EVALUATION OF GROWTH PERFORMANCE, CARCASS AND MEAT QUALITY OF LAMBS REARED ON COVER CROP AND GRAIN FINISHING SYSTEMS.

By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Animal Science – Master of Science

2021

ABSTRACT

EVALUATION OF GROWTH PERFORMANCE, CARCASS AND MEAT QUALITY OF LAMBS REARED ON COVER CROP AND GRAIN FINISHING SYSTEMS.

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Brassicas used as cover crops (CC) have the potential to provide high-quality forage as part of lamb rearing systems. We compared growth, carcass, and meat quality traits in lambs finished on two brassica-based CC treatments and two grain feeding systems in 2019 and 2020. Lambs (n=60; Dorset x Polypay; 3 pens/pastures, 5 lambs each) were randomly assigned to four treatments: 1) GRN – 6 wk on grain; 2) BRO - 8 wk grazing pure brassica CC; 3) MIX – 8 wk grazing a mixture of brassica and other species; and 4) BKG - 4 wk grazing of pure brassica then 4 wk on grain. Cover crops were planted after in late summer after wheat harvest and grazed once 4 Mg DM/ha was available. Pre-grazing CC biomass did not differ; however botanical composition did, reflected as lower ADF, NDF, DM and CP in pure brassica compared to MIX (P < 0.001). Lambs fed grain grew faster (308-361 g/d) than those on CC (186-204 g/d; P < 0.001). Gain per hectare did not vary by CC but declined over time (218 to 137 kg/ha; P < 0.01). Plasma NEFA concentration was elevated in CC compared to grain diets (P < 0.001), and PUN was depressed on pure brassica CC compared to other treatments (P < 0.01). Carcass traits and IMF (3.9 – 4.2%) were not affected by CC treatment but lambs finished on CC were leaner (P <0.05) and smaller (P <0.01) than grain-fed lambs. In sensory evaluation of loin chops, consumers preferred BRO over other treatments for flavor and juiciness (P < 0.05). We conclude that brassica CC rearing systems can produce lambs of acceptable carcass and superior meat quality. Further work is needed to assess the economics of these rearing options and the basis for the depression of PUN when grazing forage with high brassica content

ACKNOWLEDGEMENTS

I wish to express my sincerest gratitude to the numerous people, whose support made this research would not have been possible. First, I would like to thank Dr. Richard Ehrhardt for serving as my major advisor. He served as a mentor and encouraged me to strive for success. I would also like to specially thank Dr. Kimberly Cassida for introducing me to the field of forages and cover crops. I extend my thanks to my thesis committee members: Dr. Jeannine Schweihofer, and Dr. Jongkyoo Kim. To them I am grateful for their guidance throughout my master's program.

There are many people to whom I owe my gratitude for their encouragement. Thank you to Barbara Makela for her willingness to teach me the methodology needed to complete certain aspects of my research. I am indebted to the employees at the Sheep Teaching and Research Center, namely Lacey Quail, Tristan Foster, and the student workers who assisted with my research. I would also like to thank Jennifer Dominguez and the meat department for their assistance with the meat phase of this project. Thank you to Dr. Andrea Garmyn for helping us complete the research on meat even when it meant a cross country trip. Many thanks go to Joe Paling, Dr. Erin Recktanwald, Danny Schaub, Allison Schafer, and Jordan Moody who were always willing to lend a helping hand.

I would also like to extend a sincere thank you to all the sheep in my study, they provided me with an education of their own. I am forever grateful to my parents Joy and Robert Macaluso, my husband Michael Chopin, and the rest of my family and friends for their love and support. Lastly, I would like to acknowledge the weather and COVID-19, which taught me the benefit of adaption.

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KEY TO ABBREVIATIONS

a*	Redness red to green
ADF	Acid Detergent Fiber
ADG	Average Daily Gain
b*	Yellowness to blue
BF	Backfat
BW	Body Weight
BWD	Body Wall Depth
CC	Cover Crop
CP	Crude Protein
CSG	Cool Season Grasses
D	Day(s)
DE	Digestible Energy
DM	Dry Matter
DMI	Dry Matter Intake
EMD	Eye Muscle Depth
FCR	Feed Conversion Ratio
GRN	Grain feedlot diet
HCW	Hot Carcass Weight
IMF	Intramuscular fat
L*	Lightness
LEA	Loin Eye Area
ME	Metabolizable Energy

MRA	Metmyoglobin Reducing Activity
NDF	Neutral Detergent Fiber
NEFA	Non-Esterified Fatty Acids
NIRS	Near-infrared Reflectance Spectroscopy
NRC	National Research Council
OCR	Oxygen Consumption Rate
PCV	Pack Cell Volume
PUN	Plasma Urea Nitrogen
SE	Standard Error
SMCO	S-methyl cysteine sulfoxide
SQ	Subcutaneous
TDN	Total Digestible Nutrients
VFA	Volatile Fatty Acid
VFI	Voluntary Feed Intake
WBSF	Warner-Bratzler Shear Force
WK	Week(s)
WSG	Warm Season Grasses
YG	Yield Grade

CHAPTER 1: REVIEW OF LITERATURE

THE SHEEP INDUSTRY IN MICHIGAN

Impact on Economy and Consumer Demand of Lamb

The Michigan sheep industry has a significant economic impact within the state and a large opportunity for growth due to the abundant natural resources, processing capacity, and consumer demand for sheep meat (both lamb and mutton) in the state. Economic estimates reveal that the Michigan sheep industry has an average yearly direct economic impact of $531 million, representing around 5% of a $104.7-billion-dollar Michigan agricultural economy over the 2014-2016 period (Knudson, 2018). Michigan possesses climate and natural resources conducive to abundant forage production providing an important base for efficient sheep production. For example, in south-central Michigan, the average precipitation from July to December varies from 41 to 88 mm a month creating a relatively uniform rainfall distribution, which favors consistent growth of quality forage (NOAA, 2021). Michigan also has the bonus of processer capacity and local consumer demand with Michigan processing roughly 10% of all federally inspected lamb and mutton in the U.S. (USDA, 2020).

The demand for sheep meat is high in Michigan. In 1999, Michigan consumed over 13 million pounds of lamb and mutton yearly and only produced 4 million pounds of lamb on a carcass basis. (Ferris, 2000). Though this study was conducted 20 years ago this trend of lower in-state production than consumption holds true today (Recktenwald and Ehrhardt, 2018), leaving room for local expansion of production.

Michigan is home to a diverse market for lamb and mutton. The U.S. sheep industry consists of a traditional market and a non-traditional market (Recktenwald and Ehrhardt, 2018). The traditional market is made up of consumers who prefer relatively heavy (>60 kg carcasses), and fat lambs finished on grain. The nontraditional market tends to be made up of consumers with distinct cultural preferences. In general, the preference for lambs in this market is for smaller and leaner lambs and many are consumer require that they are slaughtered and processed according to religious protocols, including Halal and Kosher (Shiflett et al., 2010; Recktenwald and Ehrhardt, 2018). The size of the nontraditional market in the U.S. was underappreciated until a study in 2010 estimated that approximately 60% of the lambs slaughtered in the U.S. entered the nontraditional market (Shiflett et al., 2010). In Michigan, it has been estimated that over 80% of local lambs enter the non-traditional market (Recktenwald and Ehrhardt, 2018). One reason for the large non-traditional market in Michigan is a large ethnic enclave in the metro Detroit region that has a high preference for sheep meat (Recktenwald and Ehrhardt, 2018). Currently, 10% of Michigan's population is Hispanic or Arab American, and these populations along with other ethnic enclaves are projected to increase over the next decade by up to 10% (Shiflett et al., 2010; United States Census, 2018); creating a larger demand for the nontraditional market and increasing the demand for sheep meat. Local lamb may also provide a price incentive. Consumer demand for sheep meat is negatively correlated with meat price (Schroeder et al., 2001). By producing locally, farmers may be able to improve sales by offering fresh product at lower costs due to savings in transportation cost. This combination of high local demand, low transportation cost, along with adequate processing capacity provides Michigan with an opportunity for industry growth.

Barriers to Sheep Producers Expansion in Michigan

In the Midwest, U.S. lamb production is primarily limited by similar factors that limit product in other parts of the world, including farm size, cost of feed and labor, and cost of land expansion (Blase and Hesemann, 1973; Salcedo and García Trujillo, 2006; Gaspar et al., 2008). United States Department of Agriculture (USDA) demographics of sheep production indicates that there are many small farms of less than 100 head (Jones, 2004). Sheep farming is well suited to small farms due to its relatively low cost of investment (Jones, 2004). However, expansion is often limited by land cost when land is highly valued for competing agricultural uses like row crop farming (Blase and Hesemann, 1973).

An increase in grazing opportunities can lower the cost of production and promote expansion of sheep operations (Gaspar et al., 2008). Grazing winter crops on a land lease can provide a feasible economic alternative as a growing/finishing system that reduces feed and management cost compared to feedlot, Krause et al. (2013), while reducing the cost of land purchase (Heady, 1971). Cover crops are grown between periods of commodity crop growth and are used to protect soil and enhance production of the primary commodity crop. Cover crop grazing can aid in overcoming grazing access barriers by offering the opportunity to graze land that does not usually have animals on it and rent the land instead of owning the property.

Another barrier for producers is the seasonality of the product produced, which is a challenge unrelated to scale of operation. Sheep are short-day seasonal breeders which means a larger amount of lamb will be available in the spring compared to later in the year (Jones, 2004; Redden et al., 2020). Growing lambs through the winter months can create production barriers due to feed and facility costs and may encourage producers to slaughter earlier. Slowing lamb growth through inexpensive grazing programs may stretch supply and allow sale during periods when national supply is low and prices are elevated (Redden et al., 2020).

USE OF COVER CROPS IN CROPPING SYSTEMS AND INTEGRATION OF GRAZING SYSTEMS

Benefit to Soil and Crop Quality

Cover crops provide many environmental and economic benefits to crop producers when properly utilized (Clark, 2007). They help sequester nutrients in soil and benefit future crop yields (Baggs et al., 2000). Cover crops reduce cost of production by reducing the need for herbicides and they may also help improve subsequent cash crop yields (Derpsch et al., 1986). They also benefit soil by reducing wind and water erosion by providing ground cover and increasing water infiltration rates which aids in soil conservation (Derpsch et al., 1986; Lal, 2001; Schipanski et al., 2014).

Some cover crops such as turnips (*Brassica rapa subsp. rapa* L.), radishes (*Raphanus* L.) and rye (*Lolium* L.) move soil nutrients, especially phosphorus from subsoil to surface layers where they are more easily accessed by subsequent cash crops (White and Weil, 2011). Fibrous root cereal grains and tuber species can help reduce need for nitrogen fertilizer use by immobilizing nitrogen in the soil from previous crops (Baggs et al., 2000; Clark, 2007). Utilization of rye as a cover crop system can take up a large portion of residual nitrogen in soil without affecting subsequent cash crop yields and reduce fertilizer need (Ruffo et al., 2004; White and Weil, 2011).

Species in the Brassicaceae family, hereafter referred to as brassicas, such as forage radish and forage rape (*Brassica napus* L.), are efficient in penetrating highly compacted soil making them an ideal cover crop to help reduce soil compaction (Chen and Weil, 2010). By reducing soil compaction, cover crops increase water infiltration and add organic matter back to the soil to support the microbiome, which in turn benefits and protects crop production (Clark, 2007). Use of cover crops reduces the need for herbicide use by providing leaf canopy to block growth of weeds (Clark, 2007; Kruidhof et al., 2008).

Cover crops in cropping systems can have economic benefits (Morton et al., 2006). In a study utilizing rye as a cover crop, the total cost to plant and manage rye was $55.14 per/acre whereas the cost of using herbicides was $62.61 per/acre. This produced a benefit of $7.47 per/acre for using rye as a cover crop instead of herbicides (Morton et al., 2006). The environmental benefits cover crops provide can have long-term economic benefits. However, due to the length of time it can take to see long term effects of cover crops, the economic benefit can be difficult to measure.

Cover crops have many long-term benefits such as soil conservation and increase of yield and quality of cash crops (Schipanski et al., 2014). However, these long-term benefits are often not considered in a short-term analysis. Short term analyses highlight potential disadvantages such as establishment cost, management problems and loss in cash crop yield without considering the long-term yield stability benefits provided by cover crops including cascading positive effects on cash crops yields and improved pest control (Snapp et al., 2003; Kruidhof et al., 2008). Cover crop use over winter is limited in cropping systems in the U.S. due to little immediate financial incentive to farmers (Snapp et al., 2003; Schomberg et al., 2014). Grazing cover crops during the fall could encourage winter cover crop adoption providing a favorable return to offset establishment cost without reducing crop yields (Schomberg et al., 2014).

Benefits of Livestock Integration on Cover Crops

Crop-livestock systems are important as an option for sustainable farming systems (de Faccio Carvalho et al., 2010). Adoption of integrated crop–livestock systems improve the ability of individual farmers to compete in global agricultural markets (Sulc and Tracy, 2007). Cover crops have the potential to provide both short term economic returns by reducing the cost of production of livestock via inexpensive, high-quality feed and long term returns through reduction of soil erosion and accumulation of soil carbon. Integrating crop–livestock systems have the potential to be profitable and can enhance production efficiency and environmental quality in the U.S. (Sulc and Tracy, 2007).

Grazing cover crops may reduce the production cost of growing and finishing lambs. Grazing programs are usually a less expensive feeding option than feedlot systems with a reduction in feed cost of 38% or greater demonstrated (Krause et al., 2013). Lambs on winter cover crops can have acceptable gains and production of revenue can vary; in Koch et al. (2002) cost of growing and grazing turnips was $220-$250/ha with lambs producing a revenue of $0.72 to $0.79/kg of gain in 2002. Along with a reduction in feed cost, grazing winter cover crops can extend the grazing season for lamb producers without having to rely on stored feed resources which tend to be more expensive than pasture forage. Cover crop grazing can extend grazing into fall or winter while retaining adequate growth performance in the Northern U.S. (Koch et al., 2002).

Sheep can be utilized for grazing in cover crop systems without compromising cash crop performance and can provide economic benefits (Hunt et al., 2016). Economic return from grazing cover crops can exceed the cost of cover crop production through generation of high-quality feed and money from land leases (Drewnoski et al., 2018). The cost of planting turnips or radishes for November grazing as winter cover crops vary from $4-5/kg of seed for establishment (Drewnoski et al., 2018). Estimated costs of growing and grazing turnips and other brassicas planted in July or August and grazed through November and December in 2002 was $220 to $250/ha (Koch et al., 2002).

Integrating cropping systems and ruminant livestock production on the same land base offers tremendous potential to diversify farm ecosystems while increasing production efficiency (Sulc and Tracy, 2007). An increasing number of livestock producers in the Corn Belt region are beginning to take small steps toward integrating grain and ruminant livestock production; however, questions remain on how best to develop and manage those systems (Sulc and Tracy, 2007). When grazing livestock are integrated into a cash crop rotation, soil aggregation is significantly improved, as well as the soil microbial activity (de Faccio Carvalho et al., 2010). Positive impacts were also observed by de Faccio Carvalho et al. (2010) in the chemical attributes of associated variables, such as total and particulate organic carbon and N, phosphorus availability and potassium cycling and balance. Daily intake on a dry matter basis is generally 2 to 3% of body weight in ruminants while fecal output ranges from 0.8 to 1.0% of body weight a day (Schomberg et al., 2014). Approximately one-third of the biomass consumed is returned to the fields as feces and contributes to soil organic matter inputs needed for maintaining soil quality (Schomberg et al., 2014).

Concern of Livestock use for Crop Producers

Compaction of soil alters many soil properties creating adverse effects mostly due to a reduction in permeability to air, water, and roots so efforts to manage it in crop fields are necessary (de Faccio Carvalho et al., 2010). Some physical soil properties can be negatively impacted by grazing, such as compaction, though this tends to be transient, and crop productivity is not necessarily reduced by the presence of grazing animals during the previous winter cover crop cycle especially with smaller livestock species (de Faccio Carvalho et al., 2010). Damage by sheep trampling tends to be shallow and transient and does not reduce subsequent crop yield or other physical aspects of soil (Warren et al., 1986; Hunt et al., 2016). Grazing can also provide microrelief to the soil compared to mechanical compaction by machinery (Warren et al., 1986).

Overgrazing is another justifiable concern of crop producers for integrating grazing in cropping systems. Overgrazing can negatively impact soil nutrient retention, erosion, and runoff rate. However, with proper management , cover crops can be grazed without compromising the soil physical qualities by trampling and sheep can recycle nutrients in the field (Hunt et al., 2016).

Utilization as Winter/Fall Cover

Use of winter cover crops allows for beneficial mycorrhizal fungal associations to survive winter and benefits following crops by reducing the risks of crop disease (Schipanski et al., 2014). The soil cover winter cover crops provide reduces the fluctuations in soil temperature and soil freezing by providing a barrier to the soil from the elements (Dabney et al., 2001).

Another benefit of winter cover crop is the suppression of weed competition in autumn and spring. Early light interception is important for the competitive ability of a cover crop species against weeds and voluntary crop growth (Kruidhof et al., 2008). Since earlier canopy shading is expected at higher sowing densities, higher weed suppression increases as cover crop sowing density is increased (Kruidhof et al., 2008). Suppression of weed establishment in spring is greatest for overwintering cover crop species and least or absent for winter-killed species (Kruidhof et al., 2008).

LAMB PERFORMANCE ON BRASSICAS

Nutritional Composition of Brassica Species

Brassica cover crops are high in digestible energy and hold nutritional value after frost, and therefore have the potential for grazing as stockpiled forage after the main growth period ends in autumn. The nutritional characteristics of these crops put them into the high moisture, concentrated feed category (Guillard and Allinson, 1988; Westwood and Mulcock, 2012). Nutrient composition of some brassica species is shown by plant component in Table 1.

Table 1. Nutrient composition of common brassica species including kale (*Brassica oleracea L. var acephala),* turnip (*Brassica septiceps*), radish (*Raphanus* L.), swede (*Brassica napus ssp. Napobrassica)* and forage rape (*Brassica napus* L.)

Species	Component [1]	Study	DM, %	CP, %	ME, MJ/kg	ADF, %	NDF, %
Kale	Herbage	Reid et al., 2014	.	13.3	.	.	.
Kale	Herbage	NRC, 2006	14.0	.	.	17.5	20.1
Kale	Herbage	Westwood and Mulcock, 2012	17.3	9.7	11.2	23.5	28.0
Kale	Herbage	Barry et al., 1981	.	.	.	.	.
Kale	Herbage	Barry, 2013	14.1	16.7	.	12.9	20.1
Kale	Herbage	Sun et al., 2012	.	.	12.7	.	.
		Mean	15.1	13.2	12.0	18.0	22.7
Turnip	Herbage	Reid et al., 2014	.	13.0	.	.	.
Turnip	Herbage	Barry et al., 1971	12.7	.	.	.	.
Turnip	Herbage	Westwood and Mulcock, 2012	13.7	22.6	13.0	13.5	15.6
Turnip	Herbage	Koch et al., 2002	.	14.6	.	19.8	23.8
Turnip	Herbage	NRC, 2006	18.0	16.0	10.5	13.0	.
		Mean	14.8	16.6	11.8	15.4	19.7
Turnip	Tuber	NRC, 2006	9.0	12.0	13.0	34.0	44.0
Turnip	Tuber	Koch et al., 2002		10.2		17.2	20.9
Turnip	Tuber	Reid et al., 2014	.	10.7	.	.	.
Turnip	Tuber	Westwood and Mulcock, 2012	10.1	14.2	11.7	18.9	22.5
Turnip	Tuber	Barry et al., 1971	7.6	.	.	.	.
		Mean	8.9	11.8	12.4	18.0	21.7
Radish[3]	Herbage	NRC, 2006	6.0	15.7	.	14.1	15.5
Radish	Herbage	Koch et al., 2002	.	11.9	.	18.7	25.6
		Mean	6.0	13.8	.	16.4	20.6
Swedes	Whole Plant	Westwood and Mulcock, 2012	10.3	13.7	13.8	13.9	15.2
Swedes	Whole Plant	Barry, 2013	9.4	16.2	.	12.1	17.6
		Mean	10.9	15.0	13.8	13.0	16.4
Rape	Herbage	Westwood and Mulcock, 2012	14.3	10.8	12.9	20.3	23.2
Rape	Herbage	Sun et al., 2012	.	.	13.2	.	.
Rape	Herbage	Barry, 2013	12.6	19.3	.	16.3	23.4
		Mean	13.5	15.1	13.1	18.3	23.3

[1]Component: Herbage=above ground portion of plant including stem and leaf; tuber=below ground portion of plant including tuber; whole plant=herbage + tuber.

Brassicas tend to vary in dry matter concentration with dry matter (DM) varying from 10.9% in swedes (whole plant) to 15.1% in kale herbage (Table 1). Brassica herbage did not differ much in dry matter ranging from 13.8-15.1% in the species evaluated. Brassica tubers tend to be lower in DM concentration (9%) compared to herbage. Whole brassica plants are lower in DM concentration (9.4–14.1%) than common cool season grasses such as perennial ryegrass (average of 17.6% DM; Barry, 2013).

The crude protein (CP) concentration of brassicas varies more by structural component of the plant and less by species. The CP concentration of brassica herbage reported ranged from 13.2% for rape to 16.2% for turnips which are both significantly higher than that found in brassica tubers (8.9% CP in turnip tubers) (Table 1). As a forage species, brassicas vary considerably in CP according to plant component with herbage being comparable to that found in perennial ryegrass (15% CP) and with tubers being far lower (Sun et al., 2012; Table 1).

The ADF concentration of forage is a strong predictor of fiber digestibility with ADF concentration and fiber digestibility displaying a strong inverse relationship (Koch et al., 2002). Overall, the ADF concentration did not vary greatly according to plant structural component or species (13-18.3%) but was markedly lower than in reference forage species such as perennial ryegrass (27.7%; Table 1). The low ADF concentration in brassica suggests a rapid rate of digestion in the rumen when compared to other forage species.

Neutral detergent fiber (NDF) is a measure of plant cell wall content, and an index of total plant fiber concentration. Overall brassica herbage ranged from 19.7% in turnips to 23.3% in rape (Table 1) indicating that the NDF concentration of brassica herbage is similar across species. Brassica tuber was comparable to herbage in NDF with turnip tubers at 21.7%. Brassica NDF concentration is much lower than reference forage species such as perennial ryegrass (65% NDF; Sun et al., 2012).

The molar proportion of volatile fatty acids (VFA) in the rumen changes based on diet and can be informative of the digestibility of a diet. Higher acetic and butyrate concentrations are seen in more fibrous diets compared to grain diets (Doreau et al., 2011). In sheep fed brassicas, VFA molar proportion tend to be 51-62% acetic, 20-35% propionic, and 10-18% butyric (Sun et al., 2012). For comparison, corn (*Zea maus* L.) has a VFA proportion in sheep ranging around 65-70% acetic, 16-18% propionic and 9-18% butyric (Lettat et al., 2010). In perennial ryegrass VFA molar proportions are 62-67% acetic, 18-21% propionic and 11-12% butyric (Sun et al., 2012). Overall, brassica VFA molar proportion is intermediate between corn and ryegrass, however when compared to ryegrass, brassicas digestibility is 22-34% higher than ryegrass (Sun et al., 2012). Based on VFA molar proportion, brassicas fit the category of a high energy forage that is low in fiber and high in rapidly digestible carbohydrate.

Animal Performance and Health Concerns on Brassica Species

Growing lambs have high energy needs which can be challenging to meet in a grazing system. Brassicas are high in energy, however, when grazed as a monoculture, the performance of ruminants is often lower than would be predicted by their energy concentration (Barry et al., 1971). For all brassica crops evaluated, estimated protein intake has been predicted to support considerably higher growth rates than observed in grazing sheep (Barry et al., 1971). Some theories on why lambs have lower performance than expected include the presence of high levels of sulfur-containing plant secondary compounds, an imbalance in dietary energy and protein, and the fact that brassicas are often grazed during cold weather periods which requires higher energy expenditure to maintain homeothermy.

Plant secondary compounds can be a concern for lamb producers as they can impact animal health. Brassicas often contain high levels of two secondary compounds: glucosinolates and S-methyl cysteine sulfoxide (SMCO), that are potentially toxic to livestock (Fales et al., 1987). In the rumen, microbes convert SMCO into dimethyl disulfide, with SMCO-lyase (Fales et al., 1987). Dimethyl disulfide impacts erythrocytes by causing precipitation of hemoglobin forming aggregates often referred to as Heinz bodies which often leads to anemia (Fales et al., 1987; Cox-Ganser et al., 1994). Several brassica species can be high in SMCO including kale (*Brassica oleracea* L.), a common brassica cover crop grazed by lambs, which has been reported to contain around 6.82 mg/kg DM of SMCO (Sun et al., 2012). Other brassica species commonly grazed by sheep may contain SMCO at similar or even higher concentrations including rape, swedes, and turnips with SMCO concentration recorded at 7.52, 12.12 and 9.36 mg/kg DM respectively (Sun et al., 2012). Lambs grazing kale have been shown to exhibit low growth rates (120 g/day) which has also been associated with the development of hemolytic anemia especially during the first several weeks of introduction to the crop (6 weeks; Barry, 2013). This anemia is characterized by rapid formation of Heinz bodies and a small decrease in packed cell volume (PCV; Cox-Ganser et al., 1994). While hemolytic anemia is common in lambs grazing brassica with elevated SMCO concentration, it does not necessarily impact lamb growth appreciably (Cox-Ganser et al., 1994). In general, the growth rate of lambs grazing brassica forage has been demonstrated to be more variable than on other forages, possibly due to SMCO and glucosinolates concentration (Reid et al., 1994).

Glucosinolates are another plant secondary compound found in high concentrations in brassicas. Glucosinolates produce nitriles and iso-thiocyanates which impact ruminant physiology by depressing voluntary feed intake and by acting to depress iodine absorption in the gastrointestinal tract (Barry et al., 1981; Cox-Ganser et al., 1994). Glucosinolates are high in brassicas and are known goitrogens that upon rumen fermentation produce thiocyanate compounds which inhibit iodine uptake (Barry et al., 1981). Iodine is a critical component of thyroid hormone as it is covalently bound to several tyrosine residues of both T3 and T4 (Cox-Ganser et al., 1994). When animals become deficient in iodine, thyroid stimulating hormones seeks to compensate causing hypertrophy of the thyroid gland forming a goiter, to maintain thyroid hormone synthesis (Smith, 1978). Lambs grazing brassica may also exhibit depression of serum thyroid hormone concentration while grazing which can be fully mitigated by oral dosing with iodine (Cox-Ganser et al., 1994). This is not a universal finding however as Barry et al. (1981) found that thyroid function was not dissimilar to that of animals grazing perennial pasture and that T4 production was elevated in lambs grazing a monoculture of kale compared to those grazing perennial pasture.

The secondary compounds found in brassicas may impact the animal's ability to absorb plant protein thereby reducing gains (Barry, 2013). Barry (2013) found that protein absorption related to ME was 14% for brassicas compared to 20% for grasses. This absorption level is significantly lower than what would be expected from a forage crop. This low absorption may be due to elevated dimethyl disulfide in this forage which may explain in part the reduced animal gains on brassicas compared to other forages (Barry, 2013). Dimethyl disulfide has been proposed to reduce protein absorption by inactivating sulfhydryl groups on proteins thus blocking protein absorption by the animal (Barry et al., 1985).

The secondary compounds in brassicas have also been suggested to depress voluntary feed intake (VFI). Nitriles, thiocyanates, and dimethyl disulfide have all been implicated in reducing VFI (Barry, 2013). This difference in DE intake can be due to the secondary compounds produced by SMCO and glucosinolates in the rumen causing a depression in voluntary intake of the animal (Barry, 2013). This depression in gains is seen usually in the first 4-6 weeks of grazing and is associated with the rumen fermentation of SMCO into dimethyl disulfide and glucosinolates into iso-thiocyanates. This depression in gain can be reduced by growing brassicas in low sulfur soil which reduces the presence of these secondary compounds in brassicas (Barry, 2013). This correlation between reduced sulfur soils and decreased growth depression supports the theory that that these secondary compounds may be the cause of decreased VFI and poor gains (Barry, 2013).

The DE requirements for grazing sheep on winter brassica forage crops has been reported to be 29% greater than sheep grazing perennial pasture, however, this difference may be attributed to the winter season and not to brassica forage *per se* (Barry et al., 1971). The added energy needed for winter grazing is attributed to the exposure to cold, wind, and rain, which increases the heat increment required for lambs to bring the water in the forage to body temperature and to maintain homeothermy. This added cost due to *in situ* energy harvest can reduce animal gains during the winter compared to summer grazing regardless of forage type.

IMPACT OF LAMB FINISHING SYSTEMS ON GROWTH, CARCASS, AND MEAT QUALITY

Effect of Finishing System on Lamb Growth

The finishing system lambs are raised on can have a major influence on lamb growth. A study done by Koch et al. (2002) compared three growing/finishing methods for lambs using weaned Columbia x Rambouillet lambs: lambs grazing brassica only, lambs fed grain only and then lambs grazing brassica followed by grain feeding. It was found that lambs on brassicas gained 180 g/d whereas those on grain in a feedlot lambs gained 230 g/d (Koch et al., 2002). It was also found that lambs that started on brassica-based cover crop and finished with grain in a feed lot had the same growth rates when placed on dry lot as lambs started on feedlot however it took longer for grazing lambs to reach the same weight as feedlot lambs (Koch et al., 2002). Lambs fed grain tend to have higher growth performance and reach target final weights earlier than those of grazing systems due to the higher energy concentration in grain diets (Ekiz et al., 2013).

The disadvantages of grazing systems can be slower growth rate of lambs and lower carcass yield. In a study performed by Ekiz et al. (2013), lambs weaned at 60 days of age and grazed in pasture did not reach the slaughter weight of 30 kg during the period of grazing on grass-legume pasture, but these lambs displayed compensatory growth during the period of grazing on wheat stubble and then reached the target slaughter weight. Lambs finished in a feedlot or with supplementation under extensive systems exhibit faster growth rates, achieve target weights quicker, and produce heavier carcass weights when compared to grazing lambs (de Brito et al., 2017). Overall, animals finished on grain exhibit significantly higher ADG then animals on grazing finishing systems (Berthiaume et al., 2006).

Carcass Quality Factors

The major factors contributing to carcass composition of lambs at slaughter are diet, sex, and stage of growth relative to mature size (Beermann et al., 1995). Forage-based diets can produce leaner lambs with a lower fat content; however, forages with higher energy values with sufficient CP need to be utilized to get acceptable rates of growth and carcass fat content. The use of forages with high nutritive value such as cover crops can provide lambs with good growth rates, heavy carcass weights, and desirable carcass composition (de Brito et al., 2017). The rate of fat deposition in lambs is a function of several factors including degree of physiological maturity, plane of nutrition and sex (Butterfield et al., 1988; de Brito et al., 2017). Genetics can influence carcass quality; however, this influence is mostly realized by changes in mature size as lean meat yield is highly related to the degree of maturity and most breeds of sheep differ only subtly in body composition when evaluated at the same fraction of mature size (Taylor et al., 1989). The rate of growth in lambs impacts body composition, as lambs with high energy intake partition excess energy into fat at a greater rate than those consuming less energy. Ram lambs grow faster than ewe lambs and are leaner due to the anabolic effects of testosterone which allows a greater rate of protein deposition and reduced lipid deposition (Beermann et al., 1995; Okeudo and Moss, 2008).

Using brassicas as a feedstuff can influence the yield grade and fat depth seen in lambs. In a study performed by Koch et al. (2002), yield grade and fat depth of lambs in the feedlot were greater than for lambs grazing turnips, however it was also found that yield grade and fat depth were similar for lambing grazing brassica and those fed grain in a feedlot when fed to the same bodyweight. Lambs grazing turnips and radishes, produced acceptable market size and carcass grade but required more time than feedlot lambs to reach similar weight (Koch et al., 2002). When compared to pasture-fed lambs on a ryegrass/clover mix, forage rape-finished lambs had greater hot carcass weight (25.4 vs 21.2 kg), and backfat thickness (14.8 mm vs 12.6 mm; Hopkins et al., 2001). Although lambs grazing brassicas tend to have a lower rate of fat deposition than grain-fed feedlot lambs, the delay in reaching market weight might be beneficial if, as a result, lambs are marketed later when supply is slower and prices greater (Koch et al., 2002).

Dressing percent is the amount of live animal that becomes carcass after slaughter. Sex can influence lamb dressing percent with ewes have higher dressing percentages than rams and wethers (Kremer et al., 2004; Okeudo and Moss, 2008). Thonney et al. (1987) indicated that this difference in dressing percentage due to sex is mostly due to greater body fat content but is also impacted by a lower relative mass of non-carcass components (gut, head, feet, pelt, and organs) than ewes at the same degree of mature size. As animals mature the proportion of offal to carcass changes. The proportion of offal relative to body weight is greatest at birth and declines over time (Jenkins and Leymaster, 1993).

Diet can also influence lamb dressing percent by influencing fatness and gut fill. Kitessa et al. (2010) found that lambs fed grain had a higher dressing percent at 48% compared to lambs grazing pasture who had a dressing percent of 45%. In another study Koch et al. (2002), dressing percentage was greatest in lambs in the feedlot (50%) and lowest in those grazing radishes or turnips (46.5-48.8%). In a similar study evaluating camelina (*Camelina sativa*), a flowering brassica species, Ponnampalam et al., (2019) observed similar dressing percent between lambs fed camelina forage (47.6%) or meal (47.3%) as compared to those fed a standard grain diet (47.5%) containing barley grain (*Hordeum* L.), lupins (*Luphinus* L.), and oat hay (*Avena* L.) and grain. Reid et al. (1994) compared the dressing percentage of lambs grazing either turnip, cabbage (*Brassica oleracea* L.) or grass-clover pastures. Lambs grazing turnip or cabbage had higher dressing percentage (46.2-46.5%) compared to those on grass-clover (42.8%). Overall, dressing percentage tends to be higher for lambs on grain diets compared to brassica-based diets, however there are exceptions.

Impact of finishing system on meat quality

The quality of meat produced is an important factor in getting more consumers interested in lamb. The color of meat is considered a visual measure of freshness and quality in meat (Gao et al., 2014). The age of slaughter can influence the color of meat in a carcass (Hopkins et al., 2007). In a study performed by Hopkins et al. (2007), longissimus muscle quality was evaluated; and it was observed that as the age at slaughter increased, the longissimus muscle presented darker coloration. Diet can also be a strong influence on meat color. Different diets produce different proportions of VFA's in the rumen which can influence metmyoglobin in meat, oxygen consumption rate (OCR) and metmyoglobin reducing activity (MRA; Priolo et al., 2002; Gao et al., 2014). MRA and OCR impact the degree of red and brown color seen in meat. Gao et al. (2014), found that animals on forage-based diets exhibited longer color stability in meat compared to grain-fed lambs. Forage-based diets and longer grazing periods were also found to decrease meat OCR and metmyoglobin accumulation and to increase meat MRA (Gao et al., 2014).

Meat color is commonly captured in three measurements: lightness (L*), redness (a*) and yellowness (b*). In lamb growing/finishing systems, Frank et al. (2016) found lambs grazing ryegrass have similar lightness to those grazing rape at L* of 36.47 and 36.70-37.36 depending on variety of rape. Meat from lambs grazing brassica tend to be lower (18.20-18.57) in redness compared to those grazing ryegrass (19.01). Meat from lambs grazing brassica also tends to be less yellow (1.72-1.99) than those grazing ryegrass (2.11; Frank et al., 2016). In comparing grass and grain finishing, Priolo et al. (2002) found that grain-finished lambs had lighter meat color (49.23) lower redness (7.35) and greater yellowness (10.71) than those raised on pasture. The color of meat can be influential on consumer preference as consumers tend to use color as a visual representation of freshness (Gao et al., 2014).

Intramuscular fat (IMF) deposition is positively correlated with eating quality of lamb (Ye et al., 2020). Low IMF content in lamb meat has been associated with meat tasting dryer and is less preferred by consumers (McPhee et al., 2008). Consumers show greatest preference for lamb with an IMF content at 4% and decreased preference for lamb above or below that point (Realini et al., 2021). IMF content in lamb is associated with animal maturity, sex, and diet. IMF deposition accelerates early in development in sheep up to 14 months and then declines thereafter (McPhee et al., 2008). As an animal matures, fat is deposited at a higher rate than lean tissue as protein accretion decreases. Hopkins et al. (2007) and McPhee et al. (2008) found a significant difference in IMF concentration due to sex, with ewes having greater IMF compared to rams. Elevation of IMF in ewes contributes to the lower shear force since intramuscular fat is negatively correlated with shear force (Okeudo and Moss, 2007).

Factors that can influence the tenderness of a carcass include age, diet, and exercise. Shear force testing provide a physical measure of tenderness and is influenced by age of both animal and meat. In general, as animal harvest age increases so does shear force resulting in a loss of tenderness (Sanudo et al., 1998; Hopkins et al., 2007). One reason why younger animals tend to be more tender is because they have more soluble collagen present in the carcass (Sanudo et al., 1998). Sex does not influence tenderness when age is accounted for (Okeudo and Moss, 2007).

Diet can be a major factor in the tenderness of lamb, especially dietary energy. Priolo et al. (2002) found that consumers found grain-finished lambs to be more tender than pasture-finished lambs. Frank et al. (2016) found that meat from lambs grazing to have similar tenderness as those grazing ryegrass. Tenderness, both measured physically and by consumer perception via sensory evaluation panels has been found to be positively correlated with fatness (Priolo et al., 2002).

Factors that impact lamb flavor

Familiarity with the flavor of lamb and mutton can be a barrier for consumers, and undesirable feed-induced flavors may also compromise acceptability by consumers (Watkins et al., 2013). Pasture-associated flavors may be considered normal by consumers accustomed to meat from pasture-fed sheep but, this flavor may be unfamiliar to consumers of meat produced from grain feeding (Watkins et al., 2013). Diet also impacts flavor because it can affect the amount of intramuscular fat and the fatty acid composition of the meat, which has a direct effect on meat juiciness and texture as well as flavor (Watkins et al., 2013).

Brassica forage is often viewed as a nutritious feedstuff for lambs however it is sometimes not utilized as a finishing diet due to the concern of off- flavors in meat (Frank et al., 2016). Using gas chromatography-mass spectrometry-olfactometry, Frank et al. (2016) found that 3-methylbutanal, 1-penten-3-one, dimethyl disulfide, and dimethyl trisulfide are the main odor active compounds in cooked samples of lamb that were grazing brassicas, with dimethyl disulfide and dimethyl trisulfide being derived from the breakdown of SMCO in the rumen. These compounds were higher in lambs on brassica treatments compared to pasture treatments however consumer panel testing indicated that meat odor intensity and liking was not significantly different between ryegrass and brassica rape treatments. Lamb flavor was considered more intense for brassica treatments compared to ryegrass, however consumers perception of flavor between treatments was not significant (Frank et al., 2016). This finding differed from prior studies evaluating flavor of lamb meat through sensory evaluation in which lambs grazing forage rape had a stronger and less acceptable flavor from those grazing vetch or oat pasture (Park et al., 1972; Watkins et al., 2013). Hopkins et al. (2001) found similar results to Watkins et al. (2013) where animals on forage rape had a stronger aroma and flavor than those raised on irrigated pasture, however the sensory panel indicated that lambs finished on rape were as acceptable as those finished on ryegrass/clover mix pasture. Hopkins et al. (1995) did note a potential reason for the stronger aroma and flavor of brassica finished lambs suggesting it may be due to the greater age of the lambs as they were on treatment longer. In Hopkins et al. (1995) lambs were on treatment for four months, however Wheeler et al. (1974) noted that aroma and flavor were not affected by grazing duration. Overall, the lower acceptability of brassica fed lambs is associated with a stronger aroma and an unfamiliar flavor when compared to lambs grazing perennial pasture and those on a grain diet.

SUMMARY AND FUTURE QUESTIONS

Grazing cover crops in grazing leases offers a unique solution for both crop and sheep producers to reduce respective production barriers for each farming system. Crop producers benefit by the potential to reduce cover crop cost through grazing leases and/or sharing of cover crop establishment cost with livestock producers. For livestock producers, cover crop grazing provides an opportunity to reduce annual feed cost and to provide high quality forage. This system can also provide benefit for integrated crop/ livestock operations as well, however cash crop harvest can impact grazing options.

Use of brassicas as cover crops in the fall can be used to extend the grazing season of lambs. However, widespread utilization of brassicas in lamb diets has been limited due to the potential effects of secondary compounds; SMCO and glucosinolates on animal health and performance, and their potential impact on flavor and quality of meat produced. Research is needed to determine if grazing brassica dominant cover crops allows for sufficient forage yield, lamb growth performance, and carcass and meat quality to make this part of or a complete, stand alone, lamb finishing option

CHAPTER 2: EVALUATION OF GROWTH PERFORMANCE, CARCASS AND MEAT QUALITY OF LAMBS REARED ON COVER CROP AND GRAIN FINISHING SYSTEMS.

INTRODUCTION

Seasonal forage availability is a constraint on the local lamb supply in Michigan. A unique solution may be grazing lambs on cover crops during fall months. Grazing cover crops offers an option that can reduce production barriers for both crop and sheep production systems. Crop producers benefit by the potential to reduce the economic cost of cover crop use and still receive the environmental and long-term economic benefit of cover crops (Sulc and Tracy, 2007; Drewnoski et al., 2018). Livestock producers benefit from an opportunity to reduce annual feed costs, provide high quality forage, and extend the grazing season (Koch et al., 2002; Krause et al., 2013). Sheep have benefits over other livestock species in cover crop grazing as they provide less risk for soil compaction and are more portable, making them an ideal livestock for temporary grazing (de Faccio Carvalho et al., 2010; Hunt et al., 2016). Cover crops in the Brassicaceae family, such as radishes (*Raphanus sativus* L.), turnips (*Brassica rapa* subsp. *rapa* L.), and rapeseed (*Brassica napus* L.), can be planted in late summer and used to extend the fall grazing season for lambs. Forage brassicas provide a high-yielding forage that is nutritious enough to finish lambs (Barry et al., 1971; Reid et al., 1994; Koch et al., 2002; Westwood and Mulcock, 2012). Nevertheless, widespread utilization of brassicas in lamb diets has been limited. Brassicas are high in metabolizable energy (ME) and crude protein (CP), but the gain observed in grazing animals often does not match the nutritional potential of these crops (Barry, 2013). Reduced growth performance may be due to the high content of S-methyl cysteine sulfoxide (SMCO) and glucosinolates in these forages (Barry et al., 1971). These secondary compounds may impact feed intake and protein absorption (Barry et al., 1981; Reid et al., 1994) or cause subclinical anemia in lambs grazing brassicas (Cox-Ganser et al., 1994). Another concern is the potential for negative impact of brassicas on flavor and quality of meat produced. Previous studies suggest that lambs finished on brassica cover crops produce an off flavor in meat (Park et al., 1972; Hopkins et al., 1995; Frank et al., 2016). Dimethyl disulfide and dimethyl trisulfide from rumen fermentation of SMCO are the main secondary compounds associated with off flavors in meat, however concentration of SMCO can impact flavor potentially (Frank et al., 2016). However, off-flavor and foreign flavor impact has not been a consistent finding in brassica-finished lambs (Wheeler et al., 1974).

There are few published reports on use of grazed brassica cover crops for lambs in the Upper Midwestern U.S. and no published work evaluating lamb meat quality or consumer acceptability for this management system. We hypothesized that grazing brassica cover crops in fall can allow a sufficient plane of nutrition for lamb finishing and produce meat with acceptable quality and flavor characteristics for consumers. Our objectives were to examine the growth performance and carcass and meat quality of lambs finished on systems utilizing grazing of cover crops that vary in brassica content as part of or as an exclusive lamb finishing program.

MATERIALS AND METHODS

Experimental Design

All experimental activities were conducted within the Michigan State University South Campus Farm located at East Lansing, Michigan (42.73 °N and 84.5 °W, elevation 271 m). The experimental design was a randomized complete block with three replications within two adjacent field sites, one grazed in 2019 and the other in 2020. Each of the nine pastures within each site-year was an approximately 0.4-ha strip with dimensions approximately 12 x 275 m. The four lamb treatments were: 1) GRN - finished on grain for 6 weeks; 2) BRO - finished grazing a pure brassica cover crop mixture (forage rape: *Brassica napus* L., radish: *Raphanus sativus* L., turnip: *Brassica rapa subsp. rapa* L.) for 8 weeks; 3) MIX - finished grazing a cover crop mixture of greater diversity (forage rape, radish, turnip, pearl millet: *Pennisetum glaucum* L., Japanese millet: *Echinochloa esculenta* (Link), berseem clover: *Trifolium alexandrinum* L., field pea: *Pisum sativum* L., oats: *Avena sativa* L., rye: *Secale cereale* L.) for 8 weeks; and 4) BKG - backgrounded by background grazing the brassica mixture for 4 weeks followed by finishing on grain for 4 weeks. Varieties and seeding rates used in cover crop seed mixes are shown in Table 2. Specific cover crops were selected based on their potential to provide grazed forage yield and quality acceptable for finishing lambs within two months of fall grazing. Rape, turnip, radish, oats, and peas were the primary components contributing forage mass and quality. Rye, berseem clover, and millets were included to provide additional biodiversity.

Table 2. Cover crop seeding rates for all-brassica and complex mixtures (MIX) planted in August in 2019 and 2020 at East Lansing, MI.

			Seed Mixture			
		Functional	All Brassica		MIX	
Species	Variety	Group	2019	2020	2019	2020
			------------------------------kg/ha		------------------------------	
Rape	Winfred	forb	4.4	3.4	1.3	1.5
Radish	Tillage	forb	7.8	6.4	2.4	3.1
Turnip	Purple Top	forb	4.4	3.4	1.2	1.4
Pearl Millet	not stated	WSG [1]	-	-	1.1	1.5
Japanese Millet	not stated	WSG	-	-	1.0	1.6
Berseem Clover	Frosty	legume	-	-	2.3	2.7
Field Pea	4010	legume	-	-	11.8	13.5
Oats	Bob	CSG [2]	-	-	15.9	17.7
Rye	Hazlet	CSG	-	-	7.7	8.1

[1] WSG, warm season grass.
[2] CSG, cool season grass.

Cover crop management, samples, and procedures

The soil type was a mix of Marlette loam, Colwood-Brookston loam, and Marlette fine sandy loam (NRCS Web Soil Survey, 2021). Winter wheat was grown on each site prior to planting cover crops. Wheat was combined on July 29, 2019, and July 15, 2020. Solid pack beef manure was applied over the wheat stubble to supply 144, 41, and 154 kg/ha of N, P, and K in 2019 and solid pack sheep manure to supply 139, 17, and 74 kg/ha of N, P, and K in 2020. Manure was incorporated immediately to a depth of 20 cm using a disk. The field was cultipacked before and after planting. Cover crops were planted with a wheat drill (17.5-cm row spacing) on August 7, 2019, and July 31, 2020. Precipitation and air temperature data (Table 3) were obtained from a weather station located on the South Campus Farm, 3 km away from the study sites.

Table 3. Actual and 30-year normal precipitation and average air temperature from August to December 2109 and 2020 at East Lansing, MI. [1]

Variable	Averages 2019	2020	30-Year Normal [2]
Mean Precipitation, mm			
July	58	63	83
August	25	53	88
September	76	97	81
October	129	58	79
November	26	35	65
December	78	39	41
Mean Air Temperature, °C			
July	23.3	23.6	22.3 ± 1.3
August	20.2	21.2	21.4 ± 1.3
September	18.4	15.8	17.6 ± 1.5
October	10.1	8.7	10.8 ± 1.3
November	0.6	6.6	4.6 ± 2.4
December	0.4	-0.5	-0.9 ± 2.6

[1] Weather data was obtained at MSU Horticulture Teaching and Research Center, East Lansing, MI, Latitude: 42.6734, Longitude: -84.4870 (Enviroweather, 2021).
[2] National Oceanic and Atmospheric Administration (NOAA) used to provide 30-year average in East Lansing MI, from 1991-2020. Station East Lansing 4 S, MI U.S.(NOAA, 2021).

Pastures were strip-grazed with a back fence starting on the beginning of the treatment period (Figure 1; October 21 in 2019 and October 12 in 2020). Grazing was initiated when estimated available dry forage biomass reached 2.24 Mg/ha and continued for the designated treatment duration. Animals were moved to a new strip approximately once per week (plus or minus one day depending on weather events). Pre-grazing forage mass was measured on each strip by hand-clipping all available biomass to ground level from three randomly selected 0.33-m^2 quadrats per strip. Turnip and radish tubers were severed at ground level so that measured biomass simulated the portion that was accessible for grazing. Forage was separated into top biomass consisting of leaves and stems, hereafter referred to as herbage, and tubers and composited by strip for the herbage and tuber fractions. Tubers were washed to remove soil and sliced to increase surface area. Herbage was not washed. Herbage and tuber samples were weighed fresh, dried on metal mesh racks in a forced air oven at 57 °C for a minimum of 48 h for herbage and 72 h for tubers, and then reweighed to determine total dry biomass and the proportion of herbage and tuber fractions. Dried herbage samples were coarsely ground through a 4-mm mesh in a Thomas Wiley Mill (Philadelphia, PA) and roots were ground through a 2-mm mesh. All samples were then ground through a 1-mm mesh in a cyclone mill (UDY, Fort Collins, CO).

Neutral detergent fiber (NDF), acid detergent fiber (ADF) and crude protein (CP) were estimated using near-infrared reflectance spectroscopy (NIRS). Herbage and tuber samples were scanned on a Foss DS 2500 spectrometer (Foss North America, Eden Prairie, MN). Nutritive value of herbage samples was predicted using a grass hay calibration from the NIRS Consortium (Berea, KY). Nutritive value of tubers was predicted using an internal calibration based on 60 tuber samples with representative spectra. Sequential NDF and ADF were determined using a batch digestion system (Ankom Fiber Analyzer, Macedonia, NY), with amylase used in the NDF step. Nitrogen concentration was determined by combustion at a commercial forage testing laboratory (Dairyland Labs, Madison, WI) and converted to crude protein (CP) using a multiplication factor of 6.25. Herbage and tuber predictions were validated using 15 independent samples of each type measured at a commercial forage testing laboratory (Dairyland Labs, Madison, WI).

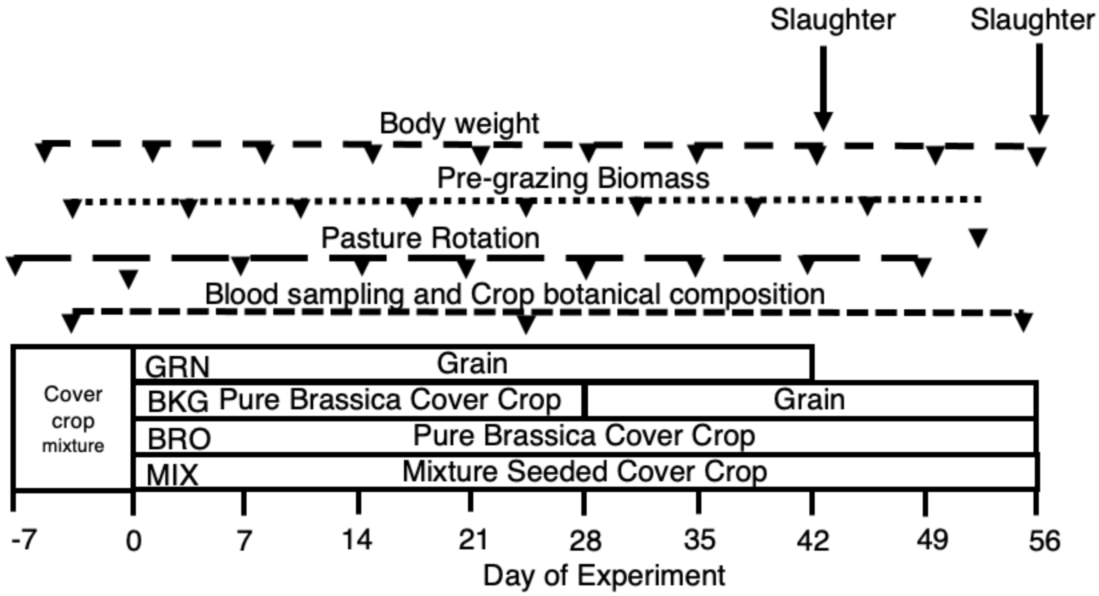

Figure 1. Timeline of study. Lambs were fed grain (GRN), background (BKG), brassica (BRO) or mixture (MIX) diets for 8 weeks except for GRN which was fed for 6 weeks.

Botanical species composition of the cover crop pastures was determined three times over the grazing period each year (October 17, November 26, December 13, 2019; and October 14, November 4, November 27, 2020). After collection of the pre-grazing biomass samples, composited herbage was hand mixed and random grab samples were taken in four locations of the pile for hand separation into the nine planted species, volunteer wheat, and weeds. Species proportions in tuber samples were determined by hand separating washed radish and turnip tubers. All separations were dried in a forced air over at 57 ^{o} C and weights were used to calculate species proportions. For data presentation, species proportions were further pooled into weeds plus four functional plant groups: forbs (rape, radish, turnip), cool-season grass (oats, rye, wheat), warm-season grass (Japanese and pearl millet), and legumes (pea, clover).

Animal management, samples, and procedures

All animal procedures in these experiments were reviewed and approved by the Michigan State University Institutional Animal Care and Use Committee (PROTO201900247). A total of 60 Dorset-sired lambs were evaluated each year. Lambs were born between mid-May and early June and consisted of 60 wether lambs in 2019 and 45 wethers and 15 ewe lambs in 2020. Wether lambs were castrated at 4-6 weeks of age. All lambs were reared indoors with their dams where they were allowed unlimited access to a grain diet (15% crude protein [CP], 2.91 Mcal metabolizable energy ([ME] per kg dry matter [DM], 23% neutral detergent fiber [NDF]) until weaning at 66 ± 8 d in late July. After weaning, lambs remained indoors and continued with unlimited access to the same grain diet until reaching 35 kg of bodyweight. Lambs were then acclimated to a diet with greater forage content achieved by restricting grain feeding to 2% of bodyweight while offering 200 g DM per head per day of legume/grass hay (13-18% CP, 40-50% NDF, 2-2.4 Mcal ME/kg DM) for 30 days followed by moving lambs to a grass/legume pasture for 21 days (primarily red clover: *Trifolium pratense* L., ryegrass: *Lolium perenne* L., orchardgrass*: Dactylis glomerata* L.) where they also received the pre-weaning grain ration at 2% of bodyweight. Lambs were also offered unlimited access to a trace mineralized salt mixture while on pretreatment pasture (Table 3). Lambs were transitioned off grain over a 10-day period and then allowed to graze a mixture of all cover crop species planted in the headland of the experimental field for 7 days prior to the beginning of the treatment period. Lambs were treated with a sequential treatment of anthelmintics 13 days prior to the onset of the treatment period consisting of moxidectin (0.2 mg/kg BW), levamisole (0.3 g/kg BW) and albendazole (7.5 mg/kg BW). A quantitative fecal egg count was conducted on each lamb 7 days after anthelmintic treatment (Zajac and Conboy, 2012) to verify efficacy of treatment, at which time all lambs had less than 50 strongyle eggs/gram of feces.

Lambs were allocated to pasture treatment groups at the onset of the grazing treatment period (Figure 1; October 14 in 2019 and on Oct 6 in 2020). In 2019, lambs were stratified by body weight and then randomly allocated to the four treatments with five lambs per replicate. In 2020, lambs were first blocked by sex (15 ewes and 45 wethers) and then randomly allocated by body weight to the four treatments with one ewe and four wethers per replicate. Mean weight of lamb at the onset of treatment was 42.1 kg in 2019 and 41.2 kg in 2020. Lambs were weighed weekly adjacent to their pasture strip using a portable handling system and weigh cage. Weekly weights were taken starting on day -7, 23-25 h after introduction to a new paddock.

Lambs transitioning from pasture to a grain diet (GRN group at onset of study and BKG group midway through the study) were placed on a 30% finishing diet and 70% soy hull feed diet immediately after removal from pasture with added soy hull feed reduced at 10% per day over a 7-day period until the lambs were on the 100% finishing diet. Finishing diet ingredient and nutrient composition are indicated in Table 4. Grass/legume hay (14-16% CP, 44-48% NDF, 2-2.4 Mcal ME/kg DM) was also fed during this transition starting at 900 g on the first day grain feeding and transitioning steadily to 200 g by day 7 of grain feeding with no hay offered thereafter.

Table 4. Ingredient and nutritional composition of grain diet [1] expressed on a DM basis.

Item	
Ingredient, % [2]	
Soybean Meal	10.0
Soy Hull Pellets	20.0
Coarsely ground corn	51.8
Dried Distillers with Soluble	10.0
Limestone	2.0
Trace mineralized salt [3]	1.0
Vitamin E [4]	0.8
Ammonium Chloride	0.5
Molasses	3.0
Decoquinate [5]	1.0
Nutrient Composition, % [2]	
Dry Matter	86.3
Crude Protein	14.4
ADF	14.4
aNDF	22.7
TDN	79
ME, Mcal/kg [6]	3.16

[1] Grain diet was fed during pretreatment phase and fed to grain (GRN) treated lambs for 6 weeks and to background (BKG) treated lambs for 4 weeks.
[2] All feed ingredients are expressed on a DM basis
[3] Sheep Trace Mineral Salt, (Marvo Mineral Co, Inc. Hillsdale, MI) containing 95-98.5% sodium chloride, 0.35% zinc as zinc oxide, 0.34% iron as iron carbonate, 0.2% manganese as manganous oxide, 0.03% iodine as calcium iodate, 0.012% selenium as sodium selenite and 0.005% cobalt as cobalt carbonate.
[4] Vitamin E: 44,000 units per kilogram
[5] Deccox® : 0.5% decoquinate.
[6] ME, NEm, and NEg were calculated according to NRC 2001.

Lambs on pasture were allocated a daily forage DM allowance based on 9-10% of lamb BW depending on weather conditions with greater allowance on weeks of high rainfall when muddy conditions existed. Forage allowance for each week was set by altering the strip length within individual pastures according to the measured fresh weight of pre-grazing biomass four days before lambs were moved. For the purposes of timely calculation of forage allowance, pregrazing biomass DM concentration was estimated as equivalent to the previous week values except for week 1 when estimates of previous crops of similar composition were used from similar climates and season. Lambs on grazing diets were allowed unlimited access to the trace mineral salt mix (Table 3) and had continuous access to supplemental fluid water until temperatures dropped below freezing and access to fluid water was no longer possible. During this period, lamb water needs were predicted to be met by forage water content according to (Forbes, 1968). Forage water concentration was > 79% during this period.

Lambs on the grain-finished treatment were housed indoors in pens 2.3 m wide by 6.4 m long with 5 lambs per pen, resulting in 14.7 m^2 of floor space and 0.5 m of bunk space per lamb with fresh water supplied to each pen with an automatic waterer. Grain was fed daily between 07:30-08:30 h for the duration of treatment and pen daily feed intake was recorded. A feed refusal rate of 20-30% was allowed. Lambs were weighed weekly indoors using the same schedule and portable weigh cage as for the lambs on cover crop pasture.

Blood samples were taken at 08:00 h for grain-fed lambs and between 09:00-12:00 h for pasture-fed lambs. Blood samples were taken at d -7, and d 28 for all treatments. Lambs on GRN had their final sample taken at d 42 with all other groups at d 56. Samples were drawn using a 1 inch, 18 g needle into 10 mL collection tubes containing sodium heparin (BD Vacutainer, Preanalytical Solutions, Franklin Lakes, U.S.) and immediately placed on ice. Within 2 h of collection, blood samples were centrifuged at 1660 x g at 4 °C for 15 minutes, and plasma was gathered and stored at -20 °C until further analyses. Packed cell volume was measured in duplicate on samples taken on day: -7, 28 and 42 for GRN group and 56 for BKG, BRO, MIX groups.

Plasma glucose concentration was determined in triplicate using the glucose oxidase method (Sigma Chemical, St. Louis, MO) with an interassay CV of < 4% and an intraassay CV of < 10%. Plasma non-esterified fatty acid (NEFA) concentration was measured in triplicate by an enzymatic kit based on coupled reactions of NEFA with acyl CoA synthetase and acyl CoA oxidase (NEFA-D kit, WAKO Chemicals U.S., Dallas, TX) with an interassay CV of <6% and an intraassay CV of < 10 %. Plasma urea nitrogen concentration was measured using a modification of the phenol-hypochlorite method (Chaney and Marbach, 1961) adapted for use in a 96 well plate format. Jack bean urease Lot #SLCB6717 (Sigma Chemical, St. Louis, MO; 100 U per 30 mL of buffer) was solubilized in 20 mM sodium phosphate buffer at pH 6.5 and added to sample and left to incubate for 20 minutes at 20 degrees C. Sample/buffer mix (10 µl) was transferred to a 96 well plate and 25 µl Phenol hypochlorite and 25 µl sodium nitroprusside were subsequently added along with 200 µl of double distilled water was added, samples were incubated for 30 minutes, and absorbance was read at 620 nm. Ammonia standards were created using ammonium sulfate and double distilled water, at N concentrations of 0, 2, 8, 15, and 30 ng/dL. Absorbance reading for all plasma samples were corrected for that observed with plasma incubated without urease. Plasma PUN concentration was measured in triplicate with an interassay CV of < 6% and an intraassay CV of < 15%

Lambs were removed from dietary treatment after 6 weeks for GRN treatment and 8 weeks for all other treatments at 14:00 h and transported 97 kilometers to a livestock sales center for weighing and then 95 kilometers to Wolverine Packing Company in Detroit, Michigan and slaughtered at 06:00-07:00 h the next morning under Halal practice (Farouk et al., 2014).

Hot carcass weight was recorded after dressing procedure and then all carcasses were rapidly chilled to less than 4 °C. Post slaughter carcass measurements were taken 27-30 hours post slaughter. Backfat, body wall depth, eye muscle depth, and loin eye area were all measured at the 12^{th} rib for both the left and right side to compose an average for the carcass (USDA, 1992). Flank streaking and leg score was determined by the same person to calculate quality grade. Yield grade was calculated as YG = 0.4 + (10 x adj BF; USDA, 1992).

After carcass data collection, the loin bone-in portion of the carcasses were removed, and vacuum packaged and transported to the MSU meat lab for aging at 3 °C for 7 days. In 2019, 48 loins collected (4 loins per replicates with 3 replicates = 12 per treatment) and in 2020 all loins were collected (15 per treatment). In 2019, full loins were frozen at -27 °C after 7 days of aging. In 2020, full loins were boned-out and cut into loin chops after 7 days of aging and stored at -27 °C. Full loins were cut to 25.4-mm chops. Chops from the same anatomical position (anterior to posterior) within each loin were analyzed for each respective procedure (chemical, shear force, sensory analyses). All chops were subjected to vacuum packaging in 3 mm polypropylene and placed in the freezer at -27 °C, until analysis with the exception of the chops subjected to chemical analysis in 2020 which were further processed to dissect the longissimus dorsi muscle which was to cut to cubes and frozen at -27 °C until analysis. Chops were prepared for chemical analysis in 2019 by dissecting the longissimus dorsi muscle out after thawing just prior to analysis.

Six cores from 3 chops per animal were used from 2019 and 2020 to determine shear force (n=108 lambs). Chops were thawed for 24 h at 3 °C and weighed to allow calculation of cooking loss. Chops were cooked on a George Foreman clamshell grill (Model GR390FP, Spectrum Brand Inc, Middleton, WI). Chops were cooked until chops reached an internal temperature of 70 °C which took 4-5 min. After cooking, chops were removed from the grill and allowed to rest for 2 minutes and then weighed. Chops were then placed on individual polystyrene foam plates covered with polyvinyl chloride film, and chilled at 3 °C for 24 h. Warner-Bratzler shear force (WBSF) values were obtained 24 h after cooking by removing two 1.3-cm cores per chop parallel to the muscle fiber for a total of 6 cores per animal. Cores were sheared individually perpendicular to the muscle fibers using a WBSF Texture Analyzer and blades (G-R Elec. Mfg., Manhattan, KS) with a crosshead speed of 200 mm/min.

Three chops per animal were used to determine meat color. Chops were thawed prior to color measurement for 24 h. After thawing, chops were removed from packaging and allowed to sit for 15 minutes prior to color measurement. Individual loin sample muscle color was measured for L* (lightness), a* (redness) and b* (yellowness) values with Hunter Miniscan XE Plus (Model 4500 L, Reston, VA).

Cubed loin chop samples were further processed by grinding through a NutriBullet (Capital Brands Distribution LLC., Los Angeles, CA) to produce a homogenized sample and obtain a minimum of 100 g of sample. Ground loin chop samples them immediately analyzed using AOAC-approved methodologies for proximate analysis (FoodScan, FOSS NIRsystems, Inc., Laurel, MD; Anderson, 2007) to allow measure of fat, moisture, and protein concentration.

The Michigan State University Institutional Review Board approved procedures for use of human subjects for consumer sensory panel (STUDY00005994). The sensory panel used four lamb chops from each lamb finished in 2020 (n=60 animals) and was conducted in Grand Rapids MI (Contract Testing Inc.). People who consumed lamb on a frequent basis were asked to participate in the study. Cooking procedures were as described for shear force analysis. Each cooking round consisted of 16 chops (four animals, one from each treatment). Samples were cooked until the loin internal temperature reached 70 °C (4-5 min) followed by a 2 min rest period. Following the rest period, each chop was cut through the midline into equal halves which served as sample portions. Panels were conducted in two sample rooms with fluorescent lighting. Panelists (n = 105) were recruited from the local community and were compensated for participation. Panel sessions were conducted with 6-10 consumers per session, with sessions lasting less than 30 min per session.

Verbal instructions were given to consumers prior to each panel regarding the ballot and the procedure to follow for the panel. Each ballot contained a demographics information portion (age, gender, employment nationality, favorite meat, location of lamb consumption, frequency of lamb consumption and preference for fresh versus frozen lamb), four sample evaluation ballots, and a recipient information sheet. Panelists were seated in numbered booths and were provided with one half-chop portion from each of the four treatments. The consumers rated the four samples using 100-point line scales for tenderness (0 = not tender, 100 = extremely tender), juiciness (0 = not juicy, 100 = extremely juicy), flavor liking (0 = dislike extremely, 100 = like extremely), and overall liking (0 = dislike extremely, 100 = like extremely; Appendix Table 12). Consumers were asked to also rate each sample's acceptability as yes or no.

Statistical Analysis

Analysis of variance was conducted using PROC MIXED in SAS (SAS, Inc., Cary, NC). Replicate, sex, and site-year were treated as random factors and diet treatment as a fixed factor for animal variables. For forage variables, replicate and site-year was treated as random factor and diet treatment as a fixed factor. Time factors within years (day or period) were treated as repeated measures. The experimental unit for animal and forage variables was replicate of dietary treatments (n=3 replicates). Variance was tested for homogeneity using PROC MIXED, and samples were grouped based on variance as needed. LSD-Letters were assigned at alpha=0.05.

RESULTS

Forage crop growth, composition, quality growing conditions

Average daily temperature, total precipitation, and 30-year normal values are summarized across trial months in Table 3. Air temperatures were largely within one standard deviation of normal for all months except November 2019, which was unusually cold, and September and October 2020, when temperatures were slightly cooler than the normal range. Precipitation was less than expected right after planting in August both years, which was observed to delay seedling emergence and early growth. Precipitation was uneven between 2019 and 2020, compared to the average, but total cumulative rainfall over the entire study period for 2019 and 2020 (392, 345 mm, respectively) was similar to the 30-year normal (437 mm).

Pre-grazing forage biomass did not differ ($P > 0.05$) between cover crop treatments but did differ over time during the trial (Figure 2). Total biomass at day 0-14 (4.1 Mg/ha, 2019: October 14 – November 1, 2020: October 7 - 2021) was significantly less than all other days of treatment (4.6 – 5.1 kg/ha).

Botanical composition of the cover crop pure brassica seeding treatments (BRO and BKG) did not differ ($P > 0.05$), with forbs as the dominant component (93-96% of biomass) and with minor proportions of cool season grass (1-2% of biomass) and weeds (2-9 % of biomass) across all measurement dates (Table 5). When compared to the pure brassica seedings across all measurement dates, the MIX cover crop contained less brassica (BRO 95%, BKG 94%, MIX 72%; $P < 0.001$), more cool-season grass (BRO 1%, BKG 2%, MIX 20%; $P < 0.001$), and more legume (BRO 0%, BKG 0%, MIX 5%; $P < 0.05$). The proportion of warm-season grass and weeds in biomass did not differ by cover crop treatment ($P > 0.05$). Across all cover crops, the proportion of weeds was greater at d -7 (8%) than at d 28 (3%), while weed proportion at d 56 (7%) was comparable to d -7 and 28.

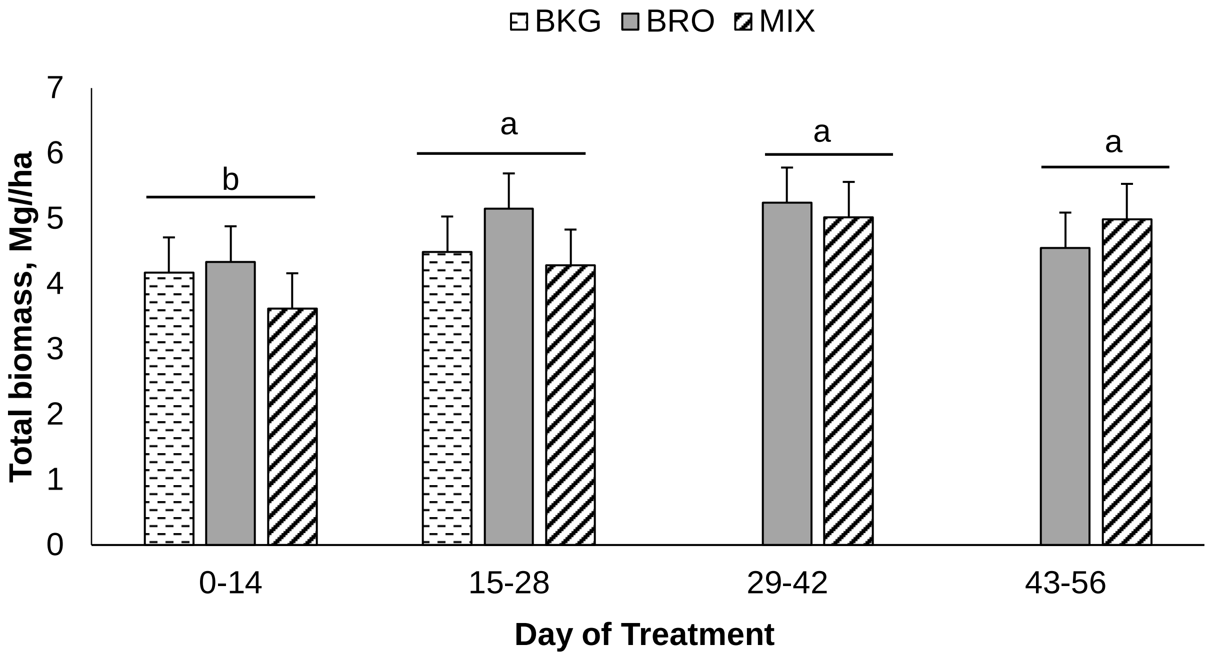

Figure 2. Pre-grazing forage biomass. Pre-grazing forage biomass in Mg/ha off the total forage biomass was calculated by averaging the pre-grazing samples components over a 2-week periods for the brassica-based treatments: background on pure brassica seeding (BKG), finished on pure brassica seeding (BRO), finished on brassica-based mixture seeding (MIX). Bars assigned different letters within panels are significantly different overall by time (*P* < 0.05).

Table 5: Botanical composition of cover crop pastures in East Lansing, MI, before grazing began (d -7) and at 28 and 56 days on pasture.

Treatment [2]	Days on pasture	Functional Group, % [1]				Weeds
		Forbs	Cool Season Grass	Legumes	Warm Season Grass	
BKG	-7	94.0[a]	0.5[b]	0	0	7.5[a]
	28	96.0[a]	0.6[b]	0	0	2.7[b]
BRO	-7	93.5[a]	2.1[b]	0	0	6.7[a]
	28	95.8[a]	1.9[b]	0	0	2.5[b]
	56	93.1[a]	0.8[b]	0	0	8.7[ab]
MIX	-7	69.7[b]	18.9[a]	3.6	1.4	10.7[a]
	28	75.6[b]	20.2[a]	4.8	1.2	4.9[b]
	56	70.3[b]	21.7[a]	6.5	1.3	4.7[ab]
SE[3]		4.7	2.8	2.0	1.3	6.1
P-Value [4]	Time	NS	NS	NS	NS	**
	Treatment	***	***			NS
	TRT*Time [4]	NS	NS			NS

[a-d] Least square means with different letters in the same column are different ($P < 0.05$).
[1] Species components were grouped into forbs (turnip, radish, forage rape), cool season grasses (wheat/rye and oats), legumes (field pea and clover), warm season grasses (pearl millet, Japanese millet), or weeds,
[2] Treatments: BKG, background on brassica; BRO, brassica-finished; MIX, mixture-finished.
[3] SE: Standard error of the least square means
[4] P-Value: *, **, *** ($P \leq 0.05$, 0.01, and 0.001), respectively. or NS (not significant).

Proportions and nutrient composition of herbage and tubers in the pre-grazing biomass are in Table 6. Across all sampling dates, the proportions of herbage and tuber differed by treatments. The proportion of herbage was greater for MIX (891 g/kg) than for pure brassica seedings (BKG and BRO, 814 and 822 g/kg, respectively; $P < 0.001$). Tuber biomass was greater for pure brassica seedings than for MIX (BRO= 186, vs. MIX= 110 g/kg; $P < 0.001$). The proportions of herbage and tuber in the biomass did not differ across time for any treatments ($P > 0.05$).

The DM concentration of total biomass differed between treatment; BKG (105 g/kg) was less than BRO (122 g/kg) which was less than MIX (149 g/kg; $P < 0.001$). Herbage DM was greater in MIX (154 g/kg) than BRO (132 g/kg), and greater for BRO than BKG (112 g/kg; *P* <

0.001), while tuber DM did not differ. Concentration of CP in total biomass was greater ($P < 0.001$) in MIX (157 g/kg) than in BRO or BKG (143 g/kg) as also observed in herbage and tuber components. Both NDF and ADF measures in total biomass were greater ($P < 0.001$) in MIX (302 g/kg and 194 g/kg, respectively) than found in pure brassica seedings (224-227 g/kg and 173-174 g/kg, respectively) as also seen in the herbage component. In tubers, MIX had less ($P < 0.05$) NDF and ADF (128 and 104 g/kg, respectably), than BRO (135 and 109 g/kg, respectably), while ADF in BKG (132 and 107 g/kg, respectably) was similar to BRO and MIX.

Concentration of DM in total biomass of all cover crops increased over time ($P < 0.001$), ranging from 109-117 g/kg during d 0-28 and increasing thereafter (131 g/kg at d 29-42 and then to 178 g/kg at d 43-56). Herbage DM concentration followed the same pattern as total biomass DM concentration over time ($P < 0.001$). Tuber DM concentration increased from d 0-14 (84 g/kg) to d 15-28 (93 g/kg) and then remained constant ($P < 0.05$).

Across time, CP concentration in total forage and herbage decreased ($P < 0.01$) between d 0-14 (155 and 164 g/kg, respectively) and d 15-28 (142 and 152 g/kg, respectively). In tubers CP concentration increased ($P < 0.05$) from d 0-28 (92-99 g/kg) to d 29-56 (111-114 g/kg). In total biomass NDF and ADF did not differ over time or for NDF in herbage ($P > 0.05$), herbage had greater ADF at day 43-56 (207 g/kg) than in previous intervals (190-193 g/kg ; $P < 0.001$). In tubers, both NDF and ADF was greatest at d 0-14 (116 g/kg) with no subsequent change (102-103 g/kg ; $P < 0.001$).

Table 6. **Nutrient Composition of field treatments (TRT) by component[1] (g/kg).**

	Treatment[2]			SE		Time[3], d				SE				P-Value[5]		
Proportion[4]	BKG	BRO	MIX	BKG	BRO MIX	0-14	15-28	29-42	43-56	0-14	15-28	29-42	43-56	TRT[2]	Time	TRT*Time
Herbage	822^{b}	814^{b}	891^{a}	5	5	864	849	847	812	5	5	5	5	0.01	NS	NS
Tuber	178^{a}	186^{a}	109^{b}	5	5	134	151	153	188	5	5	5	5	0.01	NS	NS
Component[1]																
Total																
DM	105^{c}	122^{b}	149^{a}	7	6	117^{c}	109^{c}	131^{b}	178^{a}	6	6	7	7	0.001	0.001	NS
CP	143^{b}	143^{b}	157^{a}	24	24	155^{a}	142^{b}	149^{ab}	148^{ab}	24	24	24	24	0.001	0.05	NS
NDF	224^{b}	227^{b}	302^{a}	11	10	258	249	257	262	10	10	10	10	0.001	NS	NS
ADF	173^{b}	174^{b}	194^{a}	18	17	183	179	180	188	17	17	18	18	0.001	NS	NS
Herbage																
DM	112^{c}	132^{b}	154^{a}	5	4	124^{c}	114^{c}	138^{b}	190^{a}	5	5	5	5	0.001	0.001	NS
CP	153^{b}	154^{b}	164^{a}	29	29	164^{a}	152^{b}	160^{a}	156^{ab}	29	29	29	29	0.01	0.01	NS
NDF	242^{b}	246^{b}	322^{a}	8	7	272	267	278	291	8	8	8	8	0.001	NS	NS
ADF	184^{b}	188^{b}	205^{a}	17	17	190^{b}	190^{b}	193^{b}	207^{a}	17	17	18	18	0.001	0.001	NS
Tuber																
DM	91	87	92	9	9	84^{b}	93^{a}	92^{a}	91^{a}	9	9	9	9	NS	0.05	NS
CP	86^{b}	96^{b}	116^{a}	18	18	99^{b}	92^{b}	111^{a}	114^{a}	18	18	18	18	0.001	0.05	NS
NDF	132^{ab}	135^{a}	128^{b}	5	4	142^{a}	127^{b}	126^{b}	128^{b}	4	4	4	4	0.05	0.001	NS
ADF	107^{ab}	109^{a}	104^{b}	4	4	116^{a}	103^{b}	102^{b}	103^{b}	4	4	4	4	0.05	0.001	NS

[a-d] Least square means with different letters in the same column are different ($P < 0.05$).

[1]Component: Forage components were broken into herbage (aboveground stem and leaf portion of plant), tuber (aboveground bulbous root portion of turnip and radish plants), and total biomass (herbage + tuber portion).

[2]Treatment (TRT): Brassica-based treatments: background on brassica (BKG), brassica-finished (BRO); and the mixture seeded cover crop treatment (MIX).

[3]Time: Days of treatment broken into 14-day segments, 0-14 d , 15-28 d, 29-42 d, 43-56 d.

[4]Proportion: The proportion of herbage in the total biomass represented as g/kg.

[5]P-Value: Main effect treatment (TRT) and time, (P = 0.05, 0.01, 0.001, or NS (not significant)).

Animal growth and plasma metabolites

This study was designed to provide the same daily forage allowance for all replicates and treatments at 90-100 g of forage DM per kg of BW. This range was met or slightly exceeded for all treatments over time (Figure 3) except for the MIX cover crop during the d 0-14 (78 g DM /kg BW) and d 15-28 (87 g DM/kg BW) periods ($P < 0.05$).

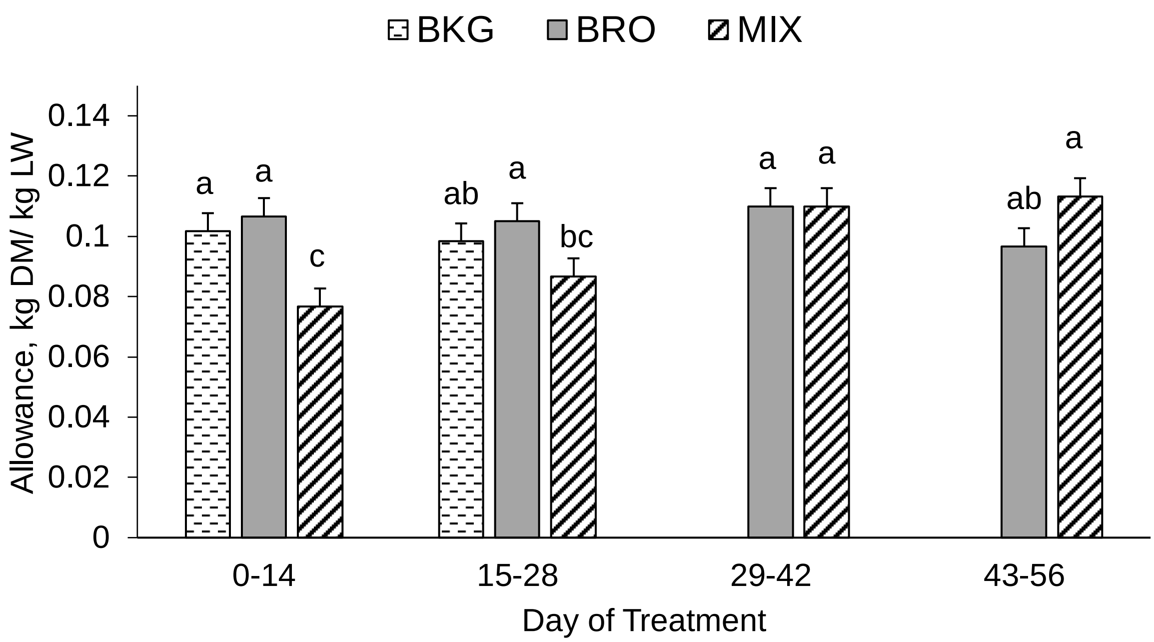

Figure 3. Interaction of forage allowance by treatment and time. Forage allowance was calculated by averaging the pre-grazing biomass over a 2-week period for the brassica-based treatments; background on brassica (BKG), brassica-finished (BRO) and the mixture seeded cover crop treatment (MIX) and dividing this by the pen liveweight for this period (kg). Error bars represent standard error. Bars assigned different letters are significantly different by the interaction of treatment and time ($P < 0.05$).

Packed cell volume was higher in the MIX group (34.4%) relative to the other treatments (range 33.7 to 34.9) during the entire course of the study ($P < 0.05$). There were no changes in PCV noted over time and no animals exhibited clinical anemia (PCV of all lambs > 25%) at any time during the study.

Grain-fed lambs (GRN and BKG after day 28) grew faster than lambs grazing all cover crop treatments ($P < 0.001$; Figure 4). Lambs fed grain exclusively (GRN) declined in growth during the final 2 weeks of their 6-week treatment period ($P < 0.05$). Lambs in BKG exhibited markedly faster growth than other treatments when transitioned to grain after day 28 ($P < 0.01$), with these lambs exhibiting the greatest gains of all study lambs during the final 2 weeks of the study ($P < 0.05$). Lambs grazing cover crop exhibited less growth during the final 2 weeks of the study as compared to the first 6 weeks ($P < 0.05$). Lamb weight gain when expressed on a land area basis (kg gain/ha) did not change by treatment but differed over time in this study with d 15-28 (218 kg/ha) having the highest gains with a decline at d 43-56 (137 kg/ha; Figure 5).

Average daily dry matter intake (DMI) and feed conversion ratio (FCR) were evaluated over 2 weeks study periods as shown in Figure 6 for lambs in treatments when fed grain (GRN 0-42 d and BKG 29-56 d). Daily dry matter intake expressed as a percentage of BW was greater during 0-14 d for GRN lambs (4.3%; $P < 0.05$) compared to all other periods and treatments which did not differ (3.5-3.7%). The FCR was highest in the GRN treatment during the last 2 weeks of that treatment (d 29-49; FCR of 6.0) and was greater ($P < 0.05$) than that observed during the last 2 weeks (43-56 d) of the BKG treatment (FCR of 4.3).

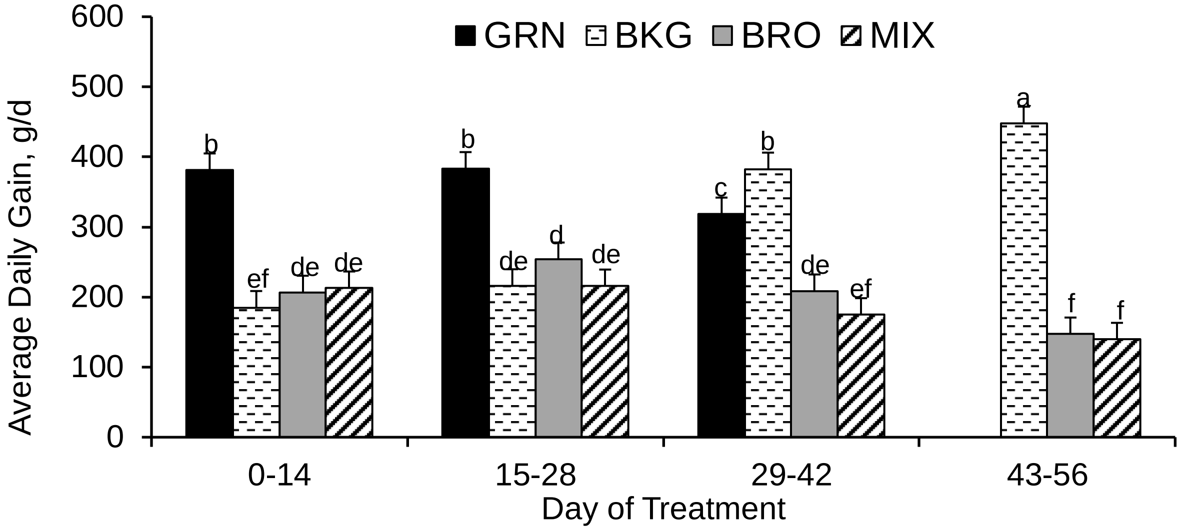

Figure 4. Dietary treatment on average daily gain by interaction of treatment and 2-week periods. Lambs were fed grain (GRN), background (BKG), brassica (BRO) or mixture (MIX) diets for 8 weeks except for GRN which was fed for 6 weeks. Lambs were weighed weekly to determine average daily gain. Least square means average daily gains (g/d), of lambs fed GRN, BKG, BRO, or MIX over a 6 week (GRN) or 8 weeks (BKG, BRO, MIX). Error bars represent standard error. Bars assigned different letters are significantly different by the interaction of treatment and time
($P < 0.05$).

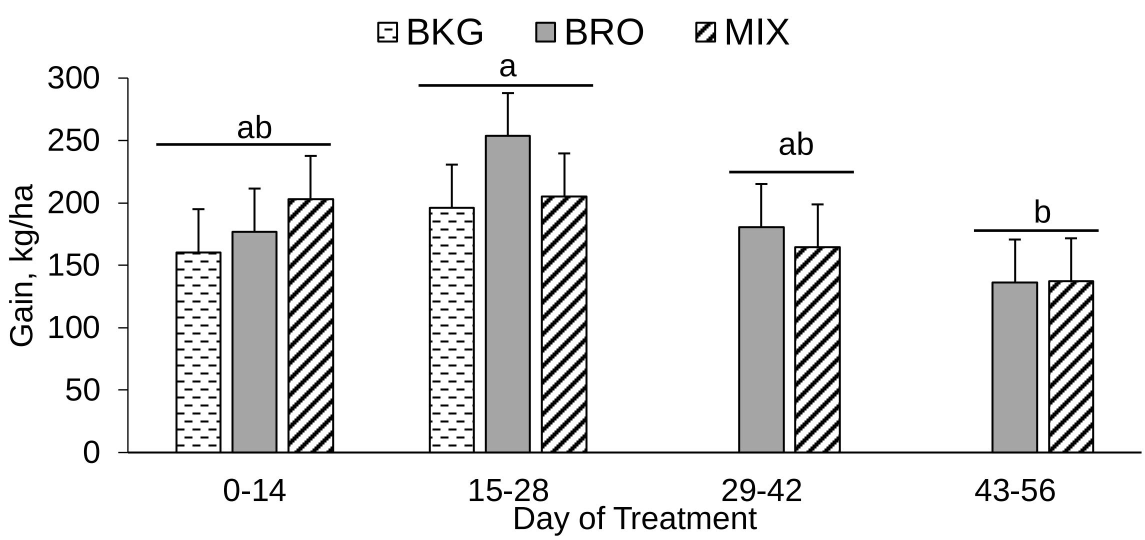

Figure 5: Dietary treatment on gain per hectare in pasture diets by 2-week periods. Lambs were fed background (BKG), brassica (BRO) or mixture (MIX) diets for 8 weeks. Lambs were weighed weekly to determine average daily gain. Least square means of gain (kg/ha), of lambs fed BKG, BRO, or MIX over 8 weeks. Error bars represent standard error. Bars assigned different letters are significantly different by time ($P < 0.05$).

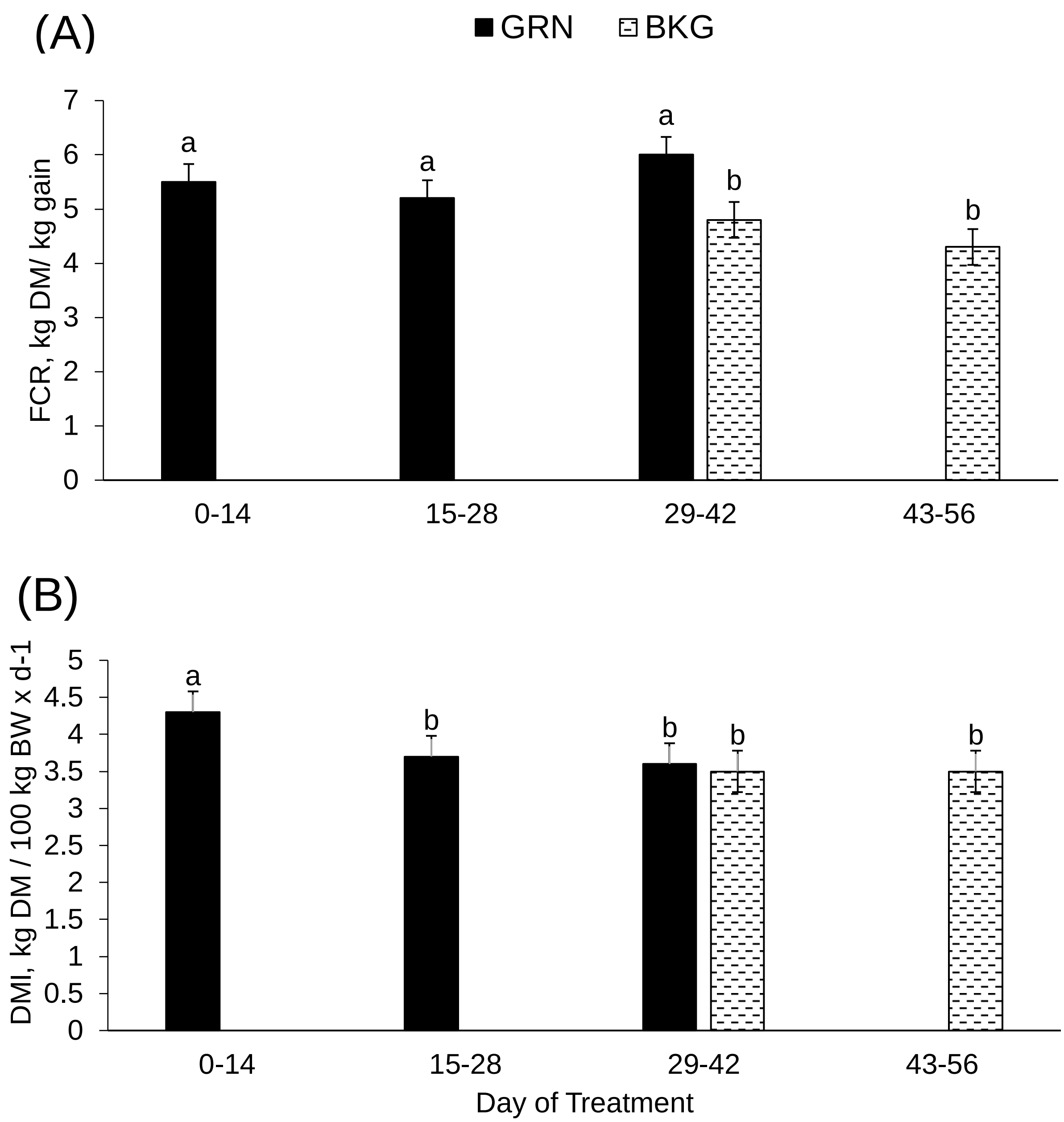

Figure 6: Feed efficiency (a), and dry matter intake (b) by 2-week periods of lambs on grain diets. Lambs were fed grain for 6 weeks from 0-42 d of GRN treatment or for 4 weeks from 29-56 d on BKG treatment. Least square means are shown for feed conversion rate (FCR) and daily dry matter intake (DMI). Error bars represent standard error. Bars assigned different letters are significantly different by treatment ($P < 0.05$).

The concentration of plasma metabolites expressed as least square means over the treatment period is displayed in Table 7 and changes in metabolite concentration according to treatment over time are displayed in Figure 7. The plasma glucose concentration of lambs on MIX were slightly elevated compared to other treatments during the entire study period (P < 0.05). Modest declines in glucose were noted over the study period for both GRN and BKG (P < 0.05) but not MIX and BRO. Grain-fed lambs (GRN and BKG after day 28) had lower plasma NEFA concentrations than lambs grazing CC (P < 0.05). Lambs grazing a pure brassica pasture (BRO the entire study and BKG during the first 28 days) exhibited lower plasma PUN concentration than lambs consuming GRN or MIX (P < 0.05). Plasma PUN concentration increased in BKG lambs after they transitioned to a grain diet (P < 0.05).

Table 7. Least square means of plasma glucose, non-esterified fatty acids (NEFA), and plasma urea nitrogen (PUN) concentrations on lambs reared on different treatments[1].

	Treatment[1]					P-Value[2]		
Variable	GRN	BKG	BRO	MIX	SE[3]	Diet	Time[4]	TRT*Time[5]
Glucose, mg/dL	73.2[b]	74.3[b]	73.8[b]	78.9[a]	3.5	0.05	<0.001	<0.01
NEFA,mEq/L	100[c]	132[bc]	138[b]	180[a]	36	<0.001	NS	<0.01
PUN, ng/ml	2.7[a]	2.2[b]	1.9[b]	2.8[a]	0.4	<0.01	NS	<0.001

[a-d] Least square means with different letters in the same column are different (P < 0.05).
[1] Treatments: Lambs were either fed for 8 weeks on pasture as a pure brassica mix (BRO), a diverse mix of brassica, legumes, and grasses (MIX), 4 weeks of BRO then finished for 4 weeks on grain diet (BKG) or fed for 6 weeks on grain (GRN).
[2]P-Value: P- value refers to a statistical model accounting for the fixed effect of diet, week, and interaction.
[3]SE: Standard error of the least square-mean.
[4]Time: Day in which lambs were sampled during dietary treatment; d 28 and d 42 for GRN and d 28 and d 56 for all other treatments.
[5]TRT*Time: The interaction effect of time and treatment on metabolite concentrations in plasma.

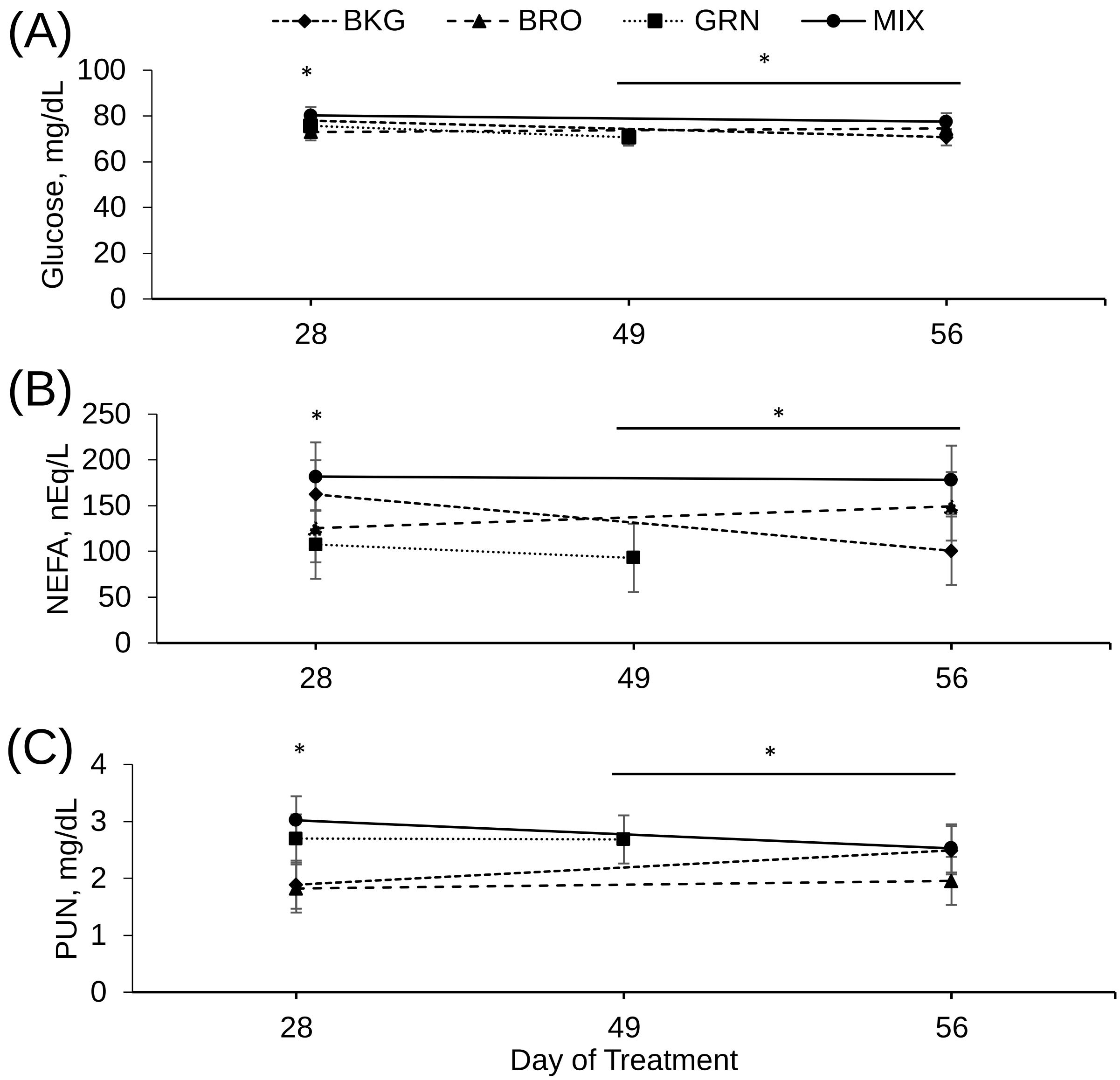

Figure 7: Interaction of the effect of dietary treatment and time on plasma glucose concentration (A), NEFA concentration (B) and PUN concentration (C). Lambs were fed grain (GRN), background (BKG), brassica (BRO) or mixture (MIX) diets for 8 weeks except for GRN which was fed for 6 weeks. Blood samples were collected prior to dietary treatment (d -7), and at d 28 and d 56 for all treatments except for GRN which was collected at d -7, 28 and 42. Significant difference ($P < 0.05$) between one or more treatment at a given time point is indicated by an "*". GRN d 49 was compared to BKG, BRO and MIX d 56.

Carcass and meat characteristics

Lambs fed grain for the entire experiment (GRN) or final 4 weeks (BKG) of the treatment period had greater HCW (29.8 kg GRN and 30.2 kg BKG; $P < 0.05$) than those grazing cover crops the entire study period (27.9 kg BRO and 27.3 kg MIX) which did not differ (Table 8). Lambs on GRN had larger loin eye muscle depth (EMD; 3.8 cm) that those on BKG (3.5 cm; $P < 0.01$); which were greater than lambs grazing cover crop (BRO and MIX, both at 3.4 cm; $P < 0.01$). Lamb LEA was greater in GRN lambs than in those grazing cover crop for the entire study ($P < 0.05$).

Backfat depth in lambs receiving grain during all or part of the study period (BKG 0.51 cm and GRN 0.45 cm) were similar and greater ($P < 0.05$) than in lambs grazing cover crop the entire study (BRO 0.40 cm and MIX 0.38 cm) which did not differ. The same relative differences were observed in yield grade as yield grade is a function of backfat depth. Similarly, lambs fed grain exhibited greater BWD (GRN 2.28 cm and BKG 2.35 cm) than lambs grazing cover crop the entire study (BRO 1.95 cm and MIX 1.92 cm; $P < 0.05$).

Lamb carcass quality grade differed according to treatment ($P < 0.001$). Lamb on the GRN treatment had the highest quality grade (Choice^{+}) followed by BKG (Choice) with lambs grazing cover crops the entire study (MIX and BRO) the same but lower in quality grade (Choice^{-}). The carcass dressing percentage was less ($P < 0.05$) in BKG lambs (50.6%) than in the other treatments which did not differ (range of 51.5 to 51.8%). Final liveweight was greater in grain diets (GRN 57.6 kg and BKG 59.3 kg) than in cover crop diets (BRO 53.6 kg and MIX 52.1 kg; $P < 0.001$).

Lamb loin chops were processed from whole loins collected at slaughter and evaluated for shear force, cooking loss and various measures of color including, L*, a*, and b* shown in Table 9. Dietary treatment had no effect on either shear force or cooking loss; however, it did impact measures of color (P < 0.05). The GRN lambs had lower a* (21.6) than other treatments (range of 23.1 to 24.0) which did not differ (P < 0.05). The GRN lambs had higher L* (30.0) than BKG lambs (27.3) which was greater than BRO lambs (25.2). The MIX lambs had L* values (26.6) intermediate between and not different from BKG and BRO lambs. The dietary treatments did not affect measures of b*.

The longissimus dorsi muscle was dissected from lamb loin chops and analyzed for chemical composition. Dietary treatment did not impact the measure of muscle pH (range of 5.64 to 5.68) nor moisture (range of 72.7-73.1 %), intramuscular fat (IMF range of 3.2 to 4.1%) or collagen (range of 2.0 to 2.2) concentrations. Protein concentration was elevated (P < 0.001) in muscle from lambs grazing cover crops the entire study (BRO and MIX, both 24%) relative to the grain treatments (GRN and BKG, both 23.3%)

Lamb loin chops were cooked and subjected to sensory analysis by a consumer panel (Table 10). Overall, loin chops from lambs on the BRO treatment excelled in various aspects of sensory analysis. BRO was superior in flavor (60.7) compared to GRN (52.1; P < 0.05) with BKG (55.7) and MIX (57.7) not different from other treatments. Lamb from BRO treatment also excelled in juiciness (P < 0.01; 60.4) compared to all other treatments (range of 49.5 to 50.4) which did not differ. Tenderness did not differ between treatments. Lamb from the BRO treatment (83.8) was greater than BKG (69.5) in overall acceptability with MIX and GRN (both 76.2) intermediate and not different from other treatments. Demographic data of panelist are shown in Appendix Table 13. In our panel, the majority of consumers were between the age of 35-54 years. Over 60% of panelists identified as female and as full-time employees. 96% of panelists identified their nationality as U.S. Panelists listed poultry (39%) as their favorite meat followed by beef (37.1%) with 1.9% stating lamb as their favorite meat. When asked to select all the locations where they consume lamb the most common was restaurants (82%) followed closely by home (70%). Lamb consumption occurred regularly with a majority of panelist eating lamb once a month (39%), followed by once every two to three weeks (20%) and then by once every two to three months (16%). When asked their preference for fresh versus frozen lamb, the majority of panelists showed preference for fresh lamb (52%) with the rest having no preference or slight preference for fresh (38% and 9%, respectively).

Pearson correlation coefficients (Table 11) revealed a significant positive correlation between overall liking and flavor ($P < 0.05$) and both scores were also positively correlated with meat collagen concentration ($P < 0.05$). Significant negative correlations existed between fat concentration and overall acceptability, between fat concentration and collagen concentration, and between fat concentration and tenderness ($P < 0.05$ for all). Quality grade and flavor had a negative correlation ($P < 0.05$).

Table 8: Carcass traits of lambs on reared on various treatments [1].

	Treatment[1]					
Carcass Trait	GRN	BKG	BRO	MIX	SE[4]	P- Value[5]
Live Weight, kg	57.6[a]	59.3[a]	53.6[b]	52.1[b]	1.91	<0 .001
Hot Carcass Weight, kg	29.8[a]	30.2[a]	27.9[b]	27.3[b]	1.29	< 0.001
Dressing Percentage, %	51.5[a]	50.6[b]	51.8[a]	51.5[a]	1.29	< 0.05
Backfat Depth, cm	0.45[ab]	0.51[a]	0.40[bc]	0.38[c]	0.03	0.01
Body Wall Fat Depth, cm	2.28[a]	2.35[a]	1.95[b]	1.92[b]	0.14	< 0.001
Loin Eye Area, cm	20.6[a]	20.0[ab]	19.1[bc]	18.7[c]	1.09	< 0.001
Eye Muscle Depth, cm	3.77[a]	3.52[b]	3.40[c]	3.37[c]	0.04	< 0.001
Yield Grade[2]	2.16[ab]	2.37[a]	1.98[bc]	1.86[c]	0.10	0.01
Quality Grade[3]	3.00[a]	2.20[b]	1.67[b]	1.83[b]	0.20	< 0.001

[a–d] Within a row, least squares mean without a common superscript differ ($P < 0.05$)
[1] Treatments: Lambs were either fed for 8 weeks on pasture as a pure brassica mix (BRO), a diverse mix of brassica, legumes, and grasses (MIX), 4 weeks of BRO then finished for 4 weeks on grain diet (BKG) or fed for 6 weeks on grain (GRN).
[2]Yield grade was calculated using the backfat measurement in inches (10*backfat depth + 0.4), (USDA, 1992).
[3]Quality: Carcass leg score and flank streaking were used to determine quality grade according to (USDA, 1992). Numerical values identify quality grade: 1=Choice$^-$, 2=Choice°, 3=Choice$^+$, 4=Prime$^-$, 5=Prime°, 6=Prime$^+$.
[4]SE: standard error of least square-mean.
[5]P-Value: P- value refers to a statistical model accounting for the fixed effect of diet, week, and interaction.

Table 9. Cooking Loss, proximate and Warner-Bratzler shear force (WBSF), color and pH values of lamb on different rearing treatments.

	Treatments[1]					
Meat Trait[2]	GRN	BKG	BRO	MIX	SE[4]	P- Value[5]
Cooking Loss, %	23.2	22.0	20.8	22.5	0.9	NS
Shear Force, kg	4.24	4.67	4.21	4.08	0.85	NS
Redness, a*	21.6[b]	23.3[a]	24.0[a]	23.1[a]	1.5	0.01
Yellowness, b*	23.4	23.4	23.1	23.3	0.8	NS
Lightness, L*	30.0[a]	27.3[b]	25.2[c]	26.6[bc]	2.0	<0.001
Protein[3], %	23.3[b]	23.3[b]	24.0[a]	24.0[a]	0.2	<0.001
Moisture[3], %	73.1	73.0	72.7	72.7	1.1	NS
Fat[3], %	4.2	4.2	3.8	4.1	0.5	NS
Collagen[3], %	2.0	2.0	2.2	2.1	0.5	NS
pH[3]	5.64	5.68	5.68	5.67	0.02	NS

[a–d] Within a row, least squares mean without a common superscript differ ($P < 0.05$)
[1] Treatments: Lambs were either fed for 8 weeks on pasture as a pure brassica mix (BRO), a diverse mix of brassica, legumes, and grasses (MIX), 4 weeks of BRO then finished for 4 weeks on grain diet (BKG) or fed for 6 weeks on grain (GRN). Data was combined across years and uneven variance model was used to factor for sex.
[2]Meat Trait: Measured after 24 h of thawing.
[3]Protein, moisture, fat, collagen, and pH were measured on the longissimus dorsi muscle dissected from each loin chop.
[4]SE: standard error of least square-mean.
[5]P-Value: P- value refers to a statistical model accounting for the fixed effect of diet, week, and interaction.

Table 10. The effect of dietary treatment[1] on consumer palatability traits of lamb loin chops (n=105).

	Treatments[1]					
Sensory Traits[3]	GRN	BKG	BRO	MIX	SE[2]	P-Value[5]
Liking	57.2	58.4	64.4	60.9	2.6	NS
Flavor	52.1^{b}	55.7^{ab}	60.7^{a}	57.7^{ab}	2.8	0.05
Juiciness	50.4^{b}	51.4^{b}	60.4^{a}	49.5^{b}	2.7	0.01
Tenderness	56.4	54.0	63.2	57.3	2.9	NS
Acceptability, % [4]	76.2	69.5	83.8	76.2	4.1	NS

$^{a–d}$ Within a row, least squares mean without a common superscript differ ($P < 0.05$).
[1] Treatments: Lambs were either fed for 8 weeks on pasture as a pure brassica mix (BRO), a diverse mix of brassica, legumes, and grasses (MIX), 4 weeks of BRO then finished for 4 weeks on grain diet (BKG) or fed for 6 weeks on grain (GRN).
[2]SE: standard error of least square-mean.
[3]Sensory Traits: Consumers scored traits on a continuous scale from 0-100.
[4]Acceptability: Consumers were asked to indicate if they found the product acceptable by marking "yes or no", the % indicating "yes" is shown.
[5]P-Value: P- value refers to a statistical model accounting for the fixed effect of diet, week, and interaction.

Table 11. Pearson correlation coefficients for the relationships among consumer sensory scores and chemical compositional traits for the loin chop (Longissimus dorsi*)* portion

	Liking	Flavor	Juiciness	Tenderness	Protein %	Fat %	Moisture %
Flavor	0.96*						
Juiciness	0.82	0.73					
Tenderness	0.90	0.74	0.87				
Protein, %	0.88	0.85	0.48	0.75			
Fat, %	-0.97*	-0.89	-0.90	-0.97*	-0.81		
Moisture, %	-0.86	-0.87	-0.42	-0.67	-0.99**	0.76	
Collagen, %	0.99*	0.97*	0.87	0.86	0.80	-0.96*	-0.79

*Significant correlation ($P \leq 0.05$).
**Significant correlation ($P \leq 0.01$).

DISCUSSION

Cover crop grazing systems offer potential as partial or complete lamb finishing systems while benefitting crop production. In the present study we compared two cover crop mixtures that varied in brassica concentration planted on August 7, 2019, and July 31, 2020, after winter wheat harvest near East Lansing, MI, U.S. Total above ground biomass of both crops did not differ and reached a peak at 29-42 d of the study (75 d after planting) followed by a decline over the following 2 weeks during late fall. Our forage yield results were comparable with Reid et al. (1994) who observed that pure brassica seedings produced 5.6-10.5 Mg/ha in a late-July planting with a grazing period from September-December in West Virginia. This was also similar to that found by Guillard and Allinson (1988), who observed with an August 23rd planting, that brassica plantings produced a yield of 3.3-5.9 Mg/ha on December 4th in Connecticut. In the current study the decline in forage biomass observed during the last 2 weeks of the study also correlated with an increased in forage DM concentration in both cover crop mixtures (15%, 28-42 d to 20%, 43-56 d). An increase in DM concentration as temperatures decline was also found by Rodríguez et al. (2015) who saw increased DM concentration in brassica cover crop at 12 °C compared to 20 °C. The total forage biomass achieved in the current study was at suitable levels for grazing as has been recommended to also prevent soil erosion (>2.00 Mg/ha; Hunt et al., 2016).

In the present study, our botanical compositions differed between treatments with forbs being dominant (BRO 94%, MIX 72%), and with minor components of cool season grasses (BRO 2%, MIX 20%). Our cover crop treatments differed in forb content with consisted of brassica species and this led to differences in above ground tuber and herbage biomass. Tuber biomass constituted 180-190 g/kg of total biomass in the pure brassica cover crop and 110 g/kg in the mixture cover crop (composed of forbs, legumes, and warm and cool season grasses), with the proportion of herbage to tuber biomass remaining unchanged over the 8-week study period. The relative proportion of tubers in the forb component of both treatments was less than observed by others who have studied brassica monocultures. Guillard and Allinson (1988) recorded a tuber biomass of 370 g/kg and Koch et al. (2002) recorded 330 g/kg in monocultures of turnips. Although dominant in brassica content, we saw a relatively low proportion of tuber in our particular mixture of brassica species (60% herbage and 40% tubers in forbs component of treatments), this was not unexpected given that forage rape does not have a significant tuber component thus reducing the total proportion of tuber in this pasture compared to one containing a monoculture of tuberous brassica species, as seen in our study (forb herbage content was 45% without the forage rape portion).

Mixture cover crop had greater fiber (NDF and ADF) and DM concentration than pure brassica cover crop (BKG and BRO); however, this had no impact on lamb growth. When our pure brassica cover crops were compared to brassica species evaluated by Sun et al. (2012) we observed DM to be comparable to that of the literature brassica species (BKG 112 g/kg and BRO 132 g/kg versus 94-141 g/kg) and similar fiber concentration (NDF of BKG and BRO, 242 - 246 g/kg versus 176-240 g/kg; ADF of BKG and BRO, 184 - 188 g/kg versus 121-180 g/kg). Our pure brassica cover corps were similar in DM, CP, NDF and ADF as reported for brassicas species in Sun et al. (2012).This contrasts with findings suggesting that growth performance limitations on brassica-based cover crops might be related to low fiber concentration (< 20% ADF/ 25% NDF; Cox-Ganser et al., 1994; Guillard et al., 1995; Koch et al., 2002). However, this result is not unequivocal as Cassida et al. (1994) found that supplementing pure brassica diets with hay did not improve growth performance or DMI when lambs were fed hay ad libitum. Our brassica cover crop mixture

(MIX) treatment had lower brassica content and greater content of components with a proportionally greater cell wall fraction (warm season grass, cool season grass, and legume) compared to the pure brassica cover crop (BRO and BKG) thereby explaining its greater ADF and NDF concentration. Forbs were the dominant plant type in both pasture treatments (94-95% in pure brassica and 72% in mixture) followed by cool season grasses (1-2% in pure brassica and 20% in mixture seeding). In the mixture seeded cover crop, legumes made up an additional 5% followed by warm season grasses (1%). Cover crop mixtures with greater grass content and less forb content have been demonstrated to have greater fiber content (Sun et al., 2012). In addition, the pure brassica cover crop had a greater proportion of tuber relative to herbage which was another factor contributing to its lower fiber and DM concentration relative to the mixture cover crop seeding (Reid et al., 1994). The botanical composition of both cover crops did not change over time except for the weed component which started at 8.3% at 0 d and reduced to 3.4% at 28 d. Weeds were considered as a small component of our botanical composition and based on past study with similarly low weed content, are not predicted to influence the nutrient composition of the lamb's diet (Cassida et al., 1995).

We compared the growth performance and carcass and meat quality of lambs grazing cover crop pastures to that of lambs raised on grain or a combination of background rearing on a pure brassica cover crop seeding followed by grain finishing. This diversity of lamb finishing systems produced a large difference in lamb growth rate thereby creating differences in carcass size. Lambs on the grain finishing diets gained 300-400 g/d whereas those on cover crop diets gained 150-250 g/d. This result was expected as grain finishing diets have a greater energy concentration than pasture diets allowing animals to achieve greater growth rates (Ekiz et al., 2013). Using the equation to calculate TDN concentration for grass (Undersander et al., 2010) and NDF digestibility values for brassica forage of 46.5% and 2% fatty acids (K. A. Cassida, unpublished); we calculated that the TDN content in BRO/BKG was 63% and that in MIX was 61%. Therefore, the cover crop diets differed little in this measure of energy concentration based on fiber content and its digestibility however there was a large difference between our cover crop and grain diets (79% TDN, Table 4). Koch et al. (2002) compared brassica crop grazing to grain finishing methods and observed lambs on brassicas gained around 180 g/d compared to 230 g/d on grain. Our lambs had comparable growth on a brassica grazing diet but greater growth on grain as our lambs were fed to express their full voluntary feed intake potential whereas those in the study by Koch et al. (2002) were limited to 1.5 kg of grain per day. Reviews of numerous studies comparing pasture (brassica or other species) to grain diets, have found similar results where lambs on grain-supplemented diets show a greater growth rate than those on pasture diets (Berthiaume et al., 2006; de Brito et al., 2017). The greater growth rate of lambs fed exclusively on the high energy grain diet (GRN treatment) resulted in greater carcass weight in a shorter period of time than other treatments. Lambs on the partial grain treatment (BKG) also achieved larger carcass size than did the lambs on cover crop pasture albeit in a longer period of time than the GRN lambs. Part of this increase in carcass weight of both GRN and BKG over the cover crop treatments was explained by increased body fatness as reflected in both measures of body fatness which included fat depth over the 12th rib and body wall thickness, which is often referred to as carcass GR measurement in reference to lambs (Hopkins et al., 2007). This agrees with results seen by Koch et al. (2002) who found that yield grade and fat depth of lambs in the feedlot were greater than in lambs grazing turnips. When compared to pasture-fed lambs on a ryegrass/clover mix, lambs finished on forage rape had greater backfat thickness (14.8 mm vs 12.6 mm; Hopkins et al., 1995). The increase in carcass mass in grain-finished lambs also included a discernable increase in lean tissue mass as evidenced by increases in the area (LEA) and depth (EMD) of the longissimus dorsi muscle in lambs receiving a grain diet. Differences in muscle accretion can be associated with dietary energy concentration, as diets with greater energy concentration have been observed to produce larger LEA as observed by Field et al. (1990), Germano Costa et al. (2010) and Hopkins et al. (1995) found that lambs finished on brassica cover crop had a deeper EMD when compared to ryegrass/clover pasture lambs however, we did not observed differences between our cover crop treatments possibly because the brassica content of our diets may not have differed enough.

Average daily gain across two-week periods ranged from 201 to 223 g/d and did not differ across cover crop diets up through 42 days. A decrease in daily gain was observed during the last period (43-56 d) for lambs grazing cover crop (range of 140-147 g/d). A possible reason for this decrease in the last 2 weeks of treatment in lambs grazing cover crops was a decline in ambient temperature in December compared to earlier periods of the study (Table 3), likely causing lambs to partition more energy into maintenance rather than growth (Barry et al., 1971). This agrees with a study by Koch et al. (1987), in which lambs were grazing brassica-based cover crop in September-October gained more (280 g/d) than those in November-December (178 g/d) in Wyoming. Reid et al. (1994) saw a similar difference when comparing grazing brassicas in warm climates to cold climates finding that gains in warmer climates were 50 g/d greater than in colder climates grazing the same forage due to increased energy maintenance need.

The cover crop finished lambs gained similarly on a land mass basis during the duration of treatment period. Lamb gain per hectare was similar throughout the first 42 days of the treatment period (170-220 kg/ha) but then slowed during the final 2 weeks (140 kg/ha). The gains we observed during warmer periods were comparable to those observed by Koch et al. (2002), who observed gains of 200-300 kg/ha for lambs grazing brassica monocultures. The shifts in gain per hectare we observed in our study did not appear to be explained by differences in forage allowance. Daily allowance was consistent for BKG and BRO, between 8-12% of daily forage DM allowed per unit BW, regardless of biomass and time. Although forage allowance for MIX was less (7.8%) during the 0-14 d period, lambs grazing this pasture type did not differ in growth from those on pure brassica cover crop during this period nor for any ensuing period on any cover crop treatment. The forage allowance provided by Koch et al. (2002) was approximately half (3-4%) of the allowance provided in the present study (8-12%). It is predicted that gain per unit land would increase with lower forage allowance however additional work is needed to optimize gain per unit land and individual gain through alterations in forage allowance for this cover crop grazing system.

In addition to concerns of low fiber concentration in pure brassica diets limiting growth, others have observed some negative health consequences of lambs grazing a brassica dominant pasture (Cox-Ganser et al., 1994). This has been ascribed to elevated levels of plant secondary compounds particularly SMCO which is associated with Heinz body anemia (Fales et al., 1987; Cox-Ganser et al., 1994). We saw no evidence for this in the present study as lambs on brassica diets did not exhibit depressed PCV nor did PCV change over the 8 weeks spent grazing these brassica dominant pastures. However, Cox-Ganser et al. (1994) reported PCV declines tend to be seen in the first 3 weeks of grazing brassicas and after three weeks PCV tends to increase and stabilize. In our study, we took our interim measurement at the four-week mark so it is possible that we might not have detected a transient early decline in PCV. Nonetheless, we did not observe any other negative health-related consequences of lambs grazing pure brassica cover crop in this study and lamb growth performance on brassica dominant cover crop was higher during this period than later in the study. The concentration of SMCO in our brassica dominant pastures although not tested, may have been lower than the concentration needed to impact health. Whole turnip plants and forage rape have been reported to have SMCO concentrations of 9.36 mg/kg DM and 7.52 mg/kg DM, respectively(Sun et al., 2012). Both species were major components of our cover crop diets and therefore we speculate that the SMCO concentration of our treatments may have been lower than the proposed threshold (10 g/100 kg) reported to cause disturbance in erythrocytes (Smith, 1978; Sun et al., 2012).

Lambs reared on brassica cover crop finishing systems in the present study produced acceptable market size and carcass grade but would have required more time to reach the same weight as grain fed lambs which was also observed by Koch et al. (2002). Lambs on grain diets require less time to finish as their diets are greater in energy as has been seen in the present study and in the literature (Koch et al., 2002; Mustafa et al., 2008). Lambs on an exclusive grain diet exhibited a higher carcass quality grade than the other treatments (Choice^{+}); however, all lambs graded (Choice^{-}) or higher indicating an acceptable quality grade.

Lamb carcasses were evaluated to see how brassica diets influenced carcass quality and composition. Interestingly, dressing percent did not differ for BRO, MIX or, GRN (52% for all) but was lower in BKG (51%). This differs from many studies which have found that animals on grain diets have greater dressing percentage compared to those finished on pasture (Koch et al., 2002; Kitessa et al., 2010). Our results agree with a similar study by Ponnampalam et al. (2019) who observed no difference in carcass yield between lambs fed camelina forage and those receiving a grain diet. Dressing percentage tends to decrease on diets that create greater gut fill and a lower rate of digesta passage (Warmington and Kirton, 1990). The grain fed lambs in the present study had greater carcass fat than that of the pasture fed lambs, yet they did not have a greater dressing percentage. This suggests that the pasture fed lambs had lower gut fill and/or lower rate of passage to compensate for their lack of carcass fat relative to grain fed lambs leading to a similar dressing percentage. Brassica forage is highly digestible Sun et al. (2012), and the brassica content of both pasture diets was relatively high suggesting that this diet might have had a rate of passage comparable to the grain fed lambs. Therefore, we speculate that lack of difference observed in dressing percentage of the leaner pasture fed lambs was explained by lower gut ingesta content compared to grass-fed diets at the conclusion of the study relative to that of the grain fed lambs.

The growth and efficiency of gain of lambs on exclusive grain (GRN) and partial grain following brassica cover crop (BKG) finishing systems revealed that lambs grew faster on grain following a background period grazing a pure brassica seeding. The BKG lambs also had greater feed efficiency with an FCR of 4.6 compared to that of 6.0 for lambs on an exclusive grain diet (GRN) near the end of their finishing period. Lambs placed in a rearing program with a diet that creates a slow growth phase, such as pasture, followed by a high energy diet can show increased gains and feed efficiency known as compensatory growth when compared to lambs fed continuously on a high energy diet (Turgeon et al., 1986; Kabbali et al., 1992). As predicted, lambs on GRN decreased in feed efficiency from an FCR of 5.3 kg/kg for the first 28 days of treatment to an FCR of 6.0 in the last 14 d of treatment. This is likely explained by the changes in the composition of gain near the end of the finishing period due to greater relative fat accretion as the lambs increase in maturity. This result was similar to that observed by Mustafa et al. (2008) who recorded a FCR of 5.3 kg/kg in lambs on grain. A reason for the increase in FCR is that as animals mature, they become less efficient with their growth rate as their composition of gain changes to a much higher proportion of energy-dense fat (Butterfield et al., 1988). Lambs on the exclusive or partial grain rearing systems in this study achieved between 73 and 75% of mature size (80 kg maternal mature size for this genotype). A common target for slaughter of lambs to achieve a YG of 2 is 70% of maternal mature size (Bradford, 2002) indicating that although our lambs slightly exceeded this target, they remained relatively efficient in growth and were not overly fat, yielding an average YG of 2.3.

Further insight into the growth biology of lambs on cover crop and grain diets in the present study was gained by evaluating plasma metabolites. The plasma glucose concentration of lambs on MIX (79 mg/dL) was slightly higher then GRN (73 mg/dL), BRO (74 mg/dL), and BKG (74 mg/dL) during treatment. Lambs on grain diets, GRN (76 to 71 mg/dL) and BKG (78 to 71 mg/dL), showed reduced plasma glucose concentration compared to those on cover crop diets (BRO and MIX), over time. It was somewhat surprising to observe that plasma glucose was slightly elevated in lambs finished on MIX as these lambs clearly would not have consumed as much energy as lambs on the grain treatments. Plasma glucose, on the other hand, is tightly controlled within a narrow homeostatic range and the relatively small changes in plasma glucose concentration observed in this study are not necessarily indicative of altered whole-body glucose utilization or tissue uptake (Bell et al., 1987), which may have been present.

Lambs fed grain exhibited depressed NEFA (100 nEq/L) compared to lambs grazing cover crop (MIX 180 nEq/L, and BRO 137 nEq/L) throughout the trial. When BKG lambs were switched from cover crop grazing to grain feeding, plasma NEFA dropped from 162 nEq/L to 101 nEq/dL. The increased levels of NEFA in pasture diets can be associated with negative energy balance periods (Chilliard et al., 2000). This was not the case in present study as lambs continued to gain weight on pasture diets albeit at a slower rate than on grain diets. Instead, it is likely that the increase in NEFA observed in the present study in grazing lambs is related to lesser degree of positive energy balance in these lambs relative to that of the grain-fed lambs. The NEFA levels of BRO compared to MIX and GRN were intermediary suggesting lambs on BRO diet had greater energy intake than lambs on MIX but not quite as much as lambs on GRN. This matches with our estimates of forage TDN indicating that TDN concentration in BRO were slightly higher than in MIX but both pasture diets were considerably lower in TDN than grain diets. Changes in NEFA are a sensitive indicator of energy balance (Chilliard et al., 2000) and likely reflect this is as further supported in the present study by the greater carcass fat content found in grain-finished compared to brassica cover crop-finished lambs.

Concentrations of PUN during the 8-wk period were consistently lower in lambs grazing pure brassica seeded cover crop (1.9 mg/dL) than those grazing cover crop with lower brassica content (2.8 mg/dL) or grain (2.7 mg/dL). Furthermore, when lambs in BKG treatment transitioned from a pure brassica seeded cover crop to a grain diet there was a change in PUN concentration from 1.9 ng/mL to 2.5 ng/mL. Greater CP concentration in diets is associated with elevated PUN concentration in animals (Pfander et al., 1975). Therefore, the higher plasma concentration of PUN in MIX and grain diets suggest increased dietary protein utilization compared to strictly brassica diets as has been postulated by others (Cox-Ganser et al., 1994; Mceachern et al., 2009; Whitney et al., 2009). However, the CP concentration of our pure brassica seeded cover crop diets (BKG 136 g/kg and BRO 127 g/kg) were similar to that found on the MIX pasture (135 g/kg) or the GRN diet (144 g/kg) and growth performance of lambs on our cover crop diets did not differ. Cassida (1992) suggested that brassica diets with fiber added as hay or weeds might experience increased dietary protein utilization rates compared to pure brassica diets. The results observed by Cassida (1992) suggest a perturbation of protein absorption or metabolism unique to consumption of a high level of brassica forage, as protein intake is predicted to be similar. It has been postulated that protein absorption in the gut may be suppressed in brassica dominant diets due to SMCO blocking protein absorption with formation of sulfhydryl groups on protein molecules in the rumen (Barry et al., 1985; Barry, 2013). As discussed earlier, SMCO has been suggested to cause health-related issues reducing animal growth. We observed however that lambs grazed on pure brassica seeded cover crop grew as well as lambs on our cover crop mixture with less brassica content and did not have signs of anemia which is associated with diets high in SMCO. Further study is needed to determine if the depressed PUN observed in pure brassica seeded cover crop is due to a perturbation of catabolic or anabolic protein metabolism.

Samples of loin chops were evaluated for various aspects of meat quality in the present study including measures of tenderness, color, and chemical composition. The intramuscular fat (IMF) content of lamb loins did not differ by treatment (3.9-4.2%). IMF values in lamb range from 1-10% depending on age, sex and diet (Frank et al., 2016; Realini et al., 2021); however consumer preference is highest for lamb with IMF at 4% with lower acceptance when IMF is above or low this value (Realini et al., 2021). Although our lamb rearing treatments did not alter IMF, we did observe increased carcass fat deposition in subcutaneous (SQ) fat depots (BWD and 12th rib fat depth) in lambs fed grain compared to those grazing cover crops. The increased in SQ fat deposition observed is consistent with the predicted differences of energy intake of the lambs in this study with grain fed lambs exceeding that of lambs grazing cover crops. The plane of nutrition of lambs on cover crop was adequate to provide a level of fat deposition that allowed the lambs to reach a YG of (1.9-2.0) and quality grade of Choice. This is consistent with that observed by others (Mahgoub et al., 2000; Ekiz et al., 2013; Watkins et al., 2013) who observed greater carcass fat content in lambs fed grain or other high energy diets compared to lower energy pasture diets. Although we did not observe a difference in IMF in our study lambs, we did find that cover crop finished lambs had a greater protein concentration in loin muscle compared to grain-fed lambs.

This result agrees with the literature indicating that grain diets tend to produce meat with a lower proportion of protein due to a higher proportion of fat (Phelps et al., 2018)

Physical measure of tenderness using Warner-Brazler shear force revealed no impact of dietary treatment. This is consistent with reports indicating that lambs grazing brassica-based cover crop were as tender as lambs on grass pasture (Hopkins et al., 1995; Frank et al., 2016). However, the finding that lamb meat raised on forage diets were as tender as grain-diet lambs differs from that reported by Priolo et al. (2002) who found that lambs on pasture were less tender than those fed grain in a feedlot. Dietary energy concentration can be a major factor in the tenderness of lamb since high energy diets lead to greater fat deposition. Okeudo and Moss (2007) found a negative association between intramuscular fat content (IMF) and shear force and cooking loss value. Our results on the measures of physical tenderness and consumer perception of tenderness were similar with one important exception. We found that lambs grazing brassica-based cover crop were found by a consumer panel to be more tender than all other treatments. This was not explained by IMF concentration as we found no difference between treatments in IMF and therefore is independent of this influence. Our findings differ from that found by Priolo et al. (2002) who observed that lambs raised on native pastures are less tender than those raised on grain in a feedlot. Unlike other reports (Priolo et al., 2002; Okeudo and Moss, 2007), the lambs raised on cover crop in the present study had high levels of intermuscular fat (IMF) that were not different than those found on grain finishing treatments (Realini et al., 2021). The high level of IMF noted in our brassica dominant cover crop finished lambs (3.9-4.1%) which were not different than our grain fed lambs (4.2%) indicates that the energy intake of brassica dominant cover crop finished lambs although lower than that of the grain fed lambs resulting in clear difference in SQ fat, was sufficient to allow a high rate of fat deposition in muscle resulting in high IMF content. The favored partitioning of fat to IMF instead of subcutaneous stores in our brassica dominant cover crop fed lambs resulted in superior meat quality as measured chemically or via consumer panel. Similarly, we found no difference in cooking loss between dietary treatments which is consistent with the finding that treatment did not impact IMF in our study. Hopkins et al. (1995) also found no difference in cooking loss between pasture diets that differed in brassica content.

Muscle collagen concentration was greater in cover crop fed and background lambs compared to GRN. The factor that these lambs had in common was exercise via grazing albeit for different periods of time relative to slaughter (a 4 week period, 4 weeks prior to slaughter for BKG, and for 8 weeks up to slaughter for both cover crop treatments). This difference in collagen concentration did not correlate however with muscle tenderness as measured by WBSF or by a consumer panel. This differs from that observed by Lepetit (2007) who found a positive association between in collagen concentration and physical measures of tenderness of lamb muscle. The lambs in the present study varied little in age and were relatively young at slaughter (6.0-6.5 mo. of age). We may have observed greater impacts of muscle collagen content on tenderness if the lambs were slaughtered at older ages which is common in the industry as it has been documented that collagen in muscle fibers becomes more insoluble leading to greater toughness as lambs age (Hill, 1966; Sanudo et al., 1998; Lepetit, 2007).

In the present study, GRN lambs had significantly lower a* and greater L* than in the other dietary treatments. Khliji et al. (2010) found that consumers find lamb to be acceptable when redness is greater than 21.7. In the present study all, dietary treatments yielded acceptable levels of redness for consumers (GRN: 21.6, BKG: 23.3, BRO: 24.0, MIX: 23.1). Brassica based cover crop diets have been shown to produce greater redness than feedlot diets possibly due to the greater exercise animals experience in grazing compared to in a feedlot environment (Gao et al., 2014).

Aalhus and Price (1990) found that exercising lambs can reduce lamb oxygen consumption rate (OCR) over time, thus potentially decreasing the oxidation rate of meat resulting in a greater degree of redness. Brassica grazing diets have also been shown to have a lower degree of redness in meat compared to lambs grazing ryegrass (Frank et al., 2016). We did not observe a difference however in redness in our brassica dominant cover crop treatments that differed in brassica content. The lightness of lamb meat is positively associated with fat as observed by Priolo et al. (2002). We observed greater lightness in the grain fed lambs however they did not have greater fat compared to the other treatments (GRN: 30.0, BKG: 27.3, BRO: 25.2, MIX: 26.2). This suggests that fat content does not explain greater lightness in grain fed lambs in our study. Frank et al. (2016) also observed no difference in lightness of meat color in lambs grazing brassica-based cover crops that differed in brassica content as was found in the present study. Young et al. (1997) found that brassica-based cover crop finished lambs had darker color and also higher pH due to lower muscle glycogen content. We did not observe differences in muscle pH according to treatment in the present study suggesting that the observed color differences were not due to alteration in muscle glycogen content. Priolo et al. (2002) observed that different diets produce different volatile fatty acid (VFA) ratios in ruminants which influences myoglobin conversion in meat thus influencing overall color. We speculate that this may be the basis for some of the differences we observed in meat color in the present study. There was no difference between treatment in b* of loin chops in the present study. Others have also found little variation in b* when comparing lambs grazing perennial ryegrass versus chicory pastures (Ye et al., 2020) and when comparing lambs on pasture diets to those fed grain in a feedlot (Priolo et al., 2002).

Sensory evaluation of loin chops by a consumer panel revealed that juiciness was found to be superior in lambs on grazing a pure brassica seeded cover crop compared to all other treatments.

This is consistent with the findings of others who have shown that lambs grazing annual brassica-based cover crops had meat considered juicer, to be more flavorful, to be more tender and have a greater overall liking than lambs grazing perennial pasture (Hopkins et al. 1995; Frank et al. 2016) or other annual pastures (Park et al., 1972). It has also been found that lambs on pasture are reported by sensory panels to be more flavorful than lambs on grain (Duckett and Kuber, 2001). These treatment differences occurred with lambs grazing for 8 weeks which is a shorter time period than observed by Wheeler et al. (1974) who grazed lambs for 4 months. Others have noted that meat from lambs grazing brassicas is more intense in flavor than found in lambs grazing perennial ryegrass pasture (Park et al., 1972; Watkins et al., 2013; Frank et al., 2016). We did not observe a difference in consumer perception of flavor between pasture diets differing in brassica content in the present study. This may be because the brassica content did not vary enough to impart flavor changes. We did observe however that the liking of the flavor of lambs finished on a pure brassica cover crop seeding was superior in liking to those raised exclusively on grain. This contrasts with that suggested by Watkins et al. (2013) who indicated that consumers in the United States would be predicted to favor grain-fed over pasture finished lambs as grain-fed lambs are the most commonly raised type in the U.S. The liking of flavor in the current study also contrasts with literature that suggests that lambs raised on brassica monocultures produce a flavor undesirable to consumers (Watkins et al., 2013; Frank et al., 2016). A possible explanation for the superior overall liking of lambs grazed on our pure brassica seeding is that our consumers are frequent consumers of lamb who prefer a stronger lamb flavor which may be associated with pasture reared as compared to grain reared lamb. The panelists in the current study were frequent consumers of lamb (every two to four weeks) and appeared to have consumption habits similar to those described for the non-traditional lamb market consumers in the US who also consume lamb more frequently that typical US consumers. ((Shiflett et al. 2010). Our consumer panelists shared consumption patterns with that described for the non-traditional lamb consumer and like non-traditional consumers they also favored lamb that had lower carcass fat size than found in our grain treatments. Despite these similarities, we do not have enough information to determine if our panelists were indeed those described as non-traditional consumers. We do know however that they consumed lamb relatively frequently which differs from that of the majority of U.S. consumers, and that they showed a preference for smaller, leaner lamb raised on a pure brassica seeded cover crop. Further research is needed to determine if the typical U.S. consumer who are less familiar with lamb, would also favor lamb raised on a brassica over that raised on grain diet.

Correlation coefficients were used to understand the relationship between chemical composition of lamb chops and consumer perception of their flavor, juiciness, and overall acceptability. Flavor and overall liking were positively correlated. This agrees with others who have concluded that flavor is one of the major drivers of consumer acceptability in lamb (Phelps et al., 2018). Lamb IMF concentration was negatively correlated with tenderness and overall acceptability in the present study. This differs from that found by others (Priolo et al., 2002; Okeudo and Moss, 2007; McPhee et al., 2008; Ye et al., 2020) who demonstrated that IMF concentration was positively correlated with eating quality and other measures of acceptability including tenderness.

CONCLUSION

The present study indicated that brassica-based cover crops as pure seedings or as brassica-dominant seed mixtures with grasses and legumes provide enough biomass from October to December to provide viable options as a finishing or a backgrounding rearing system for lambs in southern Michigan. Forage intake and quality were sufficient to allow adequate fat deposition in 8 weeks of grazing to achieve the industry standard target (yield grade 2 carcasses). Furthermore, meat quality, as measured chemically or as perceived by a consumer panel, was high with loin chops from lambs grazing pure brassica seedings being preferred over those fed grain. This was unexpected and is opposite of what the literature suggests which is a preference for grain-finished over pasture finished lambs and for lambs finished on forages of higher fiber concentration over that found in pure brassica seedings (Park et al., 1972; Wheeler et al., 1974; Priolo et al., 2002; Frank et al., 2016). The preference for lambs grazing pure brassica seedings in meat flavor was an unexpected result as past research has suggested that the strong flavor produced in lambs grazing brassica is not desirable (Watkins et al., 2013; Frank et al., 2016). Further work is needed to verify these findings and establish the underlying basis for these results. Lambs reared on brassica dominant cover crop pastures were leaner than those reared on grain diets, however IMF content of longissimus dorsi did not differ between treatments at 4% which is considered optimal for eating quality. This has implications for lamb finishing in general suggesting that eating quality of lamb can be optimized without excessive carcass fatness when lambs are finished on high quality forages.

There has been concern that livestock grazing pure brassica pastures may suffer poor growth performance due to low dietary fiber concentration, high concentration of plant secondary compounds, and cold conditions during fall and winter (Cote, 1944; Barry et al., 1971; Collett and Matthews, 2014). Our pure brassica-seeded pastures did have low fiber concentration (224-227 g/kg NDF) below what others, Lambert et al. (1987), have suggested can result in poor performance and health (NDF of 400 g/kg). Lambs on these low fiber pastures grew well however (147-216 g/d), and at the same level as our cover crop pasture treatment with higher fiber concentration (140-216 g/d). This has also been shown by others (Cassida et al. 1994) and suggests that the low level of fiber found in brassicas does not limit growth in grazing lambs.

Plant secondary compounds have also been a concern with certain brassica dominant pastures causing anemia and poor growth in sheep and cattle (Fales et al., 1987; Cox-Ganser et al., 1994). We found no evidence for this in our studies as PCV in all lambs was above the threshold indicated for anemia. We did note that lambs grazing our pure brassica-seeded cover crop had lower PUN concentration than all other treatments. However, this did not result in depressed growth as these lambs grew at the same rate as the lambs on our MIX cover crop treatment that had a lower brassica content. This suggests that the depression of PUN in the lambs grazing pure brassica seeding does not reflect lower protein utilization. More work is needed to determine if the lower PUN in lambs grazing pastures high in brassica content reflects alterations in protein metabolism. Collectively, our results suggest that the concern for poor health and low growth performance of lambs grazing high brassica content pastures is lower than that documented in cattle (Cote, 1944; Collett and Matthews, 2014).

Cold weather may be a limit to adoption of cover crop grazing into late fall and early winter especially if larger carcass size is desired. Cold weather increases animal maintenance needs which can be detrimental to weight gain (Barry et al., 1971). We found that weight gain of lambs on cover crop pastures expressed on an individual animal basis and on land area basis, declined the last 2 weeks of our study which was associated with a period of cold weather. We also observed that we could correct the growth deficit of lambs grazing cover crops by transitioning them to a grain diet for a short, 4 week finishing period. This allowed for greater and more efficient gains compared to lambs that were fed grain the entire study period. This indicates that the risk of poor growth in late fall on cover crop grazing can be effectively addressed by placing these lambs on a grain diet for a short period of time.

There is a need to optimize this grazing management system for both individual gains to allow for adequate muscle IMF content and for gain per unit land for total gain to realize its full profit potential. This can be achieved by investigating the impact of altering forage allowance on individual gain and gain per unit land. Consideration should also be given to alter allowance based on ambient temperature and grazing conditions (Barry et al., 1971).

Overall, we conclude that brassica cover crop finishing systems can expand grazing options to include row crop land that is not otherwise available for grazing. This increases options for inexpensive feeding of backgrounding or finishing lambs. In addition, cover crop grazing might provide benefits for the whole crop system; however, future work into cover crop grazing and its potential impacts on crop yields and soil health are needed to confirm this potential.

APPENDIX

Table 12. Sensory questions for consumer panelist and scale for assessment

Survey Question	Scale	Description
How much do you like or dislike this sample Overall?	0 - 100	Dislike Extremely – Like Extremely
How much do you like or dislike the Flavor?	0 - 100	Dislike Extremely – Like Extremely
The Juiciness is…?	0 - 100	Not Juicy – Extremely Juicy
The Tenderness is… ?	0 - 100	Not Tender – Extremely Tender
Is this sample acceptable overall	Choose one	YES / NO

[1] Survey question: consumers were asked questions about the loin chop as read.
[2] Scale: consumers were asked to measure the survey question either with a continuous line scale (0-100) or a binomial question.
[3] Description: For the scale of measurement the description was used to clarify what the scale represented.

Table 13. Demographic Characteristics of Panelists (n=105)[1].

Trait	All consumers, %
Age	
18-24	8.6
25-29	4.8
30-34	11.4
35-39	21.0
40-44	20.0
45-49	13.3
50-54	19.1
55-59	1.9
60+	0.0
Gender	
Male	37.1
Female	61.0
No Response	1.9
Employment	
Full-Time	63.8
Part-Time	11.4
Student	4.8
Homemaker	14.3
Unemployed	5.7
Other	0.0
Nationality	
U.S.A	96.2
Canada	1.9
Mexico/Central America	1.0
Favorite Meat	
Poultry	39.0
Beef	37.1
Pork	8.6
Lamb	1.9
Fish/Seafood	13.3

Table 13 (cont'd).

Trait	All consumers, %
Location Lamb is Consumed (Select all that apply)	
Home	70.9
School	1.0
Restaurants	81.9
Fast Food Restaurants	10.5
Social Events	10.5
Other	2.9
Frequency of Consumption	
Once a week or more	0.0
Every 2 to 3 weeks	20.0
Once a month	39.1
Once every 2-3 months	16.2
Once every 4-6 months	10.5
Once or twice a year	4.8
Less often than once a year	4.8
Preference for Fresh or Frozen Lamb	
Strongly Prefer Frozen Lamb	1.0
Moderately Prefer Frozen Lamb	0.0
Slightly Prefer Frozen Lamb	0.0
No Preference	38.1
Slightly Prefer Fresh Lamb	8.6
Moderately Prefer Fresh Lamb	25.7
Strongly Prefer Fresh Lamb	26.7

[1]Location: Grand Rapids, MI

REFERENCES

REFERENCES

Aalhus, J. L., and M. A. Price. 1990. The effects of endurance exercise on live animal performance and carcass growth and development in sheep. Canadian Journal of Animal Science. 70:97–105.

Anderson, S. 2007. Determination of fat, moisture, and protein in meat and meat products by using the FOSS Foodscan[tm] near-infrared spectrophotometer with FOSS artificial neural network calibration model and associated database: collaborative study. Journal of AOAC International . 90:1073–1083. doi:10.1093/jaoac/90.4.1073

Baggs, E. M., C. A. Watson, and & R. M. Rees. 2000. The fate of nitrogen from incorporated cover crop and green manure residues. Nutrient Cycling in Agroecosystems 56.2: 153-163.

Barry, T. N. 2013. The feeding value of forage brassica plants for grazing ruminant livestock. Animal Feed Science and Technology. 181:15–25. doi:10.1016/j.anifeedsci.2013.01.012

Barry, T. N., K. R. Drew, and S. J. Duncan. 1971. The digestion, voluntary intake, and utilisation of energy by Romney hoggets fed five winter forage crops. New Zealand Journal of Agricultural Research. 14:835–846.

Barry, T. N., T. R. Manley, C. Redekopp, and T. F. Allsop. 1985. Endocrine regulation of metabolism in sheep given kale (*Brassica oleracea*) and ryegrass (*Lolium perenne*) – clover (*Trifolium repens*) fresh-forage diets. British Journal of Nutrition. 54:165–173. doi:10.1079/bjn19850102

Barry, T. N., T. C. Reid, K. R. Millar, and W. A. Sadler. 1981. Nutritional evaluation of kale (*Brassica oleracea*) diets. Copper deficiency, thyroid function, and selenium status in young cattle and sheep fed kale for prolonged periods. The Journal of Agricultural Science. 96:269–282. doi:10.1017/S0021859600066041

Beermann, D. H., T. F. Robinson, and D. E. Hogue. 1995. Impact of composition manipulation on lean lamb production in the United States. J. Anim. Sci. 73:2493–2502.

Bell, A. W., D. E. Bauman, and W. B. Currie. 1987. Regulation of nutrient partitioning and metabolism during pre- and postnatal growth. J. Anim. Sci. 65:186–212. doi:10.1093/ansci/65.suppl_2.186

Berthiaume, R., I. Mandell, L. Faucitano, and C. Lafrenière. 2006. Comparison of alternative beef production systems based on forage finishing or grain-forage diets with or without growth promotants: 1. Feedlot performance, carcass quality, and production costs. J. Anim. Sci. 84:2168–2177. doi:10.2527/jas.2005-328

Blase, M. G., and C. Hesemann. 1973. Farmland prices: explainable or illogical? Southern Journal of Agricultural Economics. 265–270.

Bradford, g. 2002. Relationships amount traits: growth rate, mature size, carcass composition and reproduction. Sheep and Goat Research Journal. 17:38–41.

de Brito, G. F., E. N. Ponnampalam, and D. L. Hopkins. 2017. The effect of extensive feeding systems on growth rate, carcass traits, and meat quality of finishing lambs. Comprehensive Reviews in Food Science and Food Safety. 16:23–38. doi:10.1111/1541-4337.12230

Butterfield, R. M. 1988. New concepts of sheep growth. Dept. of Veterinary Anatomy, University of Sydney.

Cassida, K. A. 1992. Forage brassicas in sheep production systems in the northeastern U.S.A. PhD Diss. Univ. Maine, Orono.

Cassida, K. A., B. A. Barton, R. L. Hough, M. H. Wiedenhoeft, and K. Guillard. 1994. Feed intake and apparent digestibility of hay supplemented brassica diets of lambs. J. Anim. Sci. 72:1623–1629.

Cassida, K. A., B. A. Barton, R. L. Hough, M. H. Wiedenhoeft, and K. Guillard. 1995. Productivity and health of gestating ewes grazing tyfon pastures containing weeds. Journal of Sustainable Agriculture. 64:81–95.

Chaney, A. L., and E. P. Marbach. 1961. Modified reagents for determination of urea and ammonia. Clinical Chemistry. 8: 130-132.

Chen, G., and R. R. Weil. 2010. Penetration of cover crop roots through compacted soils. Plant and Soil. 331:31–43. doi:10.1007/s11104-009-0223-7

Chilliard, Y., A. Ferlay, Y. Faulconnier, M. Bonnet, J. Rouel, and F. Bocquier. 2000. Adipose tissue metabolism and its role in adaptations to undernutrition in ruminants. Proceedings of the Nutrition Society. 59:127–134.

Clark, A. 2007. Managing cover crops profitably. 3rd ed. Sustainable Agriculture Network. Beltsville, MD.

Collett, M. G., and Z. M. Matthews. 2014. Photosensitivity in cattle grazing *Brassica* crops. International Journal of Poisonous Plant Research. 3:6–21.

Cote, F. T. 1944. Rape poisoning in cattle. Canadian Journal of Comparative Medicine. 7:38–40.

Cox-Ganser, J. M., G. A. Jungt, R. T. Pushkin, and R. L. Reid. 1994. Evaluation of brassicas in grazing systems for sheep: . Blood composition and nutrient status. J. Anim. Sci. 72:1832–1841.

Dabney, S. M., J. A. Delgado, and D. W. Reeves. 2001. Using winter cover crops to improve soil and water quality. Communications in Soil Science and Plant Analysis 32.7-8: 1221-1250.

Derpsch, R., N. Sidiras, and C. H. Roth. 1986. Results of studies made from 1977 to 1984 to control erosion by cover crops and no-tillage techniques in Parana Brazil. Soil and Tillage Research. 8:253–263.

Doreau, M., H. M. G. van der Werf, D. Micol, H. Dubroeucq, J. Agabriel, Y. Rochette, and C. Martin. 2011. Enteric methane production and greenhouse gases balance of diets differing in concentrate in the fattening phase of a beef production system. J. Anim. Sci. 89:2518–2528. doi:10.2527/jas.2010-3140

Drewnoski, M., J. Parsons, H. Blanco, D. Redfearn, K. Hales, and J. MacDonald. 2018. Forages and pastures symposium: Cover crops in livestock production: Whole-system approach. Can cover crops pull double duty: Conservation and profitable forage production in the Midwestern United States? J. Anim. Sci. 96:3503–3512. doi:10.1093/jas/sky026

Duckett, S. K., and P. S. Kuber. 2001. Genetic and nutritional effects on lamb flavor. J. Anim. Sci. 79:249–254.

Ekiz, B., G. Demirel, A. Yilmaz, M. Ozcan, H. Yalcintan, O. Kocak, and A. Altinel. 2013. Slaughter characteristics, carcass quality and fatty acid composition of lambs under four different production systems. Small Ruminant Research. 114:26–34. doi:10.1016/j.smallrumres.2013.05.011

Enviroweather. 2021. Temperature, Rainfall and Degree Day summary. https://alpha.enviroweather.msu.edu/weathermodels/weathersummary (Accessed 1 August 2021).

de Faccio Carvalho, P. C., I. Anghinoni, A. de Moraes, E. D. de Souza, R. M. Sulc, C. R. Lang, J. P. C. Flores, M. L. Terra Lopes, J. L. S. da Silva, O. Conte, C. de Lima Wesp, R. Levien, R. S. Fontaneli, and C. Bayer. 2010. Managing grazing animals to achieve nutrient cycling and soil improvement in no-till integrated systems. Nutrient Cycling in Agroecosystems. 88:259–273. doi:10.1007/s10705-010-9360-x

Fales, S. L., D. L. Gustine, S. C. Bosworth, and R. J. Hoover. 1987. Concentrations of glucosinolates and s-methylcysteine sulfoxide in ensiled rape (*Brassica napus* L.). Journal of Dairy Science. 70:2402–2405. doi:10.3168/jds.S0022-0302(87)80301-6

Farouk, M. M., H. M. Al-Mazeedi, A. B. Sabow, A. E. D. Bekhit, K. D. Adeyemi, A. Q. Sazili, and A. Ghani. 2014. Halal and kosher slaughter methods and meat quality: A review. Meat Science. 98:505–519. doi:10.1016/j.meatsci.2014.05.021

Ferris, J. 2000. An analysis of the importance of agriculture and the food sector to the Michigan economy. East Lansing, MI.

Field, R. A., J. D. Crouse, G. Maiorano, R. J. Mccormick, M. L. Riley, W. C. Russell, and F. L. Williams. 1990. Effect of plane of nutrition and age on carcass maturity of sheep. J. Anim. Sci. 68:1616–1623.

Forbes, J. M. 1968. The water intake of ewes. British Journal of Nutrition. 22:33–43. doi:10.1079/bjn19680006

Frank, D., P. Watkins, A. Ball, R. Krishnamurthy, U. Piyasiri, J. Sewell, J. Ortuño, J. Stark, and R. Warner. 2016. Impact of brassica and lucerne finishing feeds and intramuscular fat on lamb eating quality and flavor. A cross-cultural study using Chinese and non-Chinese Australian consumers. Journal of Agricultural and Food Chemistry. 64:6856–6868. doi:10.1021/acs.jafc.6b02018

Gao, X., Z. Wang, J. Miao, L. Xie, Y. Dai, X. Li, Y. Chen, H. Luo, and R. Dai. 2014. Influence of different production strategies on the stability of color, oxygen consumption and metmyoglobin reducing activity of meat from Ningxia Tan sheep. Meat Science. 96:769–774. doi:10.1016/j.meatsci.2013.09.026

Gaspar, P., M. Escribano, F. J. Mesías, A. R. de Ledesma, and F. Pulido. 2008. Sheep farms in the Spanish rangelands (dehesas): Typologies according to livestock management and economic indicators. Small Ruminant Research. 74:52–63. doi:10.1016/j.smallrumres. 2007.03.013

Germano Costa, R., J. Teodorico De Araújo Filho, W. Hauss De Sousa, S. G. Neto, M. S. Madruga, and A. B. Fraga. 2010. Effect of diet and genotype on carcass characteristics of feedlot hair sheep. Revista Brasileira de Zootecnia. 39:2763–2768. doi: 10.1590/S1516-35982010001200029

Guillard, K., and D. W. Allinson. 1988. Yield and nutrient content of summer- and fall-grown forage brassica crops. Canada Journal of Plant Science. 68:721–731.

Guillard, K., S. W. Pietrzyk, K. A. Cassida, M. H. Wiedenhoeft, R. L. Hough, B. A. Barton, and D. W. Allinson. 1995. Seasonal nitrogen and carbohydrate partitioning in forage brassicas. Agronomy Journal. 87:562–569.

Heady, E. 1971. Optimal Sizes of farms under varying tenure forms, including renting, ownership, state, and collective structures. American Journal of Agricultural Economics. 53.1:17–25.

Heitstuman, M. D. 2020. “Meating” the grade: raising market-ready youth lamb projects. Washington State University, Pullman.

Hill, F. 1966. The solubility of intramuscular collagen in meat animals of various ages. Journal of Food Science 31.2: 161-166.

Hopkins, D. L., A. S. Beattie, and K. L. Pirlot. 1995. Meat quality, carcass fatness, and growth of short scrotum lambs grazing either forage rape or irrigated perennial pasture. Australian Journal of Experimental Agriculture. 35:453–459.

Hopkins, D. L., D. G. Hall, H. A. Channon, and P. J. Holst. 2001. Meat quality of mixed sex lambs grazing pasture and supplemented with, roughage, oats or oats and sunflower meal. Meat Science. 59:277–283.

Hopkins, D. L., D. F. Stanley, L. C. Martin, E. S. Toohey, and A. R. Gilmour. 2007. Genotype and age effects on sheep meat production 3. Meat quality. Australian Journal of Experimental Agriculture. 47:1155–1164. doi:10.1071/EA06299

Hunt, J. R., A. D. Swan, N. A. Fettell, P. D. Breust, I. D. Menz, M. B. Peoples, and J. A. Kirkegaard. 2016. Sheep grazing on crop residues do not reduce crop yields in no-till, controlled traffic farming systems in an equi-seasonal rainfall environment. Field Crops Research. 196:22–32. doi:10.1016/j.fcr.2016.05.012

Jenkins, T. G., and K. A. Leymaster. 1993. Estimates of maturing rates and masses at maturity for body components of sheep. J. Anim. Sci. 71:2952–2957.

Jones, K. 2004. Trends in the U.S. Sheep Industry. United States Department of Agriculture, US.

Kabbali, A., W. L. Johnson, D. W. Johnson, R. D. Goodrich, and C. E. Allen. 1992. Effects of compensatory growth on some body component weights and on carcass and noncarcass composition of growing lambs. J. Anim. Sci. 70:2852–2858.

Khliji, S., R. van de Ven, T. A. Lamb, M. Lanza, and D. L. Hopkins. 2010. Relationship between consumer ranking of lamb colour and objective measures of colour. Meat Science. 85:224–229. doi:10.1016/j.meatsci.2010.01.002

Kitessa, S., S. Liu, J. Briegel, D. Pethick, G. Gardner, M. Ferguson, P. Allingham, G. Nattrass, M. McDonagh, E. Ponnampalam, and D. Hopkins. 2010. Effects of intensive or pasture finishing in spring and linseed supplementation in autumn on the omega-3 content of lamb meat and its carcass distribution. Animal Production Science. 50:130–137. doi:10.1071/AN09095

Knudson, W. 2018. The Economic Impact of Michigan's Food and Agriculture System: Working Paper. 1-21.

Koch, D. W., F. C. Ernst, N. R. Leonard, R. R. Hedberg, T. J. Blenk, and J. R. Mitchell. 1987. Lamb Performance on Extended-Season Grazing of Tyfon. J. Anim. Sci. 64:1275–1279.

Koch, D. W., C. Kercher, R. Jones, S. J. Falck, G. E. Carstens, and D. F. Waldron. 2002. Fall and winter grazing of brassicas a value-added opportunity for lamb producers. Sheep and Goat Research Journal. 17:1–13.

Krause, A. D., H. A. Lardner, J. J. McKinnon, S. Hendrick, K. Larson, and D. Damiran. 2013. Comparison of grazing oat and pea crop residue versus feeding grass-legume hay on beef-cow performance, reproductive efficiency, and system cost. The Professional Animal Scientist. 29:535–545. doi:10.15232/S1080-7446(15)30275-8

Kremer, R., G. Barbato, L. Castro, L. Rista, L. Rosés, V. Herrera, and V. Neirotti. 2004. Effect of sire breed, year, sex, and weight on carcass characteristics of lambs. Small Ruminant Research. 53:117–124. doi:10.1016/j.smallrumres.2003.09.002.

Kruidhof, H. M., L. Bastiaans, and M. J. Kropff. 2008. Ecological weed management by cover cropping: effects on weed growth in autumn and weed establishment in spring. Wageningen. doi:10.1111/j.1365-3180.2008.00665.x

Lal, R. 2001. Soil degradation by erosion. Land Degradation and Development. 12:519–539. doi:10.1002/ldr.472

Lambert, M. G., S. M. Abrams, H. W. Harpster, and G. A. Jung. 1987. Effect of hay substitution on intake and digestibility of forage rape (*brassica napus*) fed to lambs. J. Anim. Sci. 65:1639–1646.

Lepetit, J. 2007. A theoretical approach of the relationships between collagen content, collagen cross-links and meat tenderness. Meat Science. 76:147–159. doi:10.1016/j.meatsci.2006.10.027

Lettat, A., P. Nozière, M. Silberberg, D. P. Morgavi, C. Berger, and C. Martin. 2010. Experimental feed induction of ruminal lactic, propionic, or butyric acidosis in sheep. J. Anim. Sci. 88:3041–3046. doi:10.2527/jas.2010-2926

Mahgoub, O., C. D. Lu, and R. J. Early. 2000. Effects of dietary energy density on feed intake, body weight gain and carcass chemical composition of Omani growing lambs. Small Ruminant Research. 37:35–42.

Mceachern, J. K., T. R. Whitney, C. B. Scott, C. J. Lupton, and M. W. Salisbury. 2009. Substituting distillers dried grains for cottonseed meal in lamb-finishing diets: growth, wool characteristics, and serum NEFA, urea N, and IGF-1 concentrations 1. Sheep & Goat Research Journal. 24:32–40.

McPhee, M. J., D. L. Hopkins, and D. W. Pethick. 2008. Intramuscular fat levels in sheep muscle during growth. Australian Journal of Experimental Agriculture. Vol. 48. p. 904–909. doi: 10.1071/EA08046

Morton, T. A., J. S. Bergtold, and A. J. Price. 2006. The economics of cover crop biomass for corn and cotton. Southern Conservation Systems Conference. Amarillo. 69–76.

Mustafa, M. I., J. P. Chadwick, P. Akhtar, S. Ali, M. Lateef, and J. I. Sultan. 2008. The effect of concentrate-and silage-based finishing diets on the growth performance and carcass characteristics of Suffolk cross and Scottish Blackface lambs. Journal of Veterinary Animal Science. 32:191–197.

Okeudo, N. J., and B. W. Moss. 2007. Intramuscular lipid and fatty acid profile of sheep comprising four sex-types and seven slaughter weights produced following commercial procedure. Meat Science. 76:195–200. doi:10.1016/j.meatsci.2006.08.017

Okeudo, N. J., and B. W. Moss. 2008. Production performance and meat quality characteristics of sheep comprising four sex-types over a range of slaughter weights produced following commercial practice. Meat Science. 80:522–528. doi:10.1016/j.meatsci.2008.02.003

Park, R. J., R. A. Spurway, and J. L. Wheeler. 1972. Flavour differences in meat from sheep grazed on pasture or winter forage crops. The Journal of Agricultural Science. 78:53–56. doi:10.1017/S0021859600087682

Pfander, W. H., S. E. Grebing, C. M. Price, O. Lewis, J. M. Asplund, and C. v Ross. 1975. Use of plasma urea nitrogen to vary protein allowances of lambs. J. Anim. Sci. 41:647–653.

Phelps, M. R., A. J. Garmyn, J. C. Brooks, J. N. Martin, C. C. Carr, J. A. Campbell, A. G. McKeith, and M. F. Miller. 2018. Consumer assessment of lamb loin and leg from Australia, New Zealand, and United States. Meat and Muscle Biology. 2:64–74. doi:10.22175/mmb2017.10.0051

Ponnampalam, E. N., M. G. Kerr, K. L. Butler, J. J. Cottrell, F. R. Dunshea, and J. L. Jacobs. 2019. Filling the out of season gaps for lamb and hogget production: Diet and genetic influence on carcass yield, carcass composition and retail value of meat. Meat Science. 148:156–163. doi:10.1016/j.meatsci.2018.08.027

Priolo, A., D. Micol, J. Agabriel, S. Prache, and E. Dransfield. 2002. Effect of grass or concentrate feeding systems on lamb carcass and meat quality. Meat Science. 62:179–185.

Realini, C. E., E. Pavan, P. L. Johnson, M. Font-i-Furnols, N. Jacob, M. Agnew, C. R. Craigie, and C. D. Moon. 2021. Consumer liking of M. longissimus lumborum from New Zealand pasture-finished lamb is influenced by intramuscular fat. Meat Science. 173. doi:10.1016/j.meatsci.2020.108380

Recktenwald, E. B., and R. A. Ehrhardt. 2018. Dynamics and Preferences within the Greater Detroit Metro Non-traditional Lamb Market.

Redden, R., E. Sanko, R. Ehrhardt, and C. Hiemke. 2020. Seasonality of the U.S. Lamb Industry A Review of Current Information. Denver.

Reid, R. L., J. R. Puoli, G. A. Jungf, J. M. Cox-Ganser, and A. Mccoy. 1994. Evaluation of Brassicas in Grazing Systems for Sheep: I. Quality of Forage and Animal Performance I. J. Anim. Sci. 72:1823–1831.

Rodríguez, V. M., P. Soengas, V. Alonso-Villaverde, T. Sotelo, M. E. Cartea, and P. Velasco. 2015. Effect of temperature stress on the early vegetative development of *Brassica oleracea* L. BMC Plant Biology. 15:145. doi:10.1186/s12870-015-0535-0

Ruffo, M. L., D. G. Bullock, and G. A. Bollero. 2004. Cropping systems soybean yield as affected by biomass and nitrogen uptake of cereal rye in winter cover crop rotations. Agronomy Journal. 96:800–805.

Salcedo, A., and R. García Trujillo. 2006. Sheep production systems in the north of Granada province. Case studies. Options Méditerranéennes, Série A. 70:101–109.

Sanudo, C., A. Sanchez, and M. Alfonso. 1998. Small ruminant production systems and factors affecting lamb meat quality. Meat Science. 49:29-64.

Schipanski, M. E., M. Barbercheck, M. R. Douglas, D. M. Finney, K. Haider, J. P. Kaye, A. R. Kemanian, D. A. Mortensen, M. R. Ryan, J. Tooker, and C. White. 2014. A framework for evaluating ecosystem services provided by cover crops in agroecosystems. Agricultural Systems. 125:12–22. doi:10.1016/j.agsy.2013.11.004

Schomberg, H. H., D. S. Fisher, D. W. Reeves, D. M. Endale, R. L. Raper, K. S. U. Jayaratne, G. R. Gamble, and M. B. Jenkins. 2014. Grazing winter rye cover crop in a cotton no-till system: Yield and economics. Agronomy Journal. 106:1041–1050. doi:10.2134/agronj13.0434

Schroeder, T. C., R. J. Jerrick, R. Jones, and C. Spaeth. 2001. U.S. Lamb Demand. Sheep and Goat Research Journal.17:14-19.

Shiflett, J. S., G. Williams, and P. Rodgers. 2010. Nontraditional lamb market in the United States: characteristics and marketing strategies American Sheep Industry Association., Pennsylvania TX.

Smith, R. H. 1978. S-methylcysteine sulpoxide, the brassica anaemia factor (a valuable dietary factor for man?). Veterinary Science Communications. 2:47–61.

Snapp, S. S., S. M. Swinton, R. Labarta, D. Mutch, J. R. Black, R. Leep, J. Nyiraneza, and K. O'neil. 2003. Evaluating cover crops for benefits, costs, and performance within cropping system niches. Agronomy Journal. 97.1:322-332.

Sulc, R. M., and B. F. Tracy. 2007. Integrated crop-livestock systems in the U.S. corn belt. Agronomy Journal. 99:335–345. doi: 10.2134/agronj2006.0086

Sun, X. Z., G. C. Waghorn, S. O. Hoskin, S. J. Harrison, S. Muetzel, and D. Pacheco. 2012. Methane emissions from sheep fed fresh brassicas (*Brassica* spp.) compared to perennial ryegrass (*Lolium perenne*). Animal Feed Science and Technology. 176:107–116. doi:10.1016/j.anifeedsci.2012.07.013

Taylor, C. S., J. I. Murray, and M. L. Thonney. 1989. Breed and sex differences among equally mature sheep and goats 4. Carcass muscle, fat, and bone. Animal Science. 49. doi:10.1017/S0003356100032608

Thonney, M. L., S. C. S. Taylor, J. I. Murray, and T. H. McClelland. 1987. Breed and sex differences in equally mature sheep and goats 2. Body components at slaughter. Animal Science. 45. doi:10.1017/S0003356100018845

Turgeon, O. A., D. R. Brink, S. J. Bartle, T. J. Klopfenstein, and C. L. Ferrell. 1986. Effects of growth rate and compensatory growth on body composition in lambs. Journal Animal Science. 63.3:770–780.

Undersander, D., J. E. Moore, and N. Schneider. 2002. Relative forage quality. Focus on Forage. 4.5:1–3.

United States Census Bureau. 2018. United States Census.

United States Department of Agriculture Agricultural Marketing Service Livestock and Seed Division United States Standards for Grades of Lamb, Yearling Mutton, and Mutton Carcasses. 1992. https://www.ams.usda.gov/sites/default/files/media/Lamb%2C_Yearling_Mutton_and_Mutton_Standard%5B1%5D.pdf (Accessed 1 August 2021.)

United States Department of Agriculture. 2020. Livestock Slaughter: 2019 Summary. https://downloads.usda.library.cornell.edu/usda-esmis/files/r207tp32d/34850245n/5712mr72x/lsan0420.pdf (Accessed 1 August 2020.)

National Oceanic and Atmospheric Administration. 2021. US Climate Normals. https://www.ncei.noaa.gov/products/land-based-station/us-climate-normals (Accessed 1 August 2021.)

Warmington, B. .G., and A. H. Kirton. 1990. Genetic and non-genetic influences on growth and carcass traits of goats. Small Ruminant Research. 3:147–165.

Warren, S. D., M. B. Nevill, W. H. Blackburn, and N. E. Garza. 1986. Soil response to trampling under intensive rotation grazing. Soil Science Society of America Journal. 50:1336–1341.

Watkins, P. J., D. Frank, T. K. Singh, O. A. Young, and R. D. Warner. 2013. Sheepmeat flavor and the effect of different feeding systems: A review. Journal of Agricultural and Food Chemistry. 61:3561–3579. doi:10.1021/jf303768e

Westwood, C. T., and H. Mulcock. 2012. Nutritional evaluation of five species of forage brassica. Proceedings of the New Zealand Grassland Association. 74:31–38. doi: 10.33584/jnzg.2012.74.2881

Wheeler, J. L., R. J. Park, R. A. Spurway, and A. L. Ford. 1974. Variation in the effects of forage rape on meat flavour in sheep. The Journal of Agricultural Science. 83:569–571. doi:10.1017/S0021859600027088.

White, C. M., and R. R. Weil. 2011. Forage radish cover crops increase soil test phosphorus surrounding radish taproot holes. Soil Science Society of America Journal. 75:121–130. doi:10.2136/sssaj2010.0095

Whitney, T. R., D. F. Waldron, and T. D. Willingham. 2009. Evaluating nutritional status of Dorper and Rambouillet ewes in range sheep production. Sheep & Goat Research Journal. 24:10–16.

Ye, Y., N. M. Schreurs, P. L. Johnson, R. A. Corner-Thomas, M. P. Agnew, P. Silcock, G. T. Eyres, G. Maclennan, and C. E. Realini. 2020. Carcass characteristics and meat quality of commercial lambs reared in different forage systems. Livestock Science. 232. doi:10.1016/j.livsci.2019.103908

Young, A., J.-L. Berdaguc, C. Vialloqb, S. Rousset-Akrimb, and M. Theriezb. 1997. Fat-borne volatiles and sheepmeat odour. Meat Science. 45:183–200.

Zajac, A. Z., and G. A. Conboy. 2021. Veterinary Clinical Parasitology. 8th ed. John Wiley & Sons. New York City, NY.