, animal health protocol, and study design for this project were approved by the Institutional Animal Care and Use Committee at the University of California-Davis (UCD; protocol #20560). In June 2018, cows and calves at the University of California Sierra Foothill Research and Extension Center (Browns Valley, CA) were fence line weaned for 45 days to minimize animal stress and to monitor calf health as described by Price et al. (2003). At weaning, Angus and Angus-Herford cross steer calves were allocated to one of four treatments: 1) steers stocked on irrigated pasture to one year old, then finished in a feedyard on a concentrate-based diet (CON), 2) steers stocked on irrigated pasture to one year old, then on native annual rangeland to 20 months of age (GF20), 3) steers stocked on irrigated pasture to one year old, then on native annual rangeland to 20 months of age, and finished for 45 days on grain (45GR), and 4) steers stocked on irrigated pasture to one year old, then on native annual rangeland to 20 months of age, and then on irrigated pasture to an age of 25 months (GF25). All treatments were designed based on current beef production systems in California. After being fence line weaned, steer calves were stratified by weight (average initial body weight was 284 kg, SD 27.57 kg) and randomly assigned to treatments. In the beginning of the trial, there were 22 steers per treatment, but these numbers were reduced over time due to pinkeye infection that was treated with antibiotics as per IACUC protocols. Antibiotic-treated cattle were removed from the study as per natural program agreements. After pinkeye animals were treated, the number of cattle remaining in each treatment were: 21 cattle in CON, 18 in GF20, 13 in 45GR, and 16 in GF25. After weaning, steers were transported to summer flood irrigated pasture located in Maxwell, CA, that were irrigated bimonthly beginning the second week of July through the second week of November. Steers were rotated between two pastures throughout the grazing season. Irrigated pasture included a mix of annual grasses (predominantly *Cynodon dactylon*, *Sorghum halepense*), and clover (25-30% *Medicago* and *Trifolium*). After the summer-fall grazing season ended in late November, steers were transported to their designated feeding locations. Steers in the CON treatment were taken to the feedyard of UCD located at Davis, CA where they were housed in a group pen. At the feedyard animals were fed a starter ration for 14 days, followed by an intermediate ration for 14 days and finished on a high-energy corn-based ration for 100 days (Table 1). Steers in the GF20, 45GR, and GF25 treatments were shipped from Maxwell, CA, to the Sierra Field Research Station Browns Valley, CA, to graze winter-spring foothill rangeland. Cattle were rotated between three large-scale paddocks once every month for a total land occupancy rate of 0.41 ha/ month. Rangeland forage species composition was typical of California rangelands consisting of a mixture of grasses (e.g., *Bromus, Avena* spp.) and forbs (e.g, *Erodium, Medicago, Trifolium* spp). At the end of the winter-spring grazing season cattle in the GF20 treatment were harvested. Steers in the 45GR treatment were taken to the feedyard at UCD. While in the feedyard steers were fed a starter ration for 7 days, intermediate ration for 10 days, and finished on a high-energy corn diet for duration of the 45-day grain period (Table 1). Steers in the GF25 treatment were transported to irrigated University of California-Davis owned, flood irrigated pasture in Davis, CA. The pasture at UCD consisted of a 50:50 mixture of perennial grasses (*Cynodon dactylon* and *Sorghum halepense*), and clover (25-30% *Medicago polymorpha* and *Trifolium dubium.*). Cattle were rotated between two paddocks every two weeks. Cattle land occupation values (head/hector/month) for all the systems are listed Klopatek et al. (2020). Cattle in the GF20 and GF25 treatments followed USDA Food Safety and Inspection Services labeling guidelines (USDA, 2019). Cattle in the CON and 45GR treatments were harvested at a large-scale commercial packing house in Fresno, CA and steers in the GF20 and GF25 systems were harvested at a natural and organic beef packing house in Merced, CA. To adhere to natural standards none of the steers were implanted with anabolic steroids. Steers in the CON and 45GR treatment were fed an ionophore to replicate commercial feeding systems in CA.

Performance and Carcass Quality

Average daily gain was determined for each animal as the slope of the linear regression of body weight by days of age. At the end of the feeding period, steers were weighed after 18 h of feed withdrawal and then transported to slaughter. All carcasses were chilled for 48 h and cut between the 12th and 13th ribs. The USDA Quality and Yield Grades were assigned to each carcass by trained personnel. Carcass characteristics were evaluated as follows: hot carcass weight (HCW), percentage of kidney, pelvic, and heart fat (KPH), *longissimus thoracis* muscle area at the 12th to 13th rib (REA), body fat depth at ¾ of the width of the *longissimus thoracis* (LT) muscle, and marbling score. Dressing percentage (DP), yield grade, and quality grade were calculated using standard equations (Boggs et al., 1998).

Feed Analysis

To collect pasture/ rangeland samples, a quarter meter square (50cm x 50cm) PVC pipe was randomly thrown into the pasture. Forage samples were collected from the square by cutting the plant matter to the ground. This process was repeated 30 to 100 times along the cross-section of the given pasture. Pasture/ rangeland samples were taken every 30 days for the duration of the project. Feedyard samples were collected from the mixer wagon every 14 days.

After each collection, feed samples were combined and sub-sampled in triplicate and frozen at -35°C. Samples were thawed and dry matter was determined by oven drying at 100°C for 12h. For composition analysis, feed samples were ground to pass a 1-mm screen (Wiley mill, Arthur Gill Thomas Co., Swedesboro, NJ) and dried at 55°C for 15 h before undergoing proximate and fatty analysis. Dietary metabolizable energy (ME) values were calculated using equations published by the National Academy of Sciences, Engineering, and Medicine (2016).

For feed fatty acid analyses, samples were freeze dried, and ground through a 1.0-mm screen using a Thomas Wiley Mini-Mill (1 mm screen, Thomas Scientific, Swedesboro, NJ, USA) and sequentially methylated using base then acid catalysts to form fatty acid methyl esters (FAME) according to Jenkins (2010). Briefly, 2 mL of toluene containing internal standard (1 mg mL−1 c10-17:1, standard No. U-42M, Nu-Check Prep Inc., Elysian, MN, USA) was added to 0.5 g of feed and methylated using 2 mL 0.5 N sodium methoxide in methanol (Sigma-Aldrich) at 50 °C for 10 min followed by addition of 3 mL of 3 N methanolic hydrochloric acid and heating at 80 °C for 10 min. Hexane (2 mL) and 14% potassium chloride (4 mL) were then added, mixed, and the upper (hexane) layer containing FAME was collected and dried under nitrogen, re-suspended in 200 uL 95:5 hexane:diethyl ether, applied to a 100 mg per 1 mL silica solid-phase extraction (SPE) column (Superclean™ LC-Si SPE, Sigma-Aldrich), and FAME were eluted with 3 mL × 1 mL of 95:5 hexane:diethyl ether. FAME extracts were dried under nitrogen and resuspended in 1 mL hexane for GC analysis. Completeness of methylation was checked prior to SPE clean-up by thin-layer chromatography using silica gel G plates (Analtech Inc., Newark, DE, USA), hexane:diethyl ether:acetic acid (85:15:1) as the developing solvent, and visualization under UV light after elution after spraying with 2′,7′-dichlorofluroescein (Sigma-Aldrich) in methanol. FAME were analyzed by gas liquid chromatography (GLC) as described by Dugan et al. (2007).

Chemical Analysis

Strip loins from the right sides of each of 12 carcasses from each treatment were collected, vacuum packaged and stored under dark conditions at 4ºC for 14 days. Steaks where then cut (2.54-cm thick), individually vacuumed sealed and stored at -20 ºC. When samples were ready to process steaks were thawed overnight. All external fat and connective tissue were removed from the LT before samples were pulverized in liquid nitrogen and stored at -20°C. All proximate and mineral analysis were performed by Midwest laboratories (MWL) Inc in Omaha Nebraska. For moisture analyses the homogenized samples were spread evenly in a pre-weighed tin and a fiber filter placed over the sample and dried at 125 degrees C for four hours. The samples were cooled and re-weighed and the loss in mass was reported as moisture. Protein analysis was carried out using MWL FO 014 which is based on AOAC 992.15 and USDA/FSIS CLG-PRO04.03. Samples were weighed and placed in an instrument that combusts the sample and releases nitrogen. The amount of nitrogen is determined and then multiplied by a factor of 6.25 to convert the nitrogen value to a protein value. Fat analysis was carried out using MWL FO 007 which is based on AOAC 991.36. Samples were weighed and treated with petroleum ether to extract fat, petroleum ether was evaporated, and remaining material was weighed and reported as "crude fat". Analysis followed MWL FO 022 which references individual AOAC methods for specific materials including meats (900.02, 920.155, 920.153). For ash, samples were weighed and ashed at 600 ºC, cooled in a desiccator and re-weighed. The remaining residue was reported as ash. Analysis followed MWL ME 027 which is based on AOAC 2011.14. For iron and zinc analysis, samples were been prepared by MWL ME 077 using a wet ash process and sample extract was used for ICP where it was nebulized and introduced into high temperature plasma and analyzed following MWL ME 027 which is based on AOAC 2011.14. Samples were prepared by MWL ME 077 using a wet ash process.

Fatty acids

Analysis of fatty acids were identical to that described by Vahmani et al. (2017) where intramuscular lipids were extracted from LT and 80/20 lean to fat grind samples using a mixture of chloroform–methanol (2:1, v/v). Aliquots of muscle lipids (10 mg) were methylated separately using base (0.5 N sodium methoxide) and acid (5% methanolic HCl) reagents. Internal standard, 1 ml of 1 mg *c*10–17:1 methyl ester/ml toluene (standard no. U-42M form Nu-Check Prep Inc., Elysian, MN, USA), was added prior to addition of methylating reagents. Most fatty acid methyl esters (FAME) were analyzed by gas liquid chromatography (GLC) as described by Kramer et al. (2008), with the exception of *t*7,*c*9–18:2 and *c*9,*t*11–18:2 that were analyzed according to Turner et al. (2011).

In order to identify via the GLC the reference standard no. 601 from Nu-Check Prep Inc., Elysian, MN, USA was used. For branched-chain FAME the standard BC-Mix1 reference purchased previously from Applied Science (State College, PA, USA) was used. Conjugated linoleic acid (CLA) isomers, the UC-59M standard from Nu-Chek Prep was used which contains all four positional CLA isomers. *Trans*-18:1 CLA isomers and other BH intermediates not included in the standard mixtures were identified by their retention times and elution orders as reported by Cruz-Hernandez et al. (2004), Kramer et al. (2008), and Vahmani, Rolland, Gzyl, and Dugan (2016). The FAME were quantified using chromatographic peak area and internal standard based calculations. Specifically, from GLC analyses using authenticated standards, response factors (RF) were calculated for individual fatty acids as reported by Vahmani et al. (2017). Fatty acids were presented on a quantitative basis (mg per 114 mg serving (i.e. 4 oz)) as differences in fat content are known to influence the % fatty acid composition, but not influence quantitative intake of some FA (Wood et al. 2008)

Statistical Analysis

All statistical analyses were performed in R. The study was a completely randomized design with individual animals treated as the experimental unit. Performance data and carcass components were analyzed in a GLM procedure with model containing treatment as the fixed effect. Differences between treatments were determined by Tukey Honest Significance Difference using an α-level of 0.05.

Results and Discussion

Nutrient and fatty acid composition of experimental diets

The ingredients for the feedlot rations are listed in Table 1. Nutrient and fatty acid composition for all diets are presented in Table 2. The major fatty acids in both the feedlot rations were linoleic acid (18:2n-6) and oleic acid (c9–18:1), followed by palmitic acid (16:0), which is consistent with reports for other corn-based finisher diets (Vahmani et al., 2017; Salami et al., 2021). In contrast, the dominate FA in the GF20 and GF25 rations was 18:3n-3 followed by linoleic acid, then palmitic acid, which is consistent with diets based on fresh or conserved forage (Vahmani et al., 2017)

Carcass Traits, Proximate Analysis, and Mineral Composition

As reported in Klopatek et al. (2020), final body weights, dressing percentage, and quality grades varied significantly between treatments (Table 4). This would be consistent with differences in duration of finishing, nutrient composition of diets and our desire to finish animals to levels of finish typical for industry when using these production systems. Similar to previous studies (Duckett et al., 2009: Leheska et al., 2008), no different in LT percentage of protein was observed between treatments (*P=0.42*). Iron concentrations were higher for the grass-fed compared to grain-finished treatments (*P*<0.05). This is in contrast to Ducket et al (2013) who found no difference in iron concentrations comparing grass- and grain-fed systems. Differences between treatments may have been due to differences in dietary iron or myoglobin concentrations in the meat (Apaoblaza et al., 2019). Some of this might be due to differences in muscle fiber type, but because 45GR were only fed for 45 d in the feedyard, it is questioned whether fiber type played a role. All told, the increase in iron in forage finished beef would supply about 0.29 mg more iron per 114 g serving of beef. Young children, women of reproductive age, and pregnant women are all at risk of iron deficiency in the U.S. (NIH, 2021a), and this small increase would increase the contribution of beef from 10 to 12% of the recommended daily value. Additionally, due to the higher bioavailability of myoglobin, grass finished beef could contribute to as much as 4% more available iron. It is important to note that iron concentrations have been shown to vary between cuts (Ramos et al., 2012, Cabrera et al., 2010, Gerber, Scheeder & Wenk, 2009) with Czerwonka and Szterk (2015) showing iron to vary from 1.9 and 2.6 mg (114 mg serving). The greatest concentration of iron can be found in the beef liver, where iron accumulates over time (Murray et al., 2012). Czerwonka and Szterk (2015) determined beef liver to be 3 times the concentration of muscle iron with 7.5 mg of iron (114 mg serving). Overall, additional research needs to be performed to determine how diet affects iron concentrations between different muscles and determine how diet effects iron concentrations in beef liver. In regard to zinc, concentrations found in previous studies were not affected by dietary zinc levels (Ducket et al., 2013), however, the present study observed the differences in zinc concentrations among treatments (*P*<0.05). The GF25 had the highest concentration at 3.72

mg and GF20 had the lowest concentration at 3.21 mg. It is thought the differences between zinc concentrations relate to diet (Carmichael et al., 2019).

In regard to zinc bioavailability, meat has higher bioavailability than plant-based diets (Maares and Haase, 2020), with zinc bioavailability in beef being four-fold greater than a high-fiber breakfast cereal (Zheng et al. 1993). The average adult male requires 11 mg of zinc a day and adult female 8 mg of zinc per day (NIH, 2021b). The results in the present study indicate that diet can have a significant effect on beef iron levels; however, as with iron concentrations, zinc concentrations vary depending on muscle type (Czerwonka and Szterk, 2015). Therefore, additional studies investigating the effect of diet on multiple beef cuts need to be performed.

Fatty Acids

Total FA content of the LT differed across treatments ($P<0.001$; Table 5). This result was expected for grass-fed cattle typically finish at a lower quality grade than grain-fed diets due to the lower energy availability of grass-fed diets compared to feedlot rations (Cruz et al., 2013). However, what is unique in the present study is the degree of difference in FA between treatments. For example, at 10 grams total fatty acids per serving, the CON treatment was 26% greater than the GF25 and 170% greater than the GF20 treatment ($P>0.05$). Studies such as Leheska et al., (2008) compared grass-fed beef composite samples from 13 different states and found conventional beef to be 57% greater in fat than grass-fed beef, but they were unable to express the magnitude of difference in FA content between grass-fed systems. Additionally, by presenting multiple niche market beef production systems, the present study was the first to demonstrate that cattle finished on irrigated pasture for 5 months resulted in similar total fat and carcass quality as cattle fed on grass but finished in the feedyard for 45 days (GF45). With diminishing land resources and increased demand for niche market beef, the GF45 production system provides niche market producers an opportunity to supply a high-quality product with shorter time finishing than GF25, but the decision will also need to take into consideration the composition and health profile of the fat.

N-3 and n-6 polyunsaturated fatty acids

In beef, PUFA's are primarily incorporated into phospholipids of the muscle cell membranes, as opposed to SFA and MUFA, which are more concentrated in intermuscular and intramuscular fat (Wood et al., 2008). Due to a lower ruminal energy conversion of grass compared to grain, grass-fed beef typically finishes with lower carcass fat and intramuscular fat (Klopatek et al., 2020; Cruz et al., 2013). Thereby, the reduction in carcass fat and intramuscular fat in grass-fed beef decreases the proportion of SFA, increasing PUFA concentration. Specifically, as the total fat goes up, the proportions of PUFA rich phospholipids go down, and the SFA rich triglycerides go up, but the actual amount of PUFA provided in a serving remains relatively constant. Results from the present study were no exception as no differences in total PUFA were observed among treatments (P=0.73). Despite, control LT having twice the total fat content, the total PUFA on a mg per 114 g serving basis remained constant averaging 482 mg total PUFA, which is consistent with other studies reporting LT fatty acids on a quantitative basis (Leaska et al., 2008 and Duckett et al., 2009).

Despite the total PUFA content of LT remaining constant across diets, the total n-3 FA was greatest in forage grass-fed steers, followed by 45GR, and CON (P<0.05; Table 3). Higher content of n-3 fatty acids in the grass-fed treatments is most likely due to the higher concentration 18:3n-3 in the forage diets relative to the corn-based diets. What is of interest is that the short period of corn grain finishing for 45GF steers lead to a shift in total n-3 FA content, which is not consistent findings of Aldai et al. (2011) who found no change in total n-3 fatty acids in LT when finishing lean pasture fed bulls for only 1-2 months on a concentrate-based diet.

The most concentrated n-3 fatty acid was alpha-linolenic acid (ALA), and its content reflected differences found for total n-3 FA, being highest when finishing on forage (GF20 and GF25), followed by 45GF and control steers ($P<0.05$; Table 3). Significant reductions in LT 18:3n-3 were also found by Aldai et al. (2011) in pastured beef after 1-2 months of concentrate finishing. The amount of ALA when forage finishing was, however, not sufficient to allow a good source claim in the USA of 200 mg (FDA, 2016). Differences in ALA were not, however, entirely reflected in its elongation and desaturation products. Feeding the CON diet led to the lowest amounts of major long chain n-3 fatty acids (eicosapentaenoic acid, EPA; docosapentenoic acid, DPA), and grass finishing the highest, but amounts of long chain n-3 fatty acids with 45 d concentrate finishing (45GR) did not dramatically change their levels. Conservation of major long chain n-3 fatty acids was also found by Aldai et al (2011) with increasing periods of concentrate finishing after pasture, and speaks to their preferential retention in muscle phospholipids (Burdge, 2018). Consequently, even though a short period of grain finishing can reduce total n-3 fatty acids, its effects on the biologically most active n-3 fatty acids (i.e. ALA’s elongation and desaturation products) is minimal, and places short term grain finishing at a nutritional advantage over conventional. Grass finishing irrespective of whether there was as 45 d final finish on corn led to a virtual double in of EPA and DPA, and although less than recommended (250 mg; USDA, 2015), it could represent a substantial increase in populations that do not regularly consume marine sourced foods (Howe et al., 2006). No diet effects were found for docosahexaenoic acid (22:6 n-3; DHA; $P=0.17$), typically the least concentrated long chain n-3 fatty acid in meat. The lack of effect on 22:6n-3 is consistent with many studies demonstrating the amount of DHA is difficult to change unless feeding preformed DHA (Ponnampalam, et al., 2006; Realini et al., 2004). This is in exception to Warren et al (2007) where grass silage finishing elevated DHA compared to concentrate finishing, where grass was noted for having a special ability to increase DHA. In the present study, however, effects on long chain fatty acids remained limited to EPA and docosapentaenoic acid (DPA; 22:5 n-3), with 20GF steers yielding the greatest amounts of EPA at 44 mg per serving of beef. Overall, the amounts of long chain n-3 fatty acids were in line with other grain-fed and forage feeding studies (Ponnampalam et al., 2006; Nuernberg, et al., 2005), and in both the USA and European union both grass-fed and grain fed beef would fall short of n-3 source claims (FDA, 2016; NIH, 2021c), but again could contribute substantially to intakes in populations that do not regularly consume marine source foods (Howe et al., 2006)

Total n-6 fatty acids in LT were consistent with dietary levels, with CON LT having the greatest total n-6 fatty acids, intermediate amounts for 45GR, and lowest for forage finished steers ($P<0.050$). Differences in total n-6 fatty acids were reflected in the major n-6 FA, linoleic acid (LA; 18:2n-6), however, no changes were found in its main elongation and desaturation product (20:4n-6). These amounts were consistent with other studies feeding forage and corn-based diets (French, et al., 2005; Nori et al., 2005; Duckett et al, 2009). A dietary n-6 to n-3 ratio has been shown to increase the rate of pathogenesis of depression (Husted and Bouzinova, 2016), while higher n-3 to n-6 ratios have been shown to aid human health for example, by decreasing the risk of breast cancer (Goodstine et al. 2013). Conventional grain-fed beef systems have been shown to have higher n-6 to n-3 ratios (French, et al., 2005; Nori et al., 2005). The present study was consistent with these findings with CON resulting in the highest ratio of n-6: n-3 ratio (Figure 1; $P<0.05$) at 5.7. Despite CON having a higher n-6:n-3 ratio, the ratio was still under the recommended n-6 to n-3 ratio of 6:1 (Wijendran and Hayes, 2004). However, the omega 6 to omega 3 ratio is above the ratio of 4:1 that has also been suggested by the Mediterranean Diet (de Lorgeril et al., 1994).

CLA, CLnA and AD

During the process of ruminal biohydrogenation, when LA and ALA are reduced to 18:0, which is less toxic to rumen microbes (ref), numerous 18 carbon BHI such as CLnA, CLA, non-conjugated non-methylene interrupted 18:2 (atypical diets; AD) and t18:1 isomers are produced, and a portion of them pass from the rumen and subsequently are incorporated into tissues after post-ruminal absorption (Kepler et al., 1966). The first step in biohydrogenation of ALA is isomerization of double bonds to CLnA. It was expected that feeding the CON diet would lead to the lowest CLnA due to extended feeding of a diet very low in ALA, but CON levels were similar to GF20, which were lower than GF25, but actually higher than when finishing on 45 d of corn (GF45; $P < 0.001$). It might, therefore, be that there was some accumulation of CLnA in neutral lipids, and increased amounts of CLnA might be related to the higher total fat content found for CON. In addition, in comparison with corn grain and silage-based diets fed in the corn belt of the USA, the corn-based CON diet in the present study contained some hay, which would have provided a small but significant source of ALA. When looking at individual CLnA isomers, however, total CLnA was greater in CON compared to 45GR was due to increased amounts of c9,t11,t15- and not c9,t11,c15-18:3. Health effects of some CLnA isomers have been studied in specialty seed oils and found to have beneficial properties similar to CLA (Yuan et al., 2014), but knowledge on the health effects of CLnA isomers found in ruminants is limiting, and there has been no comparison between c9,t11,c15-18:3 and c9,t11,t15-18:3. As a result, it would be impossible to tell if the CLnA profile for grass finished beef conferred any health advantage over that found in corn fed beef.

In similarity to CLnA, we expected the AD contents in CON beef to have the lowest values, as most AD are products of 18:3n-3 biohydrogenation (i.e. have double bonds originating from the c15 double bond of 18:3n-3). Similar to ALA, however, the total AD were lowest for GF25, intermediate for CON and GF20 and highest for GF25 ($P < 0.001$). Again, however, the isomeric composition of AD differed between treatments with more t11,c15-18:2 when grass finishing, and more c9,t15-18:2 when finishing on the CON diet ($P< 0.0001$). The health effects of AD are for the most part unknown, but it is speculated t11,c15–18:2 may exert beneficial benefits through delta-9 desaturation to c9,t11,c15–18:2 (Mapiye et al., 2013).

In the present study, total CLA was greatest in GF25, lowest in GF20 and GF45 and intermediate in CON ($P< 0.01$). In terms of CLA isomers, however, the amount of c9,t11-18:2 and t11,c13-18:2 remained highest in GR 25 ($P < 0.0001$), but the highest amount of t10,c12-18:2 was found in CON ($P < 0.0001$). This is consistent with grass or forage finishing producing a rumen environment favorable to bacteria which utilize biohydrogenation pathways which include intermediate with a t11 double bonds, whereas finishing on diets where high levels of concentrate induce a shift in bacterial populations which utilize biohydrogenation pathways which include t10 double bonds (Harfoot and Hazlewood, 1998). Specifically, high grain consumption in CON and 45GR could have decreased the rumen pH, leading to reduced abundance and activity of the key rumen bacteria involved in biohydrogenation to c9,t11-18:2 including *Butyrivibrio fibrisolvens* (Bessa et al., 2000). The positive health effects of CLA were first attributed to its anticarcinogenic effects first associated with c9,t11-18:2 (den Hartigh, 2019), and its ability to repartition fat to lean in animals including rodents (Sisk et al., 2001) and pigs (Dugan et al., 1997). However, the repartitioning effects of CLA were subsequently associated with t10,c12-18:2 (Park et al., 1999), and t10,c12-18:2 was also linked to negative effects on blood cholesterol profiles (Tricon et al., 2004), blood sugar levels (Riserus et al., 2002), and inflammatory responses (Poirier et al., 2006). Consequently, it is believed that the isomeric profile in grass-fed beef would have superior health advantages over grain fed beef.

Trans-monounsaturated Fatty Acid

Since the FDA banned trans-fat from processed foods in 2018, animal fat is currently the sole source of trans-fat in the American diet, bringing renewed interest to beef's trans-fat levels. The proportion of t-MUFA isomers in beef is diet dependent (Mulvihill, 2001; Vahmani et al., 2015 Chikwanha et al., 2018). For diets high in forage the biohydrogenation processes favor production of t-11-18:1. The t-MUFA t11-18:1, is considered a "good' trans-fat, because in human body ~19% of t11-18:1 consumed readily undergoes a conversion to the RA, where it can provide health benefits such as anti-carcinogen effects (Bauman, 2006). Conversely, for diets high in concentrates (i.e. starches) biohydrogenation favors the production of t-10-18:1 which is considered a detrimental trans fatty acid as it is associated with milk fat depression (Jenkins et al., 2008), and in cell culture is related to increases in both triglyceride and cholesterol synthesis (Vahmani et al., 2015; Vahmani et al. 2020). In the present study, the total t18:1 was greatest for CON and GF25 diets, and lowest for the GF20 and GF45 diets. The high amount of t11-18:1 for GF25 was related to a higher content of precursors in the diet (18:2n-6 plus 18:3n-3) and the high amount of t10-18:1 in CON may have been linked to a shift to t10-18:1 producing bacteria in the rumen. A greater overall fat content of CON LT, and a lower rumen pH, has been associated with inhibition in the last step in biohydrogenation to 18:0 (Vahmani et al., 2015). As a consequence, grass-fed treatments resulted in t10-18:1: t11-18-1 ratios 15 to 24 time's lower compared to CON (Figure 2). In terms of healthfulness, the isomeric profile of t18:1 of GF25 would be associated with the greatest benefit as it had the highest t11-18:1, lowest t10-18:1. As a consequence, the rumenic acid equivalent (i.e. c9, t11-18:2 plus 19% of the t11-18:1; RA) for the GF25 diet would be would be 52.5 mg per serving (Figure 3). This CLA isomer RA is of special interest for enrichment in ruminant fat due to its reported health benefits (Dilzer and Park, 2012). Rumenic acid mainly originates from delta-9 desaturation of t11–18:1 in animal tissues (Griinari et al., 2000). Delta-9 desaturation activity have been reported to be 60–85% higher in pasture-fed cattle than conventionally grain-fed cattle (Yang et al., 1999).

Cis-monounsaturated Fatty Acid

Cis-MUFA servings were greater for CON compared to 45GR and GF25 ($P<0.05$) and over 200% greater than the GF20 system ($P<0.05$). These results are consistent with other studies that found grain-fed beef to be higher in cis-MUFA (Duckett et al., 2009; Duckett et al., 2013). In beef, the most common cis-MUFA is oleic acid (18:1 n-9), which is considered a desirable fatty acid in terms of human health. Although the exact serving recommendations for cis-MUFAs are unknown at this time the U.S. Food and Drug Administration has determined that there is credible evidence to support the qualified health claim that consuming oleic acid may reduce coronary heart disease (FDA, 2018). Oleic acid is found to increase in beef as marbling increases (Van Elswyk and McNeill (2014). As fat in the animals' increases stearoyl-CoA desaturase, the enzyme responsible for the conversion of all SA to OA, is upregulated (Duckett et al., 2009a). Thereby the higher marbled, higher total fat grain-finished beef, results in higher oleic acid concentrations than grass-fed beef (Noci et al., 2005; Smith et al., 2020). As expected, in the present study grass-fed treatments (GF20 and GF25) resulted in lower oleic acid servings compared to the treatments finished on grain (CON and 45GR; $P<0.05$). Both c9-16:1 and c11-

18:1 followed similar patterns with CON having the highest content and grass-fed systems having the lowest.

Branched chain fatty acids

Branched Chain Fatty Acids (BCFAs) are a group of bioactive FAs that provide metabolic benefits in adults (Taormina et al., 2020) and constitute a major component of normal healthy term newborn gastrointestinal tract (Ran-Ressler et al., 2008). Total BCFA's and all individual BCFA, with the exception of 17:0iso were greater for GF25 than grain-fed treatments (*P*>0.05). This is consistent with Liu and Brenna (2019) and Turner et al. (2015) who determined total BCFA acids were higher in grass-fed beef compared to conventional or grain-finished beef. The concentration of BCFA's in beef has been shown to be inversely related to the forage-to-concentrate ratio, due to the positive correlation of cellulolytic fermenting bacteria and increase ruminal BCFA outflow (Turner et al. 2015). Thereby it is expected that cattle consuming 100% forage diets would produce beef higher in BCFA's than high concentrate cattle.

Saturated

According to the USDA nutritional review SFA acid consumption should be restricted to 10% of calorie consumption (USDA, 2015). With red meat being high in SFA there has been increased scrutiny on red meat consumption and human health (Cai et al., 2020). In the present study, total SFA content was similar between GF20 and 45GR but higher in GF25 and CON (P<0.05) This is a unique finding for two reasons, for one SFA content was not similar between either grass-fed or grain-fed treatments and 2) SFA content did not directly coincide with total fat content. For example, although the GF45 was grain-finished resulting in greater total FA, SFA levels were not difference compared to GF20 (P>0.05). The SFA results from the present study do not align with previous findings who found no difference in total SFA levels between conventional grain-fed and grass-fed treatments (Duckett et al., 2013; Noci et al., 2005). Of the SFA's, myristic acid (14:0) and palmitic acid (16:0) are considered to be the most harmful to human health primarily due to their association with elevated low-density lipoproteins (LDL) or "bad" cholesterol (Siri-Tarino et al., 2010). In contrast stearic acid (C18:0) is considered neutral in terms of effects on LDL cholesterol and has been shown to decrease both cardiovascular and cancer risk (Kelly et al., 2001; Hunter et al., 2010). Patterns for myristic acid (14:0), palmitic acid (16:0), and steric acid (18:0) were similar to total SFA with GF25 and CON having higher levels than either 45GR or GF20. These result contrast, Leheska et al. (2008) and Noci et al. (2005) who also did not observe an effect of diet on beef's myristic or palmitic acid concentrations between grass-fed and grain-fed beef. The lower content in SFA for GF20 is most likely due to the low total fat content. Differences in stearic acid concentrations between the present study and the grass-fed treatments conducted by Duckett et al. (2013) and Leheska et al. (2008) may be due to the differences diet composition and grazing duration. These differences in management may have impacted ruminal biohydrogenation, thereby impacting the concentration of the final product of ruminal biohydrogenation, stearic acid (Vahmnai et al, 2015).

Conclusion

The present study illustrated the complexities of beef system on fatty acid composition and its relationship to human health for no system resulted in a fatty acid profile that was unequivocally superior to another. Each system resulted in trade-offs between "healthy" and "unhealthy fatty acids". For example, conventional beef was higher in MUFAs which are considered to be heart health fats, but significantly higher in t10-18:1 than all other treatments. The grass-fed systems resulted in a more favorable n-6 to n-3 ratio but fell far below the USDA dietary guidelines for daily n-3 intake requirements. Additionally, this study was the first to demonstrate how type of grass-fed beef system affected beef nutrient profile, with significant differences between GF20 and GF25 systems for SFA, BCFA, CLA, and t-MUFA. These differences elucidate why different grass-fed beef systems (i.e., difference in location, duration on grass, ext.) should be distinguished from one another when discussing health benefits. Finally, the present study was the first to show that by feeding grain for a short period of time resulted in lower SFA than GF25 or CON and higher N-3 than CON, suggesting that this type of systems not only benefits from decreased land use compared to grass-fed systems (Klopatek et al., 2020) but can have a fatty acid profile that results in similar benefits to those that are 100% grass-fed. Overall, with the increase in demand for niche market beef, more research using a holistic approach needs to be conducted to identify how different beef systems affect beef's nutrient profile.

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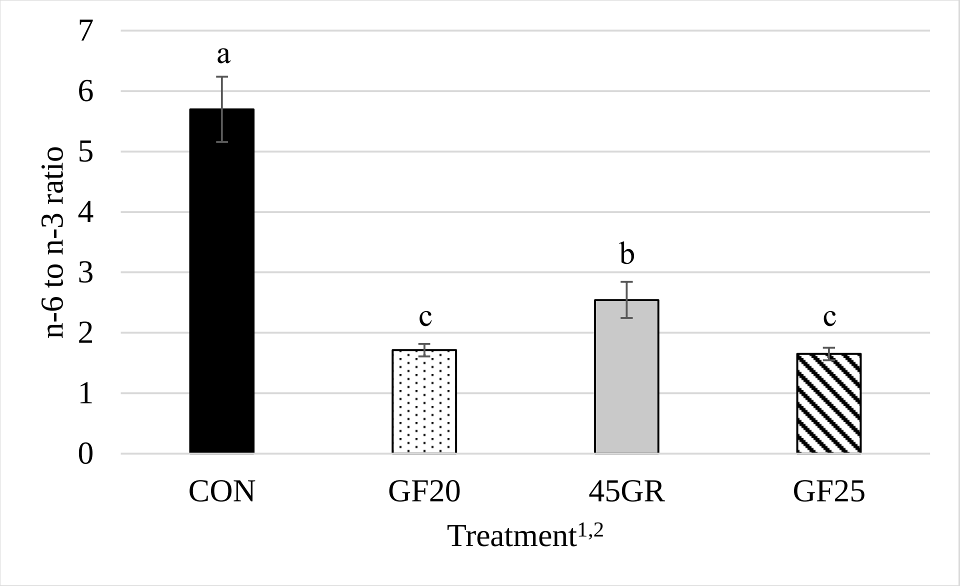
List of Figures

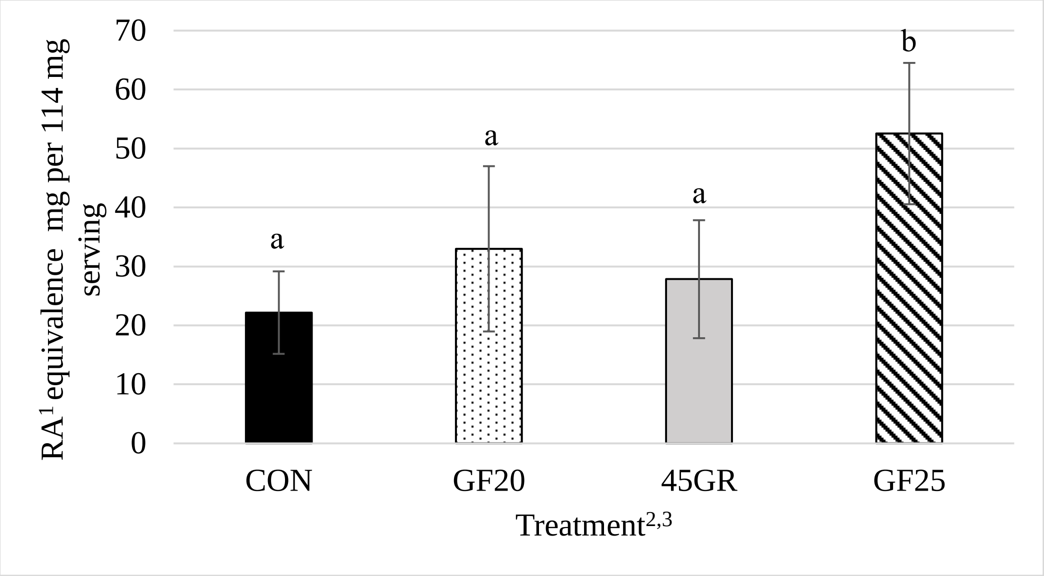
Figure 1



[1] CON - steers stocked on pasture then finished in a feedyard, GF20 - steers grass-fed for 20 months, 45GR - steers grass-fed for 20 months with a 45-day grain finish, GF25 - steers grass-fed for 25 month.

[2] Means with different subscripts indicate differences within treatments, determined by Tukey HSD.

Figure 2

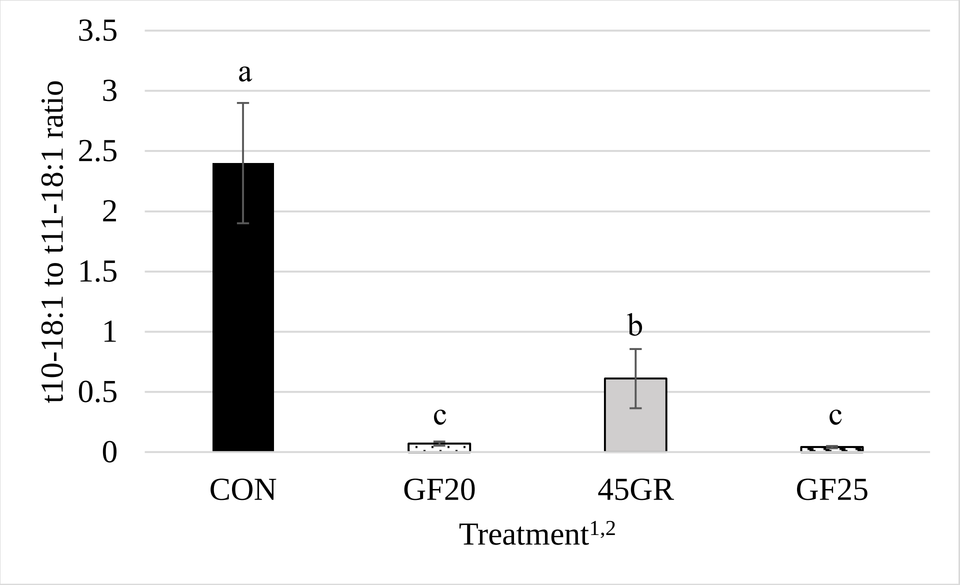


[1] Rumenic Acid (RA) equivalence equals c9, t11-18:2 plus 19% of the t11-18:1

[2] CON - steers stocked on pasture then finished in a feedyard, GF20 - steers grass-fed for 20 months, 45GR - steers grass-fed for 20 months with a 45-day grain finish, GF25 - steers grass-fed for 25 month.

[3] Means with different subscripts indicate differences within treatments, determined by Tukey HSD.

Figure 3



[1]CON - steers stocked on pasture then finished in a feedyard, GF20 - steers grass-fed for 20 months, 45GR - steers grass-fed for 20 months with a 45-day grain finish, GF25 - steers grass-fed for 25 month.

[2]Means with different subscripts indicate differences within treatments, determined by Tukey HSD.

List of Tables

Table 1

Item	Receiving[2]	Intermediate	Finishing
Ingredient		% Dry Matter Basis	
Rolled Corn	41.0	51.1	72.0
Distillers Grains	20.0	20.0	6.00
Fat	1.50	2.0	3.00
Molasses	8.00	7.00	3.00
Alfalfa Hay	15.0	10.0	5.00
Wheat Hay	12.0	8.00	6.00
Calcium Carbonate	0.82	1.15	1.80
Urea (45 N)	0.35	0.40	1.40
Magnesium Oxide	0.00	0.00	0.20
Rumensin	0.02	0.02	0.50
Beef Trace Salt[3]	0.32	0.32	0.32

[1] CON - steers stocked on pasture then finished in a feedyard, 45GR - steers grass-fed for 20 months with a 45-day grain finish.

[2] CON fed the receiving ration for 14 days, intermediate ration for 14 days and finishing ration for 100 days and GF45 fed the receiving ration 7 days, intermediate ration for 10 days and finishing ration for 22 days

[3] Beef trace salt 99% NaCl

Table 2

Analyzed composition, %	CON-feedlot ration	GF20-Rangeland	45GR[2]-feedlot ration	GF25-Irrigated Pasture
DM	86.26	34.37	88.28	23.72
CP	14.80	9.45	15.95	12.55
NDF	26.65	57.7	29.50	55.09
ADF	17.41	36.33	19.48	37.13
Ash	6.24	9.41	6.17	13.84
EE	6.83	2.91	6.74	2.04
Ca	0.68	0.41	0.63	13.93
P	0.31	0.24	0.39	0.17
Calculated energy, Mcal/kg DM[3]				
ME	3.33	2.26	3.37	2.52
NEm	2.30	1.39	2.33	1.62
NEg	1.60	0.81	1.62	1.02
Fatty Acid (mg/ g Feed)				
14:0	0.86	1.30	0.73	0.54
16:0	20.34	21.74	18.62	21.21
C9-16:1	0.88	0.47	1.13	0.35
18:0	6.81	2.32	6.07	6.87
C9-18:1	33.31	11.45	29.78	4.49
18:2n-6	33.65	22.32	39.40	19.18
18:3n-3	1.87	34.07	2.21	42.56
22:0	0.22	1.79	0.20	1.17
24:0	0.24	1.24	0.22	1.61

[1] CON - steers finished in a feedyard, GF20 - steers grass-fed for 20 months finished on rangeland, 45GR - steers grass-fed for 20 months with a 45-day grain finish, GF25 - steers grass-fed for 25 month finished on irrigated pasture.

[2] Ration composition from 45 day grain finish only

Table 3

Item	Treatment				SE	P-Value
	CON	GF20	45GR	GF25		
Calories, Cal	145.5_a	111.6_b	119.6_b	119.7_b	4.75	<0.001
Protein, %	22.25	22.76	22.53	22.9	0.13	0.42
Moisture, %	70.1_a	74.4_b	73.1_b	72.7_b	0.39	<0.001
Fat, %	5.95_a	2.18_b	3.10_b	$.42_b$	0.37	<0.001
Ash, %	1.08	0.88	1.03	1.03	0.03	<0.05
Iron, ppm	13.28_b	16.1_a	13.86_b	16.13_a	0.32	<0.01
Zinc, ppm	31.37_{ab}	29.7_{ab}	28.23_a	32.71_b	0.59	<0.05

[1] CON - steers finished in a feedyard, GF20 - steers grass-fed for 20 months finished on rangeland, 45GR - steers grass-fed for 20 months with a 45-day grain finish, GF25 - steers grass-fed for 25 month finished on irrigated pasture.

Table 4[1]

	Treatment[2,3]								
Item	CON	SD	GF20	SD	45GR	SD	GF25	SD	P-value
Final Body Weight[4], kg	632_c	43.5	478_a	26.2	551_b	39.6	570_b	25.1	<0.0001
Hot Carcass Weight, kg	372_c	25.0	230_a	13.8	303_b	22.1	292_b	15.9	<0.0001
Dressing percent, %	61.8_d	1.20	50.2_a	1.12	57.5_c	2.08	53.4_b	1.57	<0.0001
Yield Grade	2.86_c	0.52	1.45_a	0.28	2.37_b	0.41	2.14_b	0.34	<0.0001
Quality Grade[5]	7.04_c	0.57	3.94_a	1.39	5.30_b	0.75	4.81_b	0.91	<0.0001

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[1] Data presented first published in Klopatek et al., 2020.

[2] CON - steers stocked on pasture then finished in a feedyard, GF20 - steers grass-fed for 20 months, 45GR - steers grass-fed for 20 months with a 45-day grain finish, GF25 - steers grass-fed for 25 month.

[3] Means with different subscripts indicate differences within treatments, determined by Tukey HSD.

[4] Final Body Weight does not include 4% shrink

[5] Standard (−, 0, and +)—1, 2, and 3; Select (−, 0, and +)—4, 5, and 6; Choice (−, 0, and +)—7, 8, and 9; Prime (−, 0, and +)—10, 11, and 12.

Table 5

Fatty acid, mg/ 114 g serving	Treatment^{1,2} CON	GF20	45GR	GF25	SE	P-Value
∑Fatty Acid	6399^{a}	3253^{c}	3912^{bc}	5041^{b}	238	<0.0001
∑PUFA	322	310	324	299	8.59	0.728
∑PUFA, n-3	48.5^{c}	114.8^{a}	92.8^{b}	113^{a}	5.06	<0.0001
Linolenic Acid, c18:3n-3	16.8^{c}	49.4^{a}	32.1^{b}	54.9^{a}	2.52	<0.0001
Eicosapentaenoic, c20:5n-3	10.3^{c}	28.8^{a}	22.3^{ab}	20.7^{b}	1.37	<0.0001
Docosapentaenoic, c22:5n-3	15.8^{b}	30.8^{a}	32.6^{a}	31.5_{a}	1.53	<0.0001
Docosahexaenoic, c22:6n-3	3.71	4.49	4.79	3.98	0.16	0.17
∑PUFA, n-6	274^{a}	196^{b}	232^{ab}	187^{b}	7.80	<0.0001
Linoleic Acid, c18: 2n-6	208^{a}	129^{c}	169^{b}	125^{c}	6.49	<0.0001
Arachidonic Acid	43.6	50.5	44.2	42.7	1.70	0.33
∑CLnA	6.69^{b}	7.05^{b}	5.06^{c}	8.78^{a}	0.30	<0.001
c9,t11,t15-18:3	2.61^{a}	1.60^{b}	0.96^{b}	2.47^{a}	0.16	<0.001
c9,t11,c15-18:3	4.08^{b}	5.45^{a}	3.88^{b}	6.30^{a}	0.22	<0.0001
∑AD	36.6^{a}	30.0^{b}	23.1^{b}	44.8^{a}	1.71	<0.0001
t11,t15-18:2	0.065^{c}	0.11^{b}	0.07^{c}	0.18^{a}	0.01	<0.0001
c,t13-/c9,t14-18:2	9.28^{a}	5.77^{b}	5.45^{b}	8.91^{a}	0.41	<0.001
c9,c15-18:2	10.1^{a}	3.42^{d}	4.98^{c}	5.26^{b}	0.47	<0.0001
t11,c15-18:2	7.72^{c}	12.8^{b}	7.12^{c}	19.7^{a}	0.88	<0.0001
∑CLA	34.1^{ab}	30.4^{b}	24.9^{b}	43.3^{a}	1.76	<0.01
c9.t11-18:2	14.0^{b}	20.2^{b}	17.3^{b}	29.2^{a}	1.35	<0.0001
t11,c13-18:2	2.99^{b}	2.94^{b}	1.58^{c}	4.68^{a}	0.21	<0.0001
t10,c12-18:2	4.45^{a}	1.37^{b}	1.05^{b}	1.46^{b}	0.26	<0.0001
∑MUFA	3075^{a}	1353^{c}	1775^{bc}	2169^{b}	187	<0.0001
∑t-MUFA	227^{a}	118^{b}	134^{b}	196^{a}	9.44	<0.0001
t9-18:1	20.9^{a}	6.19^{c}	11.0^{b}	10.4^{b}	0.98	<0.0001
t10-18:1	98.5^{a}	4.58^{c}	31.4^{b}	5.36^{c}	6.24	<0.0001
t11-18:1	42.8^{b}	67.6^{b}	55.6^{b}	123^{a}	5.79	<0.0001
t13-t14-18:1	15.6^{a}	9.43^{b}	6.90^{b}	15.1^{a}	0.74	<0.0001
∑c-MUFA	2849^{a}	1235^{c}	1641^{bc}	1973^{b}	114	<0.0001
c9-16:1	185^{a}	94.3^{c}	113^{bc}	144^{b}	7.29	<0.0001
c9-18:1	2393^{a}	1027^{b}	1308^{b}	1668^{b}	96.9	<0.0001
c11-18:1	94.3^{a}	37.4^{c}	51.1^{b}	53.2^{b}	3.72	<0.0001
∑BCFA	60.3^{a}	63.7^{a}	43.6^{a}	100^{b}	3.92	<0.0001
15:0iso	13.8^{b}	13.4^{b}	7.04^{c}	20.7^{a}	0.90	<0.0001
15:0anteiso	6.67^{c}	9.51^{b}	5.72^{bc}	15.2^{a}	0.70	<0.0001
16:0iso	6.47^{b}	9.04^{a}	5.21^{b}	13.5^{a}	0.57	<0.0001
17:0iso	3.75^{ab}	3.65^{ab}	2.05^{b}	5.06^{a}	0.26	<0.0001

	18:0iso	5.02^{b}	5.66^{b}	3.41^{b}	8.37^{a}	0.34	<0.0001
∑SFA		2825^{a}	1433^{b}	1693^{b}	2335^{a}	111	<0.0001
	c14:0	160^{a}	77.4^{c}	77.7^{bc}	122^{ab}	7.09	<0.0001
	c15:0	26.5^{a}	18.6^{b}	14.9^{b}	28.5^{a}	1.23	<0.0001
	c16:0	1630^{a}	817^{b}	931^{b}	1331^{a}	64.5	<0.0001
	c17:0	80	34.9	40.5	58.8	3.43	<0.0001
	c18:0	904^{a}	469^{b}	560^{b}	771^{a}	35.9	<0.0001

[1] CON - steers stocked on pasture then finished in a feedyard, GF20 - steers grass-fed for 20 months, 45GR - steers grass-fed for 20 months with a 45-day grain finish, GF25 - steers grass-fed for 25 month.

[2] Means with different subscripts indicate differences within treatments, determined by Tukey HSD.

Rancher Motivations for Joining the Beef Quality Assurance Program

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Abstract

To date the most successful rancher educational program has been the beef quality assurance (BQA) program. However, it is not understood why ranchers choose to become BQA certified. Without this knowledge it becomes increasingly difficult to build new rancher educational and sustainability focused programs. Therefore, to better understand rancher motivations for adopting new practices and to gain insight on current involvement in BQA we administered an online multi-state survey to cattle ranchers in collaboration with state Cattlemen's Associations. In total, the survey consisted of 45 questions and was divided into 3 sections including: 1) Rancher Demographics, 2) Beef Quality Assurance Participation and current BQA practice application, and 3) Willingness to join new rancher educational programs. In total, 884 surveys were deemed usable. Specifically, of the survey participants, 70% were certified (n=524) or had been BQA certified at one time, and 30% had never been certified (n=360). Ranchers that were BQA certified were more likely to follow best management practices (BMP) by administering injections in the neck only, opposed to ranchers who were not certified ($P<0.05$) demonstrating the effectiveness of the BQA program. More than 80% of survey respondents who joined the BQA program (n=353) stated they believed the BQA program helped them improve animal health and welfare. Among those who have not joined the BQA program, 40% believed BQA practices did not align with their ranching operation (n=106), while 38% had not heard of the BQA program (n=99). The survey also indicated that first generation ranchers and those with less than ten years of experience were less likely to be certified (both $P<0.05$), signaling a need to reach ranchers newer to the industry. Overall, this survey provided an overview for why a rancher would or would not become BQA certified and identifying what methods to which audiences help with BMP adoption, which could be used as a model for creating sustainability and rancher educational programs in the future.

Introduction

Livestock’s environmental footprint has become a pivotal concern for American consumers. This concern has translated into grocery store purchases where consumers are now buying food items based on their perceived sustainability (McCluskey, 2015; McCluskey et al., 2005; Xue et al, 2010). In order to stay competitive in the sustainable foods movement, the beef industry has sought to improve sustainability within their own supply chains. However, before system sustainability can be achieved, more sustainability practices must be adopted and implemented by the foundation of the system. With over 725,000 cow-calf producers in the US (USDA-NASS, 2021), they are the foundation of the beef supply chain.

Identifying reasons for why a rancher would adopt an educational practice or program is critical for developing and implementing sustainability and best management practices (BMP). Although several studies have examined cow-calf producer’s motivations for volunteering for rancher education and conservation programs (Lubell et al., 2013; Roche at al., 2015; Kachergis et al. 2013), no study has investigated why ranchers choose to be part of the successful rancher educational program, Beef Quality Assurance (BQA). The BQA program was founded to improve animal health and welfare, and thereby the beef product itself. A primary objective of the program was to decrease the incidence of injection cite lesions found in carcasses. To reduce the incidence of injection site lesions the program promoted the BMP of administering injections in the neck only. Since the program’s inception, the incidence of injection site lesions has decreased by over 90% (NBQA, 2016). Furthermore, with over 137,000 producers currently enrolled in BQA (NCBA, personal communication), BQA is one of the largest volunteer ranching educational programs to date.

With a high degree of rancher involvement and BMP implementation, the BQA program serves as a model and case study for the development of future rancher educational and sustainability programs. However, the reasons why ranchers volunteered to join this program and implement BQA practices are not well understood. In addition, other than the National Beef Quality Audit (NBQA, 2016), there is little information available about what BQA BMP are being performed. Without this knowledge, the improvement of the current BQA program and future rancher educational programs becomes increasingly difficult. Therefore, in order to improve the development and adoptability of future sustainability and rancher educational programs we designed and implemented a multi-state survey investigating BQA certification. Specific survey objectives were: 1) identify why ranchers chose to participate in the BQA program, 2) determine what demographic factors influenced BQA participation, and 3) determine if there were relationships between BQA program adoption and willingness to take part in a sustainability program.

Materials and Methods

Survey design and recruitment procedures

We developed an online survey for ranchers and administered the survey using the platform Qualtrics (Provo, UT). In total, the survey consisted of 45 questions and was divided into 3 sections including: 1) Rancher Demographics, 2) Beef Quality Assurance Participation and current BQA practice application, and 3) Willingness to join new rancher educational programs. Survey questions were derived from literature and discussions with collaborating ranchers. After questions were developed, the initial survey was pilot tested with California ranchers located in northern California. Once pilot testing was completed and minor adjustments were made, the final survey was administered online to ranchers in California, Oregon, Wisconsin, Kentucky, Louisiana, Hawaii, and Texas. These states where chosen to represent ranchers in the Western, Eastern, and Southern United States. To recruit ranchers from these states' ranchers were contacted via state cattlemen association list serves. The state cattlemen associations (Kansas Cattlemen Association, California Cattlemen Association ext.) in these states are nonprofit trade organizations serving cattle ranchers, beef producers, and private owners of cattle-grazed properties. Ranchers on the respective list serves were emailed once a month over a 6-month period an invitation to complete the survey. As an incentive to fill out the survey, ranchers who completed the survey were put in a raffle to win prizes. The survey was available from June 1st to December 31st 2019. In selecting ranchers for the study, we focused on finding diverse perspectives and management approaches. Thus, we had only two requirements for inclusion in this study, 1) to be a current cattle rancher who was on a state cattlemen list serve and 2) currently own cattle.

Operator and Operation Demographics

Survey questions regarding demographics and operational characteristics included sex, age, first or multigenerational rancher, years ranching since reaching 18, and zip code. Operation characteristics included percent of income from ranching, succession planning, number of head of cattle, and type of land utilized. In addition, ranchers were asked about common rangeland and ranch management practices, type of operation, types of certifications, program involvement, vegetation management, and landscape enhancements. Qualitative questions were multiple choice and quantitative questions were fill in the blank. See supplementary material for list of survey questions.

Current BQA Best Management Practices

Respondents were asked a variety of questions regarding BQA program involvement. First, ranchers were asked if they had participated in the BQA program. To be considered currently BQA certified, as per BQA guidelines, ranchers must have certified or re-certified in the program within a three-year period. Therefore, to accurately depict BQA program involvement survey participants were asked to select from one of 5 categories: currently certified (enrolled in past 3 years), currently certified (over 3 years, recertified), was BQA certified at one time but never recertified, went to BQA program but never certified, and have not participated in BQA. For participants who were currently BQA certified or had been certified at one time they were asked to select their top 3 reasons for joining the BQA program. In addition, these participants were asked to rank on a 1-5 scale how beneficial the BQA program had been for their ranch. If the survey participant had never been BQA certified they were asked why they chose not to be a part of the program. To identify if ranchers were currently following BQA guidelines survey participants were asked about vaccination administration along with other BQA specific practices. Specifically, ranchers were asked where they gave antibiotic, vaccine, and hormone injections.

Ranchers were asked if they were willing to participate in a non-mandatory "beef sustainability" rancher education program that would be beneficial for their operation. Respondents had the answer choices of yes, no, and unsure.

Statistical Analysis

A variety of statistical analyses was used for different purposes. Regression and analysis of variance (parametric and non-parametric tests) were used for analyzing continuous variables, and cross tabulation with chi-squared tests was used for categorical variables. Statistical analysis focused on what independent variables affected BQA participation. The complete list of independent variables is provided in Table 1. Data were analyzed using STATA, version 16.1. (StataCorp 2019). Statistical significance was indicated at $P < 0.05$.

Results

In total, 884 survey responses were deemed usable. For demographics regarding participants' age, sex, location, and ranching operation characteristics, see Table 2.

BQA Participation

According to the BQA program guidelines to be considered current in BQA certification participants need to have completed the certification process within the last 3 years regardless of if they were or were not previously certified. Among the survey participants, 70% were certified or had been BQA certified at one time (n=624), and 30% had never been certified (n=269). Specifically, 24% of participants were currently certified and had enrolled in the BQA program within the last 3 years (n=212), 35% were previously certified and had recertified in the last 3 years (n=312), 24% had not participated in BQA (n=211), 11% had been certified at one time but never recertified (n=100), and 7% had gone to a BQA program but never certified (n=59; Figure 1).

The study sought to identify rancher motivations for becoming BQA certified. For those who had participated in the BQA program (either currently certified or certified at one time), the most cited motivations for joining BQA were; 1) to improve animals' health and welfare (n=524), 2) consumer perceptions/demands/concerns about animal welfare (n=353), and 3) reputation of my operation is greater when animals are a part of BQA (n=310; Figure 2). Other reasons ranchers participated in BQA included a belief that voluntary participation in BQA would prevent regulatory requirements (n=217), BQA would increase the longevity of their operation (n=323), and BQA animals would fetch a higher price (n=137). In addition, 4% of ranchers participated in the program because neighbors/competitors were performing BQA practices (n=25). When BQA participants were asked if the BQA program had been beneficial to their ranching operation, 26% stated joining the BQA program had been extremely beneficial to their ranching operation (n=164), 32% stated very beneficial (n=200), 29% beneficial (n=184), 10% somewhat beneficial (n=66), and 3% stated BQA had not been beneficial (n=17). Of the BQA participants surveyed when asked if there were any sections in the BQA guidelines only 20 producers listed program concerns with the majority of the issues relating to either weaning or vaccination procedures (n=17).

For the survey participants who did not join BQA, 40% claimed that they did not join the program because the practices did not fit their operation's goals or management strategies (n=106), 38% of participants reported they had not heard of BQA (n=99), 19% stated there was not enough financial reward (n=50), 13% stated their operation exceeds BQA standards (n=35), 14% stated the time commitment was too high (n=37), 10% stated there were no BQA certification opportunities in the area (n=27), and 1% of participants stated that BQA practices did not make sense or were confusing (n=3; Figure 3).

BQA and Ranching Practices

The core BMP taught by the BQA program is to administer all injections (antibiotics, vaccinations, and hormones) in the neck. In the current survey 92% of ranchers stated they administered antibiotics in the neck but gave injections in additional areas as well (I.e. rump, tailhead, shoulder, ext) (n=711) and 79% gave injections in the neck only (n=609; Figure 4). For vaccination injections, 92% of ranchers administered the injections in the neck and elsewhere (n=711), and 84% gave injections in the neck only (n=609). In contrast, only 56% of ranchers injected reproductive hormones into the neck and elsewhere (n=225) and 50% injected in the neck only (n=202). If ranchers were BQA certified they was a significant correlation ($P<0.05$) between being BQA certified and administering antibiotics, hormones, and vaccinations in the neck only.

When ranchers were asked about other BQA practices, 63% stated they practiced fence-line weaning (n=485), 58% castrated before 3 months of age (n=454), and 50% established a heard health plan with a veterinarian (n=394). In regards to shipping weaned calves, 49% of the ranchers waited 45 days after weaning to ship calves (n=385), 21% shipped calves in the week of weaning (n=161), and 20% shipped calves 7-45 days after weaning (n=153). Although not BQA sanctioned, 18% of respondents reported they implemented darting practices on their operation (n=139). There was a statistical relationship between BQA certified ranchers and shipping weaned calves 45 days after weaning ($P<0.05$).

From the ranchers surveyed, 50% had participated in stockmanship/stewardship training (n=397). When ranchers were asked how important it was to use low stress livestock handling techniques, 68% said extremely important (n=542) and 25% said very important (n=192). When asked if ranching educational programs have influenced breeding stock purchasing decisions, 50% said yes (n=386), 32% said maybe/unsure (n=249), and 18% of ranchers said no (n=147). Of those surveyed, 78% (n=611) said they had a grazing management plan. Of the ranchers that had a grazing management plan, 40% stated the plan was written down (n=224), 44% reported that technical services provided input into the plan (n=246), 43% of participants said family provided plan input (n=224), and 35% said the plan was updated every 1-2 years (n=197). When ranchers were asked why they implemented a grazing management plan, 81% stated they implanted a plan to ensure productivity of the herd (n=461), 65% stated resource conservation (n=360), 20% stated to improve family/business partner communication (n=111), and 6% stated the plan was mandated by the lease (n=37).

When survey participants were asked what practices they would be willing to implement as part of a voluntary rancher educational program, 82% said they would maintain animal health records (n=576), 81% stated they would individually identify each calf (n=556), 79% stated they would record birth rates (n=555), 63% stated they would record the location of each animal, 43% stated they would record stocking densities (n=299), and 28% said they would implement a biosecurity plan (n=199: Table 3).

Factors Effecting BQA Certification

Using Chi squared tests, no difference was observed between the independent variables and survey responses who were either currently certified, recertified or certified. Therefore, these three categories were combined and designated as BQA certified in the model. Those who had not participated in BQA and had gone to a BQA program, but never certified, were considered non-participants. Age did not have a statistically significant relationship with BQA certification ($P=0.115$; Table 4). However, years ranching was associated with BQA certification ($P<0.05$). Specifically, ranchers who had ranched for over 30 years had the greatest certification rate at 75%. Those that had ranched for 0-5 years and 5-10 were the least likely to participate in BQA program at 65% and 58%, respectively. Producers will more acres of land or head of cattle were more likely to be a part of the BQA program than those with less land or fewer cattle ($P<0.05$ and $P<0.05$, respectively; Table 5).

Region was associated with participation rate ($P<0.05$) with only 54% of California residents and 52% for Oregonian residents certified, compared to 88% of those certified in Kentucky. Gender had no effect on BQA certification ($P=0.10$). If the rancher personally owned grazing land they were more likely to be in a BQA program ($P<0.05$), but leasing either private or public land was not related with BQA certification ($P=0.62$ and $P=0.07$, respectively). Multigenerational ranchers were more likely to be certified than first generation ranchers ($P<0.05$). Income from ranching also affected BQA certification with respondents with ranching net incomes less than 25% being less likely to participate in BQA certification than those with a greater portion of income coming from the ranch (*$P<0.05$*). Ranchers who participated in niche certification programs were more likely to be BQA certified ($P<0.05$). Specifically, if a rancher was participating in humanely raised, verified source and age, NHTC or GAP program they were more likely to be certified in BQA (*$P<0.05$*). In contrast, if ranchers employed grass-fed, natural or organic practices, there was no clear relationship with BQA certification (*$P=0.40$*). If ranchers participated in a government land assistantship program, ranchers were more likely to be enrolled in the BQA program (*$P<0.02$*).

For grazing management plans, no relationship was observed between maintaining a grazing management plan and BQA certification (*$P=0.61$*). In addition, there was no significant relationship between having a ranch succession plan and BQA certification (*$P=0.17$*). Finally, joining a rancher educational program was not related to joining a rancher sustainability program

Discussion

Factors and Motivations for Joining the BQA Program

The decision for ranchers to adapt new agricultural practices are influenced by a variety of environmental, political, societal, and economic factors (Kachergis et al., 2013; Smit and Skinner 2002; Yung et al., 2015). The present study observed those who generated greater levels of income from ranching (75% or greater) were more likely to be BQA certified than those who received smaller portions of income from ranching (74% or less; $P<0.05$). This is consistent with previous studies that have shown level of income, capital, and access to labor to be positively correlated with the adoption of new ranching practices (Kara et al., 2008, Lamba et al., 2009; Rowan and White, 1994). In terms of diversification of income, a survey in California found ranchers with a higher numbers of off-ranch income sources participated in more conservation programs (Lubell et al., 2013). Although the current study did not observe these findings, ranchers who received income from passive recreation in addition to ranching income were more likely to be BQA certified than those who received additional income from other active recreational sources.

Currently, it is hypothesized that the larger scale of production (i.e. number of head and number of acres operated), the more likely to adopt or try new ranching practices, principally because larger operations have more economically viable and lower economic risk (Lubell et al., 2013; Thurow et al., 2000; Kreuter et al. 2004). The present study was consistent with this hypothesis, those with larger ranchers and greater number of head were more likely to be BQA certified ($P<0.05$ and $P<0.05$, respectively). However, scale of operation is a multifaceted factor in terms of effect on rancher adoption practices. In addition to greater economic viability, larger scale operations may have increased knowledge on where to access to ranching information (Liu et al., 2010) and dedicate more time searching for methodologies to improve ranching practices and animal health. As such, larger operations may have had an increased awareness of the BQA program and thereby were more likely to certify than smaller operations.

Time Horizon variables (i.e. ranching generation and succession planning) have been positively association with adoption of conservational programs (Mishra and El-Osta, 2007; Lubell et al., 2013). In the present study, although multigenerational ranchers were more likely to be BQA certified than first generation ranchers, no relationship was observed between having a succession plan and BQA practices. However, years ranching did have a statistical relationship to BQA certification with those who ranched for longer periods of time (>9.9 years) more likely to be BQA certified. The lower BQA certification for first generational ranchers and ranchers with less ranching experience compared to multigenerational and more experienced ranchers may be due to decreased exposure to ranching information platforms such as other ranchers, conferences, workshops. To improve the success of the BQA program and to be proactive in future ranching educational programs, more effort and outreach needs to be put forth to target individuals with less ranching experience.

Type of land (i.e. public or private) utilized for ranching has been identified as an influencing factor for joining conservation programs. Previous studies have indicated that ranchers who owned greater amounts of private land compared to public land were more likely to join conservation and educational programs (Neill et al., 200; Peterson and Coppock, 2001). It is thought that ranchers are less likely to put time, money, or energy into land which they do not own. The current study was consistent with these findings and found ranchers with private land were more likely to be BQA certified than those grazing predominantly on public land. However, unlike conservation programs which have land-animal interactions, the BQA program principally requires action to the animal (i.e. administering injections to the neck), not the land. Thereby, the reasons why ranchers with public lands choose not to become BQA certified are likely different than the reasons for choosing not to partake in conservation programs.

The number of niche market operations in the U.S. has been increasing rapidly (Nielsen, 2018). Despite the growth in the sector of ranching, limited data is available regarding niche market producers' motivations for program adoption. When participants in the categories of natural, grass-fed, organic were combined there was no effect of their involvement and BQA certification. It is thought because many organic, natural, and grass-fed programs have their own animal welfare standards, producers in these programs may not have found it beneficial or necessary to join BQA program. In contrast, producers in the niche category of humanly raised, verified source and age, non-hormone treated cattle and global animal partnership were more likely to be a part of the BQA program. Many cattle in these programs are sold to feedlots and produced for overseas export. Producers in these programs may have found BQA certification to add value in their operation compared to those in the organic, grass-fed, and natural niche programs that have different operational structures.

The main reason ranchers chose to become BQA certified was to improve the health and welfare of their animals (n=542), demonstrating ranchers high regard for animal care. However, the survey also demonstrates how industry and societal pressures add an additional impetuous for joining the BQA program with the second and third most popular reasons for joining BQA being "improving reputation" and "consumer concerns for animal welfare" (n=353 and n=310, respectively). This pattern of industry and societal pressure on rancher willingness to adoption practices is a common factor for increasing a producer's willingness to join a program or adapt a new practice (Prokopy et al., 2008).

Beef Quality Assurance and Best Management Practices

One of the principal objectives of the BQA program was to reduce the incidence of injection site lesions. To accomplish this task BQA implemented training seminars across the county specifying that all injections, including vaccines, antibiotics, and hormones, be administered into the triangle of the neck. When survey participants were asked where they administered antibiotics and vaccinations, those who were BQA certified gave 85% of antibiotics in the neck compared to only 66% for individuals not BQA certified. Although more work needs to be done to continue to reduce the incidence of injection site lesions, this survey demonstrates that those who are enrolled in the BQA program are effective applying BQA BMP. Furthermore, with 66% of non-certified BQA ranchers administering injections in the neck only, the BQA BMP have been able to transfer to non-certified ranchers.

In terms of hormone injections, an informational disconnect was observed between BQA teachings and ranching procedures. In contrast to vaccines and antibiotics, only 56% of BQA certified ranchers and 39% of non-certified BQA ranchers stated they administered hormone injections in the neck only. Specifically, 24% of BQA certified ranchers, administered injections on the trailhead or rump. Although this is not a BQA sanctioned practice, it can be hypothesized that ranchers may be administering hormonal drugs in the rump for breeding purposes. Presently, some pharmaceuticals used for breeding purposes are approved for tail head/ rump administration. Future BQA programs need to address if animals considered for breeding purposes are allowed to receive hormone injections outside the neck area.

Another BQA BMP is fence line weaning calves for a 45-day period. Of those that participated in this program less than 50% of BQA certified individuals (n=120) stated a willingness to partake in this practice. This practice may not be feasible for ranchers due to land space, animal handling infrastructure, or forage logistical issues.

Relationship to a sustainability program

Despite the positive relationship between BQA certification and government land assistance or conservation program participation, there was no relationship between BQA certification and desire to take part in a certification program. However, it is important to note this lack of relationship does not demonstrate a lack of willingness for ranchers to enroll in a sustainability program. Overall, over 50% of respondents said participating in a in a non-mandatory "beef sustainability" rancher education program would be beneficial for their operation and 30% said they were unsure. These positive results demonstrate that there is a willingness for ranchers to be a part of future sustainability programs.

Conclusion

This survey was the first of its kind to directly ask ranchers in a number of states about the BQA program and why and how the program has or has not been effective. This study concluded that although there were similar factors for becoming BQA certified and joining conservation programs, additional factors such as type of niche production practice influenced BQA certification. Second, although BQA certification did not increase the likelihood of willingness to be a part of a beef sustainability program, the high rate of adoption of BMP indicates that the BQA program could be a reliable model for future sustainability programs.

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List of Tables

Table 1

Operator Characteristics
- Age
- Years Ranching (Since 18 years old)
- Gender
- Have a grazing management plan
- Succession Plan
- Generation of Ranching

Ranching Operation Characteristics
- Location of Ranch
- Income from ranching
- Participation in ranching certification programs
- Participate in a government landowners assistance program
- Type of land managed and size of operation
- Number of cattle
- Additional income sources on the ranch

Table 2

Categorical Variables	Frequency	Percent
Age		
18-29	96	10.09
30-39	170	17.88
40-49	137	14.41
50-59	208	21.87
60-69	217	22.82
Over 70	124	12.93
Years Ranching (Since 18 years old)		
0-5	116	12.20
6-10	119	12.51
11-20	200	21.03
21-30	168	17.67
More than 30 years	349	35.59
Gender		
Male	701	74.10
Female	246	25.90
Location of Ranch		
Kentucky	390	39.00
California	282	28.20

Oregon	96	9.60
Louisiana	60	6.00
Texas	58	5.80
Other	146	14.6
Have a grazing management plan		
Yes	611	49.30
No	148	31.93
Unsure	250	18.77
Succession Plan		
Yes	340	36.48
No	232	24.79
In progress	286	30.69
Not applicable	75	8.05
Generation of Ranching		
First	305	32.65
Multi-generational	627	67.35
Income from ranching		
1-25%	483	52.22
26-50%	233	25.19
51-75%	93	10.05
76-100%	116	12.54
Participation in ranching certification programs (other than BQA)		
Humanly raised	105	12.06
100% Grass-fed or Grass-finished	72	8.27
All Natural	115	13.20
Certified Organic	19	2.18
Verified Source and Age	144	17.80
Non-hormone Treated Cattle (NHTC)	155	17.80
Global Animal Partnership (GAP)	27	3.10
Do not participate in ranching certification programs	270	69.12
Participate in a government landowners assistance program		
Yes	354	40.23
No	526	59.77

Table 3

Categorical Variables	Min	Max	Mean	SD
Type of Land Grazed				
Personally owned	0	250,250	1353	9530
Leased privately owned	0	180,000	936	6378
Publically Leased	0	240,000	1812	12737
Irrigated (Owned or Leased)	0	15,000	103	668
Total land managed	0	150,000	4886	52294
Number of head				
Cows and Yearling Heifers	0	14,000	162	678
Stockers	0	10,000	523	10000
Bulls	0	2,400	11	80
Sheep	0	25,000	38	808

Table 4

Variable	Person Chi	P-value
Age	8.83	0.12
Gender	2.7	0.10
Years Ranching	12.39	0.02
Location of Ranch	123.5	<0.001
Personally Owned Grazing Land	6.54	0.01
Leased privately owned grazing land	0.247	0.62
Leased publicly owned grazing land	0.994	0.32
Graze on irrigated land	4.64	0.03
Ranching Generation	4.25	0.04
Income from ranching	15.86	<0.001
Humanly Raised, Verified Source and Age, NHTC, and GAP	7.705	0.01
Grass-fed, All Natural, or Certified Organic	0.716	0.52
Participation Government Land Assistantship Program	11.71	0.02
Grazing Management Plan	2.71	0.61
Has a Succession land	11.61	0.17
Ranching Operation includes other activities that affect land management:		
Passive Recreation	13.75	0.01
Active Recreation	1.16	0.88

Table 5

Variable	Observations for not BQA Certified	Observation for BQA Certified[2]	Z-score	Probability
Total Acres Personally Owned	269	624	-2.01	0.05
Total Acres Ranched	266	614	1.65	0.10
Total Number of Cows	269	624	-2.23	0.03
Total Number of Stockers	269	619	-3.90	0.01

[1] Includes never participating in a BQA program and went to a BQA program but never certified.

[2] Includes individuals who were currently certified or had been certified at one time.