

# Effect of Starch Source in Concentrate Diets and of Days on Feed on Growth Performance, Carcass Characteristics, Meat Quality, and Economic Return of Feedlot Steers

**Anchalee Khongpradit**

Kasetsart University Kamphaeng Saen Campus

**Phoompong Boonsaen**

Kasetsart University Kamphaeng Saen Campus

**Nitipong Homwong**

Kasetsart University Kamphaeng Saen Campus

**Keiji Matsuba**

Hokkaido University Graduate School of Medicine School of Medicine: Hokkaido Daigaku Daigakuin Igaku Kenkyuin

**Yasuo Kobayashi**

Hokkaido University School of Agriculture Graduate School of Agriculture Research Faculty of Agriculture: Hokkaido Daigaku Nogakubu Daigakuin Nogaku Kenkyuin Nogakuin

**Suriya Sawanon** (✉ [agsusa@ku.ac.th](mailto:agsusa@ku.ac.th))

Kasetsart University <https://orcid.org/0000-0002-1173-3547>

---

## Research Article

**Keywords:** pineapple stem starch, starch sources, feedlot steer, carcass, meat, economic return

**Posted Date:** June 28th, 2021

**DOI:** <https://doi.org/10.21203/rs.3.rs-557272/v1>

**License:**   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

---

# Abstract

The effects of PS were determined as a concentrate added to feed and of the days it was short-term and long-term fed to fattening dairy steers on their growth performance, carcass characteristics, meat quality, and economic return. The experimental units comprised 36 feedlot dairy steers arranged as a 2 · 3 factorial in a completely randomized design. The first term (diet factors) consisted of ground corn (GC), ground cassava (CA), or pineapple stem starch (PS) at 37% dry matter (DM) in the concentrate. The second term (feeding factors) consisted of feeding the concentrate from 1 to 206 days (short-term feeding) or from 1 to 344 days (long-term feeding). At the end of the feeding term periods, the animals were slaughtered and the growth performance, carcass characteristics, and meat quality were evaluated. The average daily gain (ADG), feed:gain ratio, dry matter intake (DMI), hot carcass and cool carcass percentages, and backfat thickness were greater for steers on short-term than on long-term feeding. Feeding the different starch sources had no negative influence on the growth performance, carcass characteristics, and meat quality. However, the ADG of steers fed PS tended ( $P = 0.07$ ) to be higher than for those fed GC or CA. In addition, the concentration of the fatty acid C14:1 in the *longissimus dorsi* muscle was the highest in steers fed CA. Different starch sources had similar values for saturated fatty acid (SFA) and monounsaturated fatty acid (MUFA.) Long-term feeding increased MUFA. Pineapple stem starch could be a useful feed ingredient for feedlot steers as an alternative starch source for energy.

## Introduction

In southeast Asia, corn and cassava are commonly used as carbohydrate sources for ruminant diets because the climate and soil conditions are suited for their production. For feedlot cattle, rations have been substituted successfully with cassava, as cassava root products as a cereal substitute provide approximately 15 – 40% extra protein source (Chanjula et al. 2007, Boonsaen et al. 2017). However, concurrently, the demand for cassava and corn has increased for biofuel production, resulting in supply shortages and concomitant increases in the prices of these raw materials. Farmers have considered using cassava and corn by-products as a part of agro-industry. The by-products and blended by-products can be used as alternative raw materials and as cost-effective alternatives to cereal grains (Walter et al. 2010, Zenobi et al. 2014, Joy et al. 2017).

Thailand is one of the major countries producing and exporting pineapples in the world (FAO 2019). After harvesting the pineapple fruit in the field, the pineapple stem and leaves are considered agricultural residue. However, the pineapple stem can be used as a raw material to extract bromelain enzymes, using a simple process without applying harsh chemicals. The by-products (crushed stem and waste matter) from this process contain very high starch levels. Pineapple stem starch (PS) has a high starch content, especially of amylose (Nakthong et al. 2017). Our previous study found that feedlot steers fed a concentrate diet containing 40% PS as an energy source had an increased amount of ruminal total short-chain fatty acid (SCFA) and ruminal amyolytic group bacteria. In addition, *Ruminococcus bromii* was dominant among the microbial communities, resulting in improved steer growth performance (Khongpradit et al. 2020).

In ruminants, dietary carbohydrate is converted into various short-chain compounds (such as acetate, propionate, and butyrate) immediately after feeding. Acetate is more important than glucose as a source of lipid in both liver and adipose tissue (Choi et al. 2014, Nayananjalie et al. 2015). Lipid muscle also known as intramuscular fat (IMF), is one of the carcass traits used to determine meat quality and is mainly linked to the number and the size of intramuscular adipocytes (Hocquette et al. 2010). The quality traits of meat (such as flavor, tenderness, juiciness, or nutritional value), especially in IMF, can influence consumer purchasing power (Wood et al. 2008). However, various factors affect the IMF accumulation such as an animal breed, feed, and feeding (Pethick et al. 2004, Park et al. 2018, Mwangi et al. 2019). Hanwoo, American, and Australian crossbred cattle raised on a high-concentrate grain-fed base diet increase their IMF (Hwang & Joo, 2017). Increasing the slaughter age contributed to a higher carcass fat content, particularly in steers (Steen & Kilpatrick, 1995). Feeding strategies in finishing cattle are one of the major criteria affecting animal performance and carcass quality which can provide information useful in identifying the best time for slaughter to earn more profit (Cacere et al. 2014). In addition, the feed cost and the number of days on the feed are important criteria. PS is a high-potential, alternative feedstuff in cattle diets but very few studies have been done involving PS regarding the carcass characteristics, meat quality, and economic return for feedlot steers. The objectives of this study were to investigate the effect of pineapple stem starch on the growth performance, carcass characteristics, meat quality, and the economic return of feedlot dairy steers.

## Materials And Methods

The experimental procedures were carried out at the Ruminant Research Unit, Department of Animal Science, Faculty of Agriculture at Kamphaeng Saen, Kasetsart University, Nakhon Pathom, Thailand, in accordance with approval by the Animal Usage and Ethics Committee of Kasetsart University, Thailand (ACKU62-AGK-007).

### Animals, experimental design, and feeding

Thirty-six Holstein crossbred steers (aged 22 months) with an average initial body weight of  $453.0 \pm 35.3$  kg were used in the experiment. All animals were raised in open-air pens (2.5 m × 4 m) and had free access to freshwater. The experimental units were randomly assigned to three different starch sources of concentrates (Table 1): ground corn (GC), ground cassava (CA), or pineapple stem starch (PS) in combination with 2 feeding periods: 1) 1 to 206 days (short-term feeding) and 2) 1 to 344 days (long-term feeding) with six replicates per feed-dietary treatment arrangements as a 2 × 3 factorial in a completely randomized design. Some feedstuffs for the starch source (ground corn and ground cassava) were purchased from a commercial feed company (Betagro Co., Ltd., Samut Prakan, Thailand), while the pineapple stem starch was obtained from Hong Mao Biochemicals Co., Ltd., Rayong, Thailand. The pineapple stem starch was dried under sunlight for 2–3 days. The other feedstuffs (rice bran, defatted rice bran, defatted palm kernel meal) were purchased from Cowboyfriend Co., Ltd., Nakhon Pathom, Thailand. For roughage, Napier grass (approximately 65-days old) was harvested from the Ruminant Research Unit, Department of Animal Science, Faculty of Agriculture at Kamphaeng Saen,

Kasetsart University, Nakhon Pathom, Thailand, chopped into 2–3 cm lengths, and ensiled. Rice straw was purchased from a dealer in Suphan Buri province, Thailand. The steers were fed the concentrate *ad libitum* with Napier grass silage (2 kg DM/head/day) and rice straw (0.9 kg DM/head/day). The diets (concentrate and roughage) were offered twice a day at 7:00 am and 4:00 pm. The initial weight, final weight, and dry matter intake (DMI) were recorded and body weight gain (BWG), average daily gain (ADG) and the feed conversion ratio (FCR) were calculated to analyze growth performance.

### **Feed sampling and analysis**

Samples of the concentrate and roughage diets (Napier silage and rice straw) were taken every 2 weeks for nutrient composition analysis. The samples were analyzed for dry matter (DM), crude protein (CP), ether extract (EE), neutral detergent fiber (NDF), acid detergent fiber (ADF), calcium, phosphorus, ash (AOAC 2016), and total carbohydrates (Sniffen et al. 1992). The metabolizable energy (ME) was estimated using  $ME \text{ (Mcal/kg DM)} = 1.01 \times DE \text{ (Mcal/kg)} - 0.45$  and the digestible energy (DE) was estimated using  $DE \text{ (Mcal/kg DM)} = 0.04409 \times TDN$ , according to NRC (2001). Total digestible nutrients (TDN) was calculated using  $TDN \text{ (%DM)} = 87.84 - (0.07 \times ADF)$ , according to Schmid et al. (1976).

### **Slaughter, carcass characteristics, muscle sampling, and analysis**

When the target day of feeding was reached, the animals were deprived of feed but allowed access to freshwater. According to the halal protocol, animals were fasted for approximately 16 h before being humanely slaughtered (Zainalabidin et al. 2019). After slaughtering, the hot carcasses were weighed and chilled at 4°C. The hot carcass dressing percentage was calculated using  $(\text{hot carcass weight}/\text{slaughtered live weight}) \times 100$ . After 7 days of chilling, the cool carcass percentage using  $(\text{chilled carcass weight}/\text{slaughtered live weight}) \times 100$ . Muscle samples from the *longissimus dorsi* muscle (LM) were cut between the 12<sup>th</sup> and 13<sup>th</sup> ribs on the righthand side and transported immediately at 4°C to the laboratory for physical analysis, before being frozen prior to further chemical analysis. The pH of the LM was measured using a portable pH meter (TESTO205 pH/temperature meter; Testo Pty Ltd., Croydon South, VIC, Australia).

The drip loss of the LM was evaluated by the weight difference pre-hanging and post-hanging of the meat samples at 4°C for 24 h (Honikel 1998). Meat color ( $L^*$  = lightness;  $a^*$  = redness;  $b^*$  = yellowness) was measured on a freshly cut, transverse surface after 30 min of blooming at three spots using a color meter (HunterLab Mini Scan EZ, Reston, VA, USA) according to the protocol of CIE (1978). The irregular shape of the LM area was measured using a compensating planimeter (Cacere et al. 2014). Backfat thickness was measured using a set of calipers between the 12th and 13th ribs on the LM at three-quarters of the length of the loin eye muscle from the chine (backbone) (Orellana et al. 2009).

### **Chemical and fatty acid composition in meat analysis**

The moisture, crude protein, and crude fat contents of the LM were determined in duplicate (AOAC 2016). The fatty acid profile of IMF was extracted using the direct fatty acid methyl ester synthesis method

(Folch et al. 1957) and determined using a gas capillary chromatograph on a CP 7488, 0.20 mm × 50 m, CP – Sill 88 capillary column (Chrompack CP 9001 chromatograph, Netherlands). The initial oven temperature was 140 °C at 4 °C min<sup>-1</sup>, held for 10 min, then to 200 °C at 10 °C min<sup>-1</sup>, and held for 13 min. Helium was used as the carrier gas at a flow rate of 100 kPa. The injector was set at 270 °C and detector at 280 °C. Fatty acid profiles were identified by comparing their retention times with those of commercially available reference standards purchased from Sigma Aldrich (Germany).

## **Production cost**

The production cost was determined by considering the costs of the steers, feed, and the total cost of each animal according to the methods of Boonsaen et al. (2017) and Pintadis et al. (2020). The fixed costs included depreciation price of land, building and equipment, and the variable costs included wages, medicine, water, electricity, fuel, materials, and interest.

The economic analysis used the average regional prices for 2020. The key factors were the chilled carcass weight at 7 days post-modern and the marbling grade (Beef Cluster Cooperative Limited, Nakhon Pathom, Thailand). The price depended on the marbling score: score 1 = devoid at USD 5.74 per kg chilled carcass, score 2 = slight at USD 6.39 per kg chilled carcass, score 3 = small at USD 6.89 per kg chilled carcass, score 4 = moderate at USD 7.21 per kg chilled carcass, and score 5 = abundant at USD 7.54 per kg chilled carcass, where the conversion rate used was USD 1 = THB 30.50.

Based on the above valuation, the profit per head of steers raised during the finishing period (short term period or long-term period) was calculated using: Profit per steer = Total revenue per steer - Total cost per steer.

## **Statistical analysis**

Growth performance, carcass characteristics, and meat quality were analyzed as a 2 × 3 factorial in a completely randomized design, using the following model:  $Y_{ijk} = \mu + F_j + S_i + FS_{ij} + e_{ijk}$ , where  $Y_{ijk}$  is the observed value of the dependent variable,  $\mu$  is the overall mean,  $F_j$  is the effect of the days on feed ( $j = 1$  to 2; 1 = short-term feeding, 2 = long-term feeding),  $S_i$  is the effect of the treatment  $i$  ( $i = 1$  to 3; 1 = GC, 2 = CA, 3 = PS), and  $e_{ijk}$  is the experimental error. The hot carcass and cool carcass percentages, the crude fat, crude protein contents, the drip loss, and the fatty acid profile were transformed using an arcsine square-root transformation (Cook 1999) to achieve a normal distribution of the experimental error. Analysis of variance (ANOVA) was used. Tukey's honest significant difference test was conducted for multiple comparisons post-hoc. All statistical analyses were conducted using the R software, Version 3.6.2 (R Core Team 2020). Significance was tested at  $P < 0.05$ .

# **Results**

## **Growth performance and feed intake**

Long-term feeding of feedlot steers produced a higher weight gain and final weight ( $P < 0.01$ ) but decreased the ADG, DMI and feed:gain ratio compared with short-term feeding ( $P < 0.01$ ) (Table 2). There was no significant effect of starch source. PS tended to produce a higher ADG than GC ( $P = 0.07$ ).

### **Carcass characteristics and meat quality**

The animals were slaughtered at 29 months and 34 months of age for short-term and long-term feeding, respectively. The carcass characteristics were compared for the different starch sources. The long-term feeding had a lower ( $P < 0.05$ ) hot carcass percentage, cool carcass percentage and a higher ( $P < 0.05$ ) backfat thickness (Table 3). Meat quality parameters were considerably affected by the moisture, crude fat, and crude protein contents, the drip loss, and the lightness ( $L^*$ ), redness ( $a^*$ ), and yellowness ( $b^*$ ) of the LM. There were no differences ( $P > 0.05$ ) in these characteristics among treatments except for the lower yellowness ( $b^*$ ) in the long-term feeding treatments ( $P < 0.05$ ) (Table 4).

### **Fatty acid composition**

The fatty acid compositions in the meat of the dairy steers fed on different starch source diets are shown in Table 5. The concentrations of C14:1 (myristoleic acid) and C14:0 (myristic) were the highest in steers fed CA ( $P < 0.05$ ). The concentration of monounsaturated fatty acids (MUFA) decreased ( $P < 0.05$ ) in steers on long-term feeding. On the other hand, the different starch sources did not influence the proportions of SFA and MUFA ( $P > 0.05$ ) for either short-term or long-term feeding.

### **Production cost and economic return**

The economic return and income distribution of the steers fed the diets containing different starch sources with short-term and long-term feeding are shown in Table 6. The feedlot steers fed PS had the lowest feed cost per gain compared to those fed GC or CA for both the short-term feeding and long-term feeding. Feeding PS produced the highest profit (USD 453.62) compared to feeding GC (USD 273.02) and CA (USD 349.15).

## **Discussion**

Starch is one of the soluble carbohydrates that provides an energy source in ruminant feed. Many researchers have evaluated the effect on animal performance of using one or more sources of starch with different degrees of degradability and processing (Offner et al. 2003, Huhtanen & Sveinbjörnsson 2006, Khampa & Wanapat 2006, Huntington et al. 2006, Gómez et al. 2016). The selection of dietary carbohydrate sources is important to maintain the ruminal health and nutrient requirements of the animals. In our previous study, the PS contained in the diet did not affect rumen pH but increased total SCFA, ADG, and weight gain. The current study showed that PS tended to produce a higher ADG than for GC (Khongpradit et al. 2020). Animal weight gain is usually due to the ingestion of nutrients that are subsequently digested in the gut; thus, feed efficiency is based on the properties of the feed ingredients (Svihus et al. 2005, Stevnebo et al. 2009). The feed intake of the animal increases until

animals meet the energy requirement (NRC 2000). In the current study, the DMI and BWG of the steers fed diets containing different starch sources were not significantly different, which was consistent with the results of other researchers (Wang et al. 2009, Wanapat et al. 2011, He et al. 2015, Wang et al. 2016). However, feeding PS tended to produce a higher ADG than from feeding GC. The different sources of carbohydrates significantly influenced the intake of digestible energy (DE). Increasing DE resulted in a gain in body weight and ADG. Thus, the higher the starch level in the carbohydrate source, the higher the energy intake (Freitas et al. 2013). The fermentation products formed due to the interaction between the microbes and the diet produced SCFA, lactic acid, or other organic acids that resulted in a decreased ruminal pH and this may affect ruminal health (Castillo-González et al. 2014). Notably, in our previous study, a diet rich in pineapple stem starch resulted in a normal range in ruminal pH (Khongpradit et al. 2020). Thus, it is suggested that PS at a high ratio has potential for use as a soluble carbohydrate source in the diet of a ruminant without a risk to the animal's health. The carcass parameters such as carcass percentage, marbling, and backfat thickness were characterized according to the level of maturity of the animals.

Similarly, Nogalski et al. (2018) reported that steers slaughtered at a similar age had a similar IMF content. The pH values in the meat were within the normal range (5.5–5.8) sourced from Page et al. (2001). The lightness ( $L^*$ ), redness ( $a^*$ ), and yellowness ( $b^*$ ) were not affected by the starch source, nor did the meat quality differ among the starch sources.

Growth of fat and muscle cell typically occur as the mass increases in terms of cell numbers (hyperplasia) and size (hypertrophy) (Owens et al. 2013). In fattening steers, increased slaughter age and live weights can be related to the increase in the carcass fat content (Stehen & Kilpatrick 1995). A significant difference in the final weight was observed between short-term and long-term feeding (Table 2). Long-term feeding produced lower hot carcass and cool carcass percentages (Table 3) than from short-term feeding because feed efficiency decreases as animals age due to a decrease in the rate of muscle growth (Agastin et al. 2013). Feeding time is needed for muscle maturity and thereafter for the muscle to fill with fat content (Pethick et al. 2004). Four major adipose tissue located in animals (abdominal, subcutaneous, intermuscular, and intramuscular) and for the late fattening stage of cattle, intramuscular fat may grow continuously even though the development of the other adipose tissue sources may slow or cease (Park et al. 2018). These results can be related to the increased backfat thickness and consequently, the heavier animals and longer feeding times had higher subcutaneous fat thickness (Owens & Gardner 2000), cross-sectional area of the LM (Keane 2003) and increased fat in the IMF of Holstein-Friesian steers (Lengyel et al. 2004). Notwithstanding, this study did not show any differences in the LM area and crude fat content. The proportion of IMF increases with age, the days of feeding, the high-energy diet grain to forage ratio, and the breed (Aalhus et al. 1992). Breeds are positively correlated with muscular and carcass weight (Albertí et al. 2005). Wulf and Wise (1999) reported that lean maturity was correlated with the color parameters of  $L^*$ ,  $a^*$  and  $b^*$  values (highly with  $L^*$ ). Similarly, in the current study, the highest values of  $b^*$  resulted from long-term feeding. The  $b^*$  values and backfat thickness in the current study were similar to previous studies (Wulf et al. 1997, Page et al. 2011). Furthermore,  $b^*$  has been reported to be highly correlated with external fat thickness (Page et al. 2011).

In this study, oleic acid (C18:1 n-9 *cis*) was the most abundant fatty acid in IMF. The high proportion of oleic acid might have been due to feeding high-starch diets (Hwang & Joo 2017). Steers fed grain-based finishing diets typically display a general decrease in SCFA and increased MUFA (Huerta-Leidenz et al. 1996).

In the current study, the optimum slaughter age for the highest profit was at age 29 months. Interestingly, the price of pineapple stem starch as a raw material was lower than for ground cassava chip or ground corn (66.7 and 100 %, respectively). More importantly, the strategy for raising the feedlot cattle was to minimize feed-cost and to maximize the economic return. PS showed good potential as a starch source in a fattening diet for steers in terms of physical, chemical, or economic properties.

## Conclusions

The results of the current study indicated that the utilization of pineapple stem starch was superior to that of corn or cassava without having a negative effect on performance. The DMI among the different starch sources was probably similar. Short-term feeding produced a higher ADG, hot carcass percentage, and lower FCR, suggesting that short-term feeding (slaughtering at age 29 months) resulted in the best performance by the dairy steers and was financially beneficial. Steers fed concentrate diets containing pineapple stem starch showed no negative impacts on carcass characteristics and meat quality, while also generating the highest profit. Thus, pineapple stems have good potential as an alternative feedstuff for feedlot cattle.

## Declarations

### Funding

This work was supported by Kasetsart University Research and Development Institute (KURDI) and Agricultural Research Development Agency (ARDA).

### Conflicts of interest/Competing interests

The authors declare they have no conflicts of interest concerning the work presented in this report.

### Availability of data and material

Not applicable

### Code availability

Not applicable

### Authors' contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Suriya Sawanon, Anchalee Khongpradit, Phoompong Boonsaen, Nitipong Homwong, Keiji Matsuba and Yasuo Kobayashi. The first draft of the manuscript was written by Anchalee Khongpradit and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

### **Ethics approval**

All experiment procedures were carried out at Ruminant Research Unit, Department of Animal Science, Faculty of Agriculture at Kamphaeng Saen, Kasetsart University, Nakhon Pathom, Thailand, and in accordance with the approval by the Animal Usage and Ethics Committee of Kasetsart University, Thailand (ACKU62-AGK-007).

### **Consent to participate**

Informed consent was obtained from all individual participants included in the study. I, The Corresponding Author, confirm that the manuscript has been read and approved by all named authors. I further confirm that the order of authors listed in the manuscript has been approved by all of us.

### **Consent for publication**

The participant has consented to the submission of this research to the journal.

## **References**

1. Aalhus, J.L., S.D.M. Jones, A.K.W. Tong, L.E. Jeremiah, W.M. Robertson, & L.L. Gibson. 1992. The combined effects of time on feed, electrical stimulation and aging on beef quality. *Can. J. Anim. Sci.* 72:525–535.
2. Albertí, P., G. Ripoll, F. Goyache, F. Lahoz, J.L. Olleta, & B. Panea. 2005. Carcass characterization of seven Spanish beef breeds slaughtered at two commercial weights. *Meat Sci.* 71:514–521.
3. AOAC International. 2016. *Official Methods of Analysis of AOAC International*. 20th ed. Assoc. Off. Anal. Chem., Rockville, MD.
4. Bedford, A., L. Beckett, K. Hardin, N.W. Dias, T. Davis, V.R.G. Mercadante, **A.D. Ealy**, & R.R. White. 2018. Propionate affects insulin signaling and progesterone profiles in dairy heifers. *Sci. Rep.* 8:17629.
5. Boonsaen, P., N.W. Soe, W. Maitreejet, S. Majarune, T. Reugprim, & S. Sawanon. 2017. Effects of protein and energy sources in total mixed ration on feedlot performance and carcass quality of Kamphaeng Saen steers. *Agric. Nat.* 51:57–61.
6. Cacere, R.A.S., M.G. Morais, F.V. Alves, **G.L.D. Feijo**, **C.C.B.F. Itavo**, **L.C.V. Itavo**, **L.B. O’liveira**, & **C.B. Ribeiro**. 2014. Quantitative and qualitative carcass characteristics of feedlot ewes subjected to increasing levels of concentrate in the diet. *Arq. Bras. Med. Vet. Zootec.* 66:1601–1610.

7. Castillo-González, A.R., M.E. Burrola-Barraza, **J. Domínguez-Viveros**, & **A. Chávez-Martínez**. 2014. Rumen microorganisms and fermentation. *Arch. Med. Vet.* 46:349–361.
8. Chanjula, P., M. Wanapat, C. Wachirapakorn, S. Uriyapongson, & P. Rowlinson. 2007. Effects of replacing ground corn with cassava chip in concentrate on feed intake, nutrient utilization, rumen fermentation characteristics and microbial populations in goats. *Asian-Australas. J. Anim. Sci.* 20:1557–1566.
9. Choi, S.H., D.T. Silvey, B.J. Johnson, M.E. Doumit, K.Y. Chung, J.E. Sawyer, G.W. Go, & S.B. Smith. 2014. Conjugated linoleic Acid (t-10, c-12) reduces fatty acid synthesis de novo, but not expression of genes for lipid metabolism in bovine adipose tissue ex vivo. *Lipids* 49:15–24.
10. Commission **Internationale de L'Eclairage**. 1978. Recommendations on Uniform Color Spaces, Color-difference Equations, Psychometric Color Terms. Paris, France: Bureau Central de la CIE.
11. Cook, R.D. 1999. Applied regression including computing and graphics. John Wiley & Sons. Hoboken, NJ.
12. Folch, J., M. Lee, & S.A. Stanley. 1957. Simple method for the isolation and purification of total lipids from animal tissues. *J. Biol. Chem.* 226:497–509.
13. **Food and Agriculture Organization of the United Nations (FAO)**. 2020. FAOSTAT. Rome, Italy. Available online:<http://faostat.fao.org/>. Accessed 20 Jan 2021
14. Freitas, L.S., I.L. Brondani, L.R. Segabinazzi, J. Restle, D.C.A. Filho, L.A.D. Pizzuti, V.S. Silva, & L.S. Rodrigues. 2013. Performance of finishing steers fed different sources of carbohydrates. *R. Bras. Zootec.* 42(5):354–362.
15. Gómez, M.L., **L.S. Posada**, & **M. Olivera**. 2016. Starch in ruminant diets: a review. *Rev. Colomb. Cienc. Pecu.* 29:77–90.
16. He, M.L., J. Long, Y. Wang, G. Penner, & T.A. McAllister. 2015. Effect of replacing barley with wheat grain in finishing feedlot diets on nutrient digestibility, rumen fermentation, bacterial communities, and plasma metabolites in beef steers. *Livest. Sci.* 176:104–110.
17. Hocquette, J.F., F. Gondret, E. Baeza, F. Medale, C. Jurie, & D.W. Pethick. 2010. Intramuscular fat content in meat-producing animals: development, genetic and nutritional control, and identification of putative markers. *Animal.* 4:303–319
18. Honikel, K.O. 1987. How to measure the water-holding capacity of meat? Recommendation of standardized methods. *In: Evaluation control of meat quality in pigs* (Ed. Tarrant PV, Eikelenboom G, Monin G). Martinus Nijhoff, Dordrecht, The Netherlands. pp. 129–142.
19. Huerta-Leidenz, N.O., H.R. Cross, J.W. Savell, D.K. Lunt, J.F. Baker, & S.B. Smith. 1996. Fatty acid composition of subcutaneous adipose tissue from male calves at different stage of growth. *J. Anim. Sci.* 74:1256–1264.
20. Huhtanen, P., & **J. Sveinbjörnsson**. 2006. Evaluation of methods for estimating starch digestibility and digestion kinetics in ruminants. *Anim. Feed Sci. Technol.* 130:95–113.
21. Huntington, G.B., D.L. Harmon, & C.J. Richards. 2006. Sites, rates, and limits of starch digestion and glucose metabolism in growing cattle. *J. Anim. Sci.* 84:E14-E24.

22. Hwang, Y.H., & S.T. Joo. 2017. Fatty acid profiles, meat quality, and sensory palatability of grain-fed and grass-fed beef from Hanwoo, American, and Australian crossbred cattle. *Korean J. Food. An.* 37:153–161.
23. Joy, F., J.J. McKinnon, S. Hendrick, P. Gorka, & G.B. Penner. 2017. Effect of dietary energy substrate and days on feed on apparent total tract digestibility, ruminal short-chain fatty acid absorption, acetate and glucose clearance, and insulin responsiveness in finishing feedlot cattle. *J. Anim. Sci.* 95:5606–5616.
24. Keane, M.G. 2003. Beef production from Holstein-Friesian bulls and steers of New Zealand and European-American descent and Belgian Blue Holstein-Friesians slaughtered at two weights. *Livest. Prod. Sci.* 84:207–218.
25. Khampa, S., & M. Wanapat. 2006. Influences of energy sources and levels supplementation on ruminal fermentation and microbial protein synthesis in dairy steers. *Pak. J. Nutr.* 5:294–300.
26. Khongpradit, A., P. Boonsaen, N. Homwong, Y. Suzuki, S. Koike, S. Sawanon, & Y. Kobayashi. 2020. Effect of pineapple stem starch feeding on rumen microbial fermentation, blood lipid profile, and growth performance of fattening cattle. *Anim. Sci. J.* 91:e13459.
27. Lengyel, Z., F. Husvelth, P. Polgar, F. Szabo, & L. Magyar. 2003. Fatty acid composition of intramuscular lipids in various muscles of Holstein-Friesian bulls slaughtered at different ages. *Meat Sci.* 65:593–598.
28. Mach, N., A. Bach, A. Velarde, & M. Devant. 2008. Association between animal, transportation, slaughterhouse practices, and meat pH in beef. *Meat Sci.* 78:232–238.
29. Mwangi, F.W., E. Charmeley, C.P. Gardiner, B.S. Malau-Aduli, R.T. Kinobe, **A.E.O. Malau-Aduli**. 2019. Diet and genetics influence beef cattle performance and meat quality characteristics. *Foods.* 8:648.
30. Nakthong, N., R. Wongsagonsupb, & T. Amornsakchaic. 2017. Characteristics and potential utilization of starch from pineapple stem waste. *Ind. Crops Prod.* 105:74–82.
31. **Nation Research Council (NRC)**. 2000. Nutrient requirements of beef cattle. 7th revised edition, National Academy of Science Washington, DC.
32. **Nation Research Council (NRC)**. 2001. Nutrient requirements of dairy cattle. 7th revised edition, National Academy of Science Washington, DC.
33. Nayananjalie, W.A.D., T.R. Wiles, D.E. Gerrard, M.A. McCann, & **M.D. Hanigan**. 2015. Acetate and glucose incorporation into subcutaneous, intramuscular, and visceral fat of finishing steers. *J. Anim. Sci.* 93:2451–2459.
34. Nogalski, Z., P. Pogorzelska-Przybylek, M. Sobczuk-Szul, A. Nogal-ska, M. Modzelewska-Kapitula, & C. Purwin. 2018. Carcass characteristics, and meat quality of bulls and steers slaughtered at two different ages. *Ital. J. Anim. Sci.* 17:279–288.
35. Offner, A., **A. Bach**, & **D. Sauvant**. 2003. Quantitative review of in situ starch degradation in the rumen. *Anim. Feed Sci. Technol.* 106:81–93.
36. Orellana, C., F. Pena, A. Garcia, J. Perea, J. Martos, V. Domenech, & R. Acero. 2009. Carcass characteristics, fatty acid composition, and meat quality of Criollo Argentino and Braford steers

- raised on forage in a semi-tropical region of Argentina. *Meat Sci.* 81:57–64.
37. Page, J.K., D.M. Wulf, & T.R. Schwotzer. 2001. A survey of beef muscle color and pH. *J. Anim. Sci.* 79:678–687.
  38. Park, S. J., S.-H. Beak, D. J. S. Jung, S. Y. Kim, I. H. Jeong, M. Y. Piao, H. J. Kang, D. M. Fassah, S. W. Na, S. P. Yoo, & M. Baik. 2018. Genetic, management, and nutritional factors affecting intramuscular fat deposition in beef cattle – A review. *Asian-Australas. J. Anim. Sci.* 31:1043–1061.
  39. Pethick, D.W., **G.S. Harper**, & V.H. Oddy. 2004. Growth, development and nutritional manipulation of marbling in cattle: a review. *Aust. J. Exp. Agric.* 44:705–715.
  40. Pintadis, S., P. Boonsaen, C. Hattakum, H. Homwong, & S. Sawanoon. 2020. Effects of concentrate levels and pineapple stem on growth performance, carcass, and meat quality of dairy steers. *Trop. Anim. Health Prod.* 52:1911–1917.
  41. Pogorzelska-Przybyłek, P., Z. Nogalski, M. Sobczuk-Szul, C. Purwin, & D. Kubiak. 2018. Carcass characteristics and meat quality of Holstein-Friesian × Hereford cattle of different sex categories and slaughter ages. *Arch. Anim. Breed.* 61:253:261.
  42. R Core Team. 2020. R: a Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
  43. Schmid, A.R., R.D. Goodrich, R.M. Jordan, G.C. Marten, & J.C. Meiske. 1976. Relationships among agronomic characteristics of corn and sorghum cultivars and silage quality<sup>1</sup>. *Agron. J.* 68: 403–406.
  44. Sniffen, C.J., J.D. O'Connor, P.J. **Van** Soest, D.G. Fox, & J.B. Russell. 1992. A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. *J. Anim. Sci.* 70:3562–3577.
  45. Stenhen, R.W.J. & D.J. Kilpatrick. 1995. Effects of plane nutrition and slaughter weight on the carcass composition of serially slaughtered bulls, steers and heifers of three breed crosses. *Livest. Prod. Sci.* 43:205–213.
  46. StevnebØ, A., A. Sppala, O.M. Hartad, & P. Huhtanen. 2009. Ruminal starch digestion characteristics in vitro of barley cultivars with varying amylose content. *Anim. Feed Sci. Technol.*
  47. Svihus, B., A.K. Uhlen, & O.M. Harstad. 2005. Effect of starch granule structure, associated components, and processing on nutritive value of cereal starch: A review. *Anim. Feed Sci. Technol.* 122:303–320.
  48. Walter, L.J., J.L. Aalhus, W.M. Robertson, T.A. McAllister, D.J. Gibb, M.E.R. Dugan, **N. Aldai, & J.J. McKinnon**. 2010. Evaluation of wheat or corn dried distillers's grains with solubles on performance and carcass characteristics of feedlot steers. *Can. J. Anim. Sci.* 90:259–269.
  49. Wanapat, M., S. Foiklang, P. Rowlinson, & R. Pilajun. 2011. Effect of carbohydrate sources and cotton seed meal in the concentrate: II. Feed intake, nutrient digestibility, rumen fermentation, and microbial protein synthesis in beef cattle. *Trop. Anim. Health Prod.* 44:35–42.
  50. Wang, S.P, W.J. Wang, & Z.L. Tan. 2016. Effects of dietary starch types on rumen fermentation and blood profile in goats. *Czech J. Anim. Sci.* 61: 32–41.

51. Wang, Y.H., M. Xu, F.N. Wang, J.H. Yu, L.S. Zan, & F.X. Yang. 2009. Effect of dietary starch on rumen and small intestine morphology and digesta pH in goats. *Livest. Sci.* 122:48–52.
52. Wood, J.D., M. Enser, A.V. Fisher, G.R. Nute, P.R. Sheard, R.I. Richardson, S.I. Hughes, & M. Whittington. 2008. Fat deposition, fatty acid composition, and meat quality. A review. *Meat Sci.* 78:343–358.
53. Zainalabidin, F.A., F.M. Hassan, N.S.M. Zin, **W.N.W. Azmi, & M.I. Ismail.** 2019. Halal system in meat industries. *MJHR.* 2.
54. Zenobi, M.G., H.A. Lardner, **P.G. Jefferson, & J.J. McKinnon.** 2014. Blended by-product feed pellets for backgrounding cattle. *Can. J. Anim. Sci.* 94:533–543.

## Tables

Due to technical limitations, tables are only available as a download in the Supplemental Files section.

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [1Table1.jpg](#)
- [3Table2.jpg](#)
- [4Table3.jpg](#)
- [5Table4.jpg](#)
- [6Table5.jpg](#)
- [7Table6.jpg](#)