University of Alberta

Energetics of carcass muscle and fat growth of composite types at different harvest times

by

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ABSTRACT

The energy requirements to produce muscle and fat in five beef composites relative to harvest age were determined. In Exp. 1, the proportion of muscle in the whole carcass decreased and fat increased with harvest age ($P < 0.01$). Based on energy apportioned to muscle and fat, to obtain lean beef, the optimum time to harvest M1 is 399 d, M2 is 399 d or 427 d, M3 is 372 d or 399 d, M4 is 456 d and TX > 456 d. Small framed composites deposited energy fat subcutaneously and large framed intermuscularly. In Exp. 2, the energy used to deposit muscle and fat in the primal cuts was determined. The proportion of fat energy began to exceed 50% of the total energy at different ages in primal cuts of composites. The ratio of energy required for muscle: fat was highest in the round and lowest in the flank.

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LIST OF ABBREVIATIONS

BC	Body cavity
B	Bone
CT	Composite type
DE	Digestible energy
D	Day
F	Fat
IM	Intermuscular
M	Muscle
ME	Metabolizable energy
N	Nitrogen
NE	Net energy
NE_g	Net energy of feed for gain
NE_m	Net energy of the feed for maintenance
NRC	National Research Council
SAS	Statistical analysis system
SC	Subcutaneous
SEM	Standard error of the mean

Chapter 1. Introduction and literature review

1.1 Introduction

The Canadian per capita beef consumption has declined from 30.75 kg in 2001 to 20.20 kg in 2010 (Statistics Canada, 2010; Canfax, 2011). Some consumers are reluctant to consume red meat such as beef due to health concerns attributed to saturated fats and cholesterol (May et al., 1992). In addition, Grier (2002) stated that approximately 77% of Canadian consumers consider beef as an important ingredient of a healthy diet and the decline in consumption has occurred due to the health reasons. The main concern is the level of fatness in beef and the fatty acid profile (saturated fat) in grain fed beef. In addition to that, increasing cost of production, fluctuations of beef prices, animal health and food safety, export market and climate change impacts are some of the challenges in present Canadian beef industry (López-Campos et al., 2012). Therefore, it is very important to determine the optimum harvest end points of Canadian cattle composite types which can result in a leaner carcass, faster turnover of cattle in feedlot and less feed wastage to minimize these impacts. Understanding the growth of animal and carcass composition helps to find out optimum harvest end points for different composite types (Loveday and Dikeman, 1980).

1.2 Nature of animal growth

The term “growth” of animal is defined as an increase in size, cell number or mass over time and it is a complex biological process (Nadarajah et al., 1984;

Arango and Van Vleck, 2002). Owens et al. (1993) stated that net growth is the difference between synthesis and degradation of body tissues. Normally growth is measured as the variation in live weight or mass as well as nutrient retention and is estimated precisely through empty body weight and composition measurements (Owens et al., 1995). Growth of the animal is regulated by both genetic and non-genetic factors such as climate, nutrition, and management. In addition, intrinsic factors (sex, age, physiological status) and extrinsic factors (maternal effects and random environmental factors) have an effect on the determination of ultimate phenotypic expression of growth (Arango and Van Vleck, 2002). Animal growth begins at fertilization of the egg and is subject to a series of systematic changes to reach an embryo and further changes happen to develop into a young animal. After an animal reaches it's mature age or peak growth, a series of degenerative changes occur which finally leads to death (Sussman, 1960).

Growth at the cellular level is further described as cell multiplication or increasing in the cell number (hyperplasia), increasing in size or cell expansion (hypertrophy), cell accretion and changes of form and chemical composition (Arango and Van Vleck, 2002; Gerrard and Grant, 2003). Hyperplasia is prominent during the embryonic development period and hypertrophy is important during the post natal period. The size and weight of animal is determined primarily by the hypertrophy and hyperplasia (Trenkle and Marple, 1983). When mammals reach their mature weight, the capability of replication of specialized cells such as nerves, skeletal muscle cells etc. is halted and growth continues only through hypertrophy or incorporation of satellite cells. However, tissues like blood cell precursors, gastrointestinal epithelia, digestive tract organs and ectoderm etc. replicate throughout life (Owens et al., 1993). Although the growth rate, mature body size and growth rates of body parts are different from animal to animal (Gerrard and Grant, 2003) they all follow a similar growth pattern. The growth rate of every animal changes from time to time during its lifespan and the stages have been identified as prenatal, pre-weaning, post weaning and mature size stages (Arango and Van Vleck, 2002).

The growth of the animal is not even throughout life and follows a sigmoid or S-shaped curve (Figure 1.1) (Dalton, 1980; Goonewardene et al., 1981; Warriss, 2010). It starts from conception and grows to birth and subsequently puberty and maturity (Dalton, 1980). A growth curve is drawn by plotting body weight against age or time (Trenkle and Marple, 1983; Lawrence and Fowler, 1997). Even though the growth of all animals is sigmoidal, the shape of the curve can change according to the species, breed and sex (Gerrard and Grant, 2003). The growth curve is further divided into three main segments which are the lag phase, exponential or logarithmic phase and the stationary phase. During the lag phase the curve rises gradually and the animal is prepared for cell division through rapid protoplasmic growth. Also enzymes and raw materials such as amino acids, sugars, fatty acids, vitamins etc. which are the building materials for growth are accumulated during this period and cells become larger (hypertrophy) while remaining constant in the number.

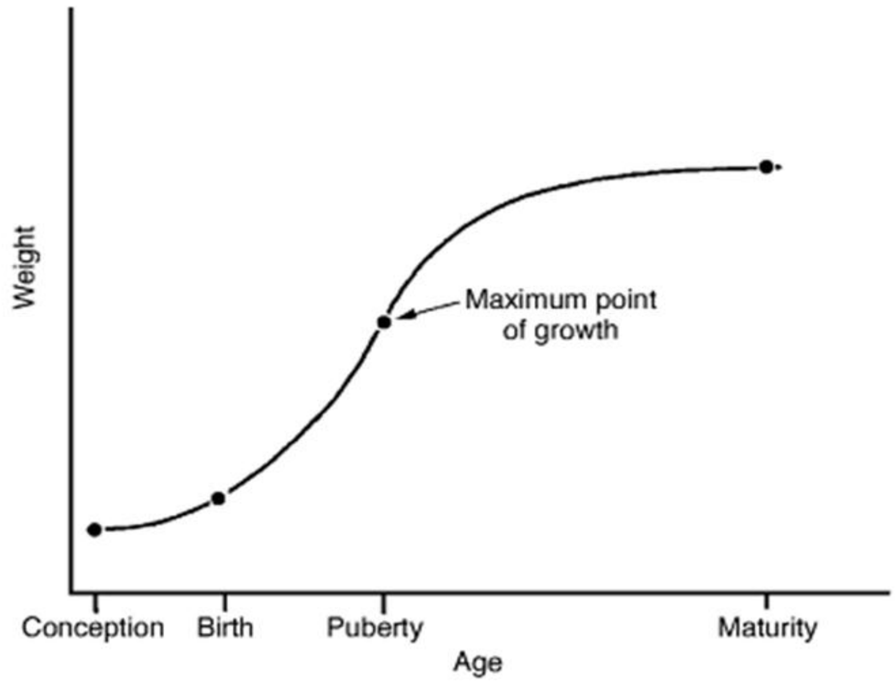


Figure 1.1 Normal growth curve of an animal
Source: Warriss (2010)

The exponential phase is the most active period and the animal more than doubles in size. During this time period growth rate increases very rapidly, resulting in a very steep slope. Puberty or sexual maturity normally demarcates the time of inflection of the curve and after inflection the rate of growth declines until final maturity size is reached (Brody, 1946; Dalton, 1980). Inflection is the interphase of the exponential and stationary phase or the point where the growth rate changes from an increasing to a decreasing rate (Brody, 1946; Brown et al., 1976). The growth rate is a maximum at the point of inflection (Warriss, 2010). After inflection at the end of the exponential curve, the rate of growth declines and the curve increases slowly and ends as a horizontal line when the rate of anabolism (synthesis) is equal to catabolism (degradation). During this phase, resistance is inbuilt on further growth of an animal (Sussman, 1960; Lawrence and Fowler, 1997). Growth curves have been used for genetic size scaling which relate to animals, compared across breeds, species and sexes (Taylor, 1980; Trenkle and Marple, 1983).

Adult size or mature size is denoted as the average size at maturity neglecting short term fluctuations as a result of some environmental, climatic effects and feed changes. Generally the mature weight represents the average genetic body size of different breeds (Arango and Van Vleck, 2002). Mature body size is influenced by several factors such as genetics, nutritional, management and hormonal status and gene x environment interactions (Owens et al., 1995). The average body weights and sizes of the larger and smaller cattle breeds are different, even though they are at similar stages of maturity (Priyanto and Johnson, 2011). In addition, contradictory growth patterns can be observed under different nutritional regimes of different composite types (Patterson et al., 1985). The carcass weight gain, as a percentage of live weight gain of the animal, is much higher in feedlot finishing phase compared to the growing phase of production. This is primarily due to an increase in dressing percentage with maturation of the animal and higher digestible energy content in concentrate diets. Typically, feedlot finishing steers are expected to gain more than 1.3 kg per day (Owens et al., 1995). However, it is shown that average daily body weight gain decreases with increasing harvest weight and days on feed (Hicks et al., 1987).

Relative growth rates, which are commonly used in the identification and quantification of the effect of nutritional experiments and genetic selection programmes, are expressed as average daily gain, empty body gain, weight per day of age and weight of fat or muscle per day of age (Trenkle and Marple, 1983). At the initial stage of life, the animal is small and relative to the whole body, growth rate is very high whereas the relative growth rate drops rapidly with the advancing growth or age of the animal (Gerrard and Grant, 2003). However, live weight is unreliable as an index of growth due to changes happening in the digestive tract such as fill by water and feed (gut fill). Shrunk weight decreases the degree of variation in live weight as a result of removing amount of digesta from gastrointestinal tract. Empty body weight is the most accurate index of energy, nutrient content of the body and subsequently growth as it is the measurement of total tissue after complete removal of the digestive tract from harvested animals (Owens et al., 1995). However, carcass weight measurements are more reliable and give a more accurate picture of an animal’s live weight and carcass composition is determined by the proportion of components which are muscle (M), fat (F) and bone (B) (Elhashmi et al., 2012).

1.3 Proportions and the growth of tissues

Compared to other animals, the efficiency of growth in beef production is a very important factor due to the low and slow rate of reproduction as well as a higher maintenance cost (Ferrell and Jenkins, 1985). Different tissues in the body of an animal have different growth rates (Owens et al., 1993). Beef cuts contain primarily M, F, and B and the proportions of tissues are influenced by age, breed, and plane of nutrition (Berg and Butterfield, 1968), harvest weight (Mukhoty and

Berg, 1973), genetic background and sex (Bruns et al., 2004). It is very important to understand the normal growth pattern of these tissues rather than focusing on the influence of external factors. Tissue depot development was first described by the Hammond (1932) and McMeekan (1940) as the sequence of B, M, and F. Bone develops early, then muscle and finally fat develops as the last tissue. The growth and development rates of these tissues are time sensitive and different to each other (Shahin and Berg, 1985; Bruns et al., 2004). The normal practice is to study the growth patterns of the tissues by dissection of animals which are harvested over the appropriate ranges of weights and ages. Recently, ultrasound measurements on live animals have been used to study the differences in the patterns of growth of M and F (Williams, 2002; Pillen, 2010). Harvest weight highly influences the carcass composition (Berg and Butterfield, 1968) and Preston (1971) stated that the bodyweight is the variable that has the greatest effect on body composition. Berg and Butterfield (1968) found that as the fattening phase begins, both the muscle and bone percentages decreased continuously whereas fat percentage increased at a greater rate. The muscle (lean) and adipose tissue (fat) are the two major edible parts in the animal's carcass (Warriss, 2010). "A superior carcass is characterized by a high proportion of muscle, a low proportion of bone and an optimal level of fatness" (Berg and Walters, 1983). Although fat was highly attractive for early hunter-gatherer populations, currently the demand for low fat, high lean beef has increased due to lower caloric requirement and health benefits of low fat beef (Warriss, 2010). The muscle to fat ratio of the carcass can be increased by several ways such as increasing mature size, supplying hormones or hormonal modifiers, controlling energy supply during the growing period or finishing period and harvesting cattle at an earlier age/stage of maturity (Owens et al., 1995).

Allometric growth explains the part to whole body relationship and describes the changes in the proportion of body parts with increasing size (Margeta et al., 2007). The allometric equation which is developed by Huxley (1932) is used to quantitatively describe the changes of tissues or organs (Suess et al., 1969; Fortin et al., 1980a). The allometric equation is described as $Y = aX^b$ where, a is a constant and b is the growth coefficient of the tissue which measures the relative growth rate of Y (weight or size of the tissue or organ) with respect to the growth of X (weight or size of the rest of the body or total tissue) (Fortin et al., 1980b; Priyanto et al., 2009; Warriss, 2010). The tissues in which the growth coefficient is greater than one are called “late developing tissues” whereas the tissues in which the growth coefficient is less than one are called “early maturing” tissues (Berg and Butterfield, 1976; Gerrard and Grant, 2003).

1.3.1 Muscle growth pattern

Muscle is the most important tissue and comprises a major part of the carcass and a higher proportion of muscle always results in higher economic merit (Mukhoty and Berg, 1973). In the carcass of a newborn calf, the ratio of M: B is 2:1, whereas at a slaughter weight of about 500 kg the ratio increases to 5:1. Accordingly, muscle has a higher relative growth rate than the bone (Berg and Butterfield, 1968) and the effect of changes of bone proportion on muscling is minimal. The proportion of muscle in the carcass is inversely related to the proportion of fat. Thus, a higher proportion of muscle results in a lower proportion of fat and vice versa (Berg and Walters, 1983).

In beef cattle, two methods have been used to study muscle weight distribution. The first method is called "semi-anatomical" is determined by physically dissecting the wholesale cuts of one carcass side into muscle, fat and bone (Pomeroy, 1960). In the second method, one half of the carcass is anatomically separated into individual muscle, bone and fat tissue parts and muscles are categorized considering their anatomical position (Brannang, 1971).

Berg and Butterfield (1976) stated that an evolutionary genetic pattern occurs before the birth of the calf to equip the well-developed muscles of the distal limb and strong muscles of the jaw to survive. These muscles help the calf to walk and suckle. After birth, remarkable changes happen in the large muscles of the hind limbs to enhance movement and locomotion. Muscles of the abdominal wall increase to support the gut and gut content especially as the calf begins to consume roughage (Butterfield, 1966; Berg and Walters, 1983). Weight of the animal shifts forward with maturity and fore limb muscles grow at higher rate than hind limb muscles to bear higher proportion of the animal's weight (Hand et al., 1992). Muscling is therefore related to function.

Berg and Butterfield (1976) have primarily categorized muscle growth into four phases: as antenatal, immediate post-natal, pre-pubertal or adolescent and maturity. In the antenatal phase, growth is almost entirely inspired by the genetic template to ensure the survival of animal at birth and is stimulated by skeletal elongation. The birth weight is doubled and muscle weight increases during the post natal phase and the growth is influenced by biological functions. In the pre-pubertal and adolescent phase, muscles of both the male and female grow at a constant rate while increasing the size. In the mature phase, relative growth of the musculature varies in the male animals to perform dual role in surviving and reproducing. This is the long phase of muscle growth and hormones highly influence the alterations and patterns of muscle growth (Berg and Butterfield, 1976; Owens et al., 1993).

The total muscle grows steadily throughout the growth period while maintaining a growth impetus about one (Berg and Butterfield, 1976). The growth impetus is the phase of growth or weight obtained relative to mature weight (Stanton and Whittier, 2006). However, different muscles have different growth impetus classifications such as high, average and low (Berg and Butterfield, 1976; Gerrard and Grant, 2003). The muscles are further grouped according to their location in the body and it helps to study the allometric growth of various muscle groups (Gerrard and Grant, 2003). The muscles which do not change in growth rate among phases or constant over time were described as monophasic whereas the muscles in which growth rate changed significantly between phases or develop at two different rates were described as diphasic (Berg and Butterfield, 1976; Gerrard and Grant, 2003). If the growth coefficient is not significantly different from one, it is considered as an average. Following this idea of the increasing and decreasing pattern of the growth coefficient from one, muscle growth was further categorized as high, low in monophasic and high-average, average –high and low-average in diphasic phases (Berg and Butterfield, 1976).

Callow (1961) stated that muscular tissues of all beef animals are around one third of live weight and Shahin and Berg (1985) have confirmed this through their study. Typically, larger muscles grow faster than smaller muscles. Muscles which are closely connected to the skeleton are the smallest, grow the slowest having a low and low-average growth impetus and important for the survival while muscles distantly related to the skeleton grow faster having high, high-average, average-high impetus and these are related to the productive work (Berg and Butterfield, 1976). Although the actual weight of the muscles increases with time, percentage of muscle in the carcass decreases at the fattening phase (Mukhoty and Berg, 1973; Goonewardene et al., 2009). Overall, the proportion of muscles in the high priced regions of the carcass, which are in proximal hind limbs and muscles surrounding the spinal column, decrease while the proportion in less valued cuts such as cuts in the neck, shoulder and abdominal area increase as the animal matures (Berg and Walters, 1983). The muscle growth coefficient of primal cuts are significantly different to each other and muscle weight distribution of different breeds change with maturity and size (Priyanto and Johnson, 2011). The loin is the latest developing part of the body because it has a connection with abdominal muscles which develop later in life (Berg and Walters, 1983).

1.3.1.1 Factors affecting muscle growth

Breed effects

The proportion of muscles in the carcass is breed dependent (Shahin and Berg, 1985). Late maturing breeds such as the Limousin, Charolais and Simmental have leaner carcasses compared to early maturing breeds such as the Angus and Hereford at similar carcass weight (Warriss, 2010). Mukhoty and Berg (1973) indicated that muscles of abdominal and neck regions are significantly different in bulls and steers of different breeds whereas breed differences are not significant for the expensive muscles which are located in proximal pelvic limb, surrounding spinal column and proximal thoracic limb. The proximal hind limb of larger *indicus* steers have more muscle than the smaller British types steers (Johnson et al., 2002). Priyanto et al. (2009) have verified this statement using steers of Brahman and Hereford. Even though smaller Hereford breeds normally have higher proportion of muscle in forelimb area, larger Brahman breeds have higher proportion of muscle in hind limb (Priyanto and Johnson, 2011). In Herefords, the proportion of muscle decreases with maturity due to a higher level of fat and earlier fattening pattern (Shahin and Berg, 1985). Guenther (1974) found that the muscle fiber diameters of Herefords (early maturing) are larger and reach their mature diameter at a younger age compared to Charolais (late maturing). Gotoh et al. (2009) indicated that double muscle cattle heavily deposit muscle in the proximal hind limb area compared to normal cattle. Furthermore, Wegner et al. (2000) reported that the fiber number of the double muscle breeds is approximately twice that of normal cattle as a result of extensive hyperplasia of muscle fibers during the development of the embryo. However, breed differences in muscle distribution is less pronounced than for fat (Koch et al., 1982).

Sex effects

Trenkle and Marple (1983) and Warriss (2010) stated that intact males have leaner carcasses compared to females. Bulls have rapid growth and utilize feed more efficiently while producing carcass with less fat and more muscle compared to steers. Growth of muscle is intermediate for steers (Seideman et al., 1982). The intact males have higher lean tissue growth and less fat deposition than castrated animals since steroids (testosterone) enhance animal performance and the lean to fat ratio (Bergen and Merkel, 1991a). Castration removes the anabolic effect of the male sex hormones and castrated male carcasses contain relatively more fat similar to females (Warriss, 2010). Normally bulls have a more prolonged impetus of muscle growth than both the steers and heifers resulting in prolonged muscle differentiation (Mukhoty and Berg, 1973). Steers contain a higher proportion of muscles in the abdominal area compared to bulls. In bulls, a higher proportion of muscle is observed in the neck and shoulder regions whereas heifers have a higher proportion of muscle in the proximal and in the hind limb as well as in the abdominal area (Seideman et al., 1982).

Nutrition and diet effects

Although Mukhoty and Berg (1973) stated that the effect of nutrition was minimal on muscle weight distribution of the cattle, Berg and Walters (1983) stated that growth and development of muscle tissues were affected by the level of nutrition. The relative growth of muscle is slightly changed with the low level of energy intake compared to high level of energy intake (Fortin et al., 1980b). The European or late maturing breeds which are grown on a high plane of nutrition, had higher lean yield than the early maturing British type breeds (Koch et al., 1982). The leanness and cutability of carcasses from forage-fed cattle is higher than in the carcasses from grain-fed cattle (Camfield et al., 1999; Brown et al., 2006). Even though Mitchell et al. (1991) and Xiong et al. (1996) found that the tenderness and flavour of the meat from grain-fed cattle was better than those of grass-fed beef, Bruce et al. (2004) stated that flavour and tenderness of meat from grain-fed was not superior compared to meat from pasture-fed beef.

Growth promoting agents

Growth hormones (GH) and β-Adrenergic agonist (βAA) are called partitioning agents and they enhance the protein accretion by partitioning nutrients and energy to protein synthesis and away from fat accretion (Bergen and Merkel, 1991b). GH increase nitrogen retention, lean tissue growth (Van Barneveld, 2003) and enhance the protein synthesis capacity in the muscle (Boyd and Bauman, 1989). However, adequate amounts of protein must be included in the diet to meet the requirement of growth of skeletal muscles (Bergen and

Merkel, 1991b). The GH implants have been used to enhance the feed efficiency by 15%, growth rate by 30% and carcass leanness by 8% of implanted compared with nonimplanted cattle of the same body weight (Bruns et al., 2005). Anabolic steroids and βAA are very effective in beef cattle production and increase carcass leanness. However, improper use can negatively affect tenderness, marbling and increase the frequency of dark cutters (Dikeman, 2007). βAA primarily influences the skeletal muscles in the animal (Yang and McElligott, 1989) and enhances muscle hypertrophy provided there is adequate protein intake (Bergen and Merkel, 1991b). They also increase the lean muscle content in the carcass while reducing fat deposition. However, βAA have a negative effect on shear force, sensory tenderness score and palatability (Leheska et al., 2009).

1.3.2 Fat growth pattern

The most variable tissue in the carcass is fat and amount as well as distribution changes significantly among different animals. Partitioning and the pattern of fat distribution in the carcass is a very important factor as it highly influences the commercial value of the animal carcass (Berg and Butterfield, 1976; Berg and Walters, 1983). The outer appearance of both the live animal and the carcass is determined by fat content as a result of the shrouding effect of subcutaneous depots as well as the structural effects created by the inter and intra muscular fat depots. The degree of partitioning and the amount of fat in different depots varies considerably throughout the growth of the animal (Berg and Butterfield, 1976). During early postnatal growth, the growth coefficient of fat is less than one and increases to greater than one with intense fat deposition happening later in life (Gerrard and Grant, 2003). The fat tissue of the animal grows at a lower rate until the animal reaches nearly one half of its physiological maturity (Trenkle and Marple, 1983). Although the adipocytes in the animal's body are developed early in life, they begin to fill after nutrient availability exceeds the requirement for skeleton and muscle growth (Allen, 1976). Even though muscles and bones are essential for body functions, fat has no such functional demand and acts primarily as a source of stored energy. Therefore, it does not follow any systematic distribution pattern as other tissues do (Jones et al., 1980b).

Four fat depots are recognized in the animal and these are subcutaneous (back fat), intramuscular (marbling), intermuscular (seam fat) and internal, body cavity or visceral fat (kidney, pelvic and heart-KPH). Deposition of fat in depots follows the order of internal, intermuscular, subcutaneous and intramuscular (De Oliveira et al., 2011). Extreme storage of subcutaneous, intermuscular and perirenal (kidney) fat have effects on meat quality and result in excess waste (Jones and Marchello, 1983). Adipose tissue development occurs through both hyperplasia and hypertrophy. During the finishing phase, early developing fat tissues such as intermuscular, perirenal (kidney) and mesenteric (visceral) complete the hyperplasic stage and deposit fat through filling existing adipocytes whereas subcutaneous and intramuscular depots create new adipocytes while depositing fat in existing cells (Sainz and Hasting, 2000). At birth, the body of the calf contains a small amount of fat which is less than 2% of body weight

(Trenkle and Marple, 1983) and this increases slowly until the fattening phase of an animal. Fat is the least necessary tissue in the early life of an animal and develops later in life (Berg and Butterfield, 1976). The body fat content of mature cattle (at maximum body protein mass) is nearly 36% of empty body weight irrespective of sex and background (Owens et al., 1995). The mass of fat increases quadratically with weight and the rate of fat accretion is often reduced with limited energy intake (Anderson et al., 1988). Generally, the rate of fat accumulation can be reached at 550 g d^{-1} which is the plateau for a finishing steer which has access to a high concentrate diet fed ad libitum (Owens et al., 1995).

Johnson et al. (1972) reported that the proportion of fat in all fat depots increased with time and the fat content in fetal calves was very small, mainly from the intermuscular and kidney fat depots. Furthermore, the foetus had no subcutaneous fat and it increased to about 30 percent of the total fat as cattle reached the early stage of fattening. Therefore, proportion of intermuscular fat gains during the early stage of the animal was much higher compared to subcutaneous fat gain. Subcutaneous fat thickness and KPH fat increase in a quadratic manner with increasing days on feed (Hicks et al., 1987; Brethour, 2000; Bruns et al., 2004) or the age of the animal.

Fat adds flavour and juiciness to beef and a sufficient level of intramuscular fat or marbling fat is required to ensure the satisfactory eating quality in certain cuts of beef. Marbling is a very important factor and exercises a strong effect on the consumer demand in some countries like Japan and the USA (Johnston, 2001). However, the carcass ideally should contain less subcutaneous and intermuscular fat as well as small amounts of internal fat since excessively fat carcasses are discounted (Tatum et al., 1986) and energetically wasteful. The intramuscular fat or marbling is the fat stored in adipose tissue between the muscle fiber bundles and it is closely linked to the blood capillary network (Albrecht et al., 2006). Even though May et al. (1992) and Van Koevering et al. (1995) stated that the growth of intramuscular fat or marbling in longissimus muscles followed a quadratic pattern in the finishing phase, Bruns et al. (2004) concluded that marbling is not a late developing tissue and it grows and accumulates throughout the normal growth process at a consistent rate during a high energy feeding programme. The variation of intramuscular fat content in muscle is very high (Callow, 1962) and dependent on many factors including measurement error due to the inaccuracy of real time ultrasound.

1.3.2.1 Factors influencing the proportion of fat

Breed effects

The partitioning and distribution of fat in different depots changes considerably with breed type (Berg and Butterfield, 1976; Patterson et al., 1985). Small framed cattle reach a specified fat level at lighter weights or at younger ages compared to large framed cattle (Block et al., 2001). The cattle which fatten at a younger age are called ‘early maturing’ whereas cattle that do not fatten until they reach older ages are called ‘late maturing’ (Butterfield, 1966). Early maturing breeds include the British beef breeds such as Hereford, Angus and Shorthorn whereas late maturing breeds are the European (Continental) breeds such as the Charolais, Simmental, and Limousin (Berg et al., 1978). The proportion of fat trim is lower for late maturing breeds than early maturing small breed crosses (Koch et al., 1976). Subcutaneous fat covers the animal body and acts as an insulation layer during cold. Hence breeds that live in cooler climates have higher subcutaneous fat depots than breeds in tropical climates (Ledger, 1965; Pitts and Bullard, 1968).

Jones et al. (1980b) observed that breed differences in fat distribution patterns occur in different wholesale cuts of beef and breeds which have rapid growth rates produced a fatter carcass at early ages. Fat partitioning among beef and dairy breeds is significantly different (Jones et al., 1980a). Cattle selected for the superior beef characteristics (Angus and Hereford) deposit a higher proportion of subcutaneous fat, in contrast to cattle selected for milk production (Ayrshire, Friesian, and Jersey) which deposit higher proportion of fat internally (Callow, 1961; Berg and Butterfield, 1976; Kempster et al., 1976; Kempster, 1981; Patterson et al., 1985; Tatum et al., 1986). Extreme fat partitioning differences are visible between breeds selected for intensive beef and milk production and continental breeds are at an intermediate position for body fat partitioning compared to British breeds and dairy breeds (Kempster et al., 1976; Tatum et al., 1986). The Holstein cattle have significantly more lean and bone, less total fat, subcutaneous and intermuscular fat compared to British breeds (Dubeski et al., 1997). In Angus steers, the proportion of subcutaneous and intermuscular fat deposited is very consistent over a wide range of total fat whereas in Hereford the intermuscular fat proportion declines while subcutaneous fat proportion increases over time. In beef cattle such as Hereford and Angus, fat thickness significantly increases with increasing carcass weight/age compared to dairy cattle (Berg and Butterfield, 1976). Charles and Johnson (1976) stated that the total dissectible fat weight was significantly variable between breeds at constant carcass weight. In Charolais crosses both subcutaneous and KPH fat increased with time while subcutaneous fat increased and KPH fat decreased in Hereford, Angus and Friesian in relation to the age of the animal.

Sex effects

Heifers fatten earlier with faster rate relative to body weight than steers and steers fatten at a younger age compared to bulls (Berg and Walters, 1983). Hence heifers can be harvested at lighter weights whereas bulls can be harvested at a heavier weight to yield an optimum fat content. Fat deposition in all depots of a steer increases as a result of castration as the effect of testosterone is removed (Berg and Butterfield, 1976; Berg et al., 1979). Seideman et al. (1982) stated that carcasses of steers contain more subcutaneous, kidney fat and marbling compared to bulls. Ntunde et al. (1977) found that bulls required more feeding days to reach 7.0 mm back fat thickness and such carcasses contained less trimmable fat compared to steers. In beef cattle production, steers are more desired than bulls since bulls have some disadvantages such as aggressive behaviour, a higher incidence of undesirable meat colour (dark cutters), lower tenderness, lower consumer acceptance and the meat is categorized under a lower USDA quality grade (Seideman et al., 1982).

Energy content of diet

High energy diet leads to fattening at an earlier and lighter weight while low energy diets results in slower fattening at heavier weights (Callow, 1961). The fat content of late maturing breeds can increase at any weight with respect to nutrient intake (Butterfield, 1966). However, Fortin et al. (1980a) found that the fat accretion of early maturing breeds was highly influenced by different energy intake levels compared with late maturing breeds and that early maturing breeds deposited more fat with higher energy levels than at lower energy levels. British heifers deposited intramuscular fat in an economical way at early stages of life on a high plane of nutrition compared to those on a moderate-high plane of nutrition (Dubeski et al., 1997). Animals fed on low levels of dietary energy showed lower subcutaneous, intermuscular and body cavity fat weights than those fed with a higher level of energy (Patterson et al., 1985). Subcutaneous fat in the carcass is lower for grass fed cattle than for grain fed cattle of the different beef breeds and Friesians (Kempster et al., 1976). Cattle become heavier and fatter under a higher energy feedlot diet compared to those feed with forage based diet (Bidner et al., 1986; Muir et al., 1998). Furthermore, cattle finished under a forage based production system have less fat compared to those finished on grain (Brown et al., 2006).

Partitioning agents and hormones

Growth hormones reduce fat deposition by enhancing lipolysis while depressing lipogenesis (Etherton, 1989). In addition, GH decreases the glucose uptake and oxidation, adipose tissue insulin sensitivity, lipogenic enzymes and stimulation of lipolysis (Boyd and Bauman, 1989). The growth stage of the animal influences the interference of growth hormone on fat deposition and storage. Thus, in young animals fat synthesis is affected and in older animals lipolysis of stored fat is affected by the growth hormones (Bergen and Merkel, 1991a). The growth hormones decrease the intramuscular adipose tissue development (Van Barneveld, 2003; Schwab et al., 2006) thus reducing marbling score and quality grade (Duckett and Andrae, 2001). β-Adrenergic agonists reduce the body fat of an animal by increasing energy expenditure or altering fat synthesis and deposition (Bergen and Merkel, 1991a). It reduces fat deposition by enhancing lipolysis and supressing lipogenesis and triacylglyceride synthesis (Yang and McElligott, 1989).

1.3.3 Bone growth

The skeletal system of an animal serves several functions: it mainly facilitates the muscle functions and acts as a source of calcium ions to maintain serum calcium levels. Bone is a multiphase material consisting of a hard collagenous matrix intermixed with rigid mineral crystals (Turner, 2006). Bone is an early developing tissue, most of it is developed during the antenatal period to facilitate the functions at birth (Berg and Butterfield, 1976). The growth coefficient of bone is less than one since incremental growth of bone is surpassed by intense growth of other tissues such as muscle and fat. However, weight of the skeleton increases several-fold from birth to maturity (Gerrard and Grant, 2003).

In the early growth phase, the skeletal system is subject to a great amount of changes and bones are continuously remoulded or reshaped to support the pressure applied by body weight and muscle mass (Trenkle and Marple, 1983). Koch et al. (1976) stated that the amount of bones in Simmental and Charolais crosses were significantly higher than the Herford, Angus, Jersey and South Devon whereas the proportions were comparatively similar on a weight constant basis.

1.4 Fat and protein accretion

Owens et al. (1995) stated that the energetic efficiency of fat accretion is nearly 1.7 times higher than protein accretion when turnover is not considered. Net efficiency of protein accretion (10-40%) in ruminant is lower compared to the efficiency of fat deposition (60-80%) as a part of energy is expended for continual and rapid protein turnover (Garrett and Johnson, 1983; Bergen and Markel, 1991b). However, due to storing more water with protein (muscle) deposition than with fat, lean tissue gain is four times as efficient as accretion of fat tissues (Owens et al., 1995). Rate and accretion of tissues may be controlled by chronological age, sex, mature size, maturity, energy intake, hormonal state, relative turnover of tissue, cell number (DNA) and activities (Owens et al., 1995). The rate of protein deposition depends on the relative rates of both protein synthesis and degradation and this rate needs to be higher for rapidly growing animals compared to slower growing animals (Castro-Bulle et al., 2007).

Tissue fluids are required to store fat and protein in growing animals and depots of fat free tissue which is protein contains approximately 73% water while fat contains 10% water (Brethour, 2004). Deposition of a unit of adipose tissue in an animal increases its energy content to more than six times that of the deposition of same weight of muscle on a dry basis (1.22 kcal g^{-1} vs. 7.97 kcal g^{-1}) (Warriss, 2010) and these values are independent of the animal or diet composition (Owens et al., 1995). The theoretical total energy requirement of protein deposition is the summation of the energy content deposited as protein and the energy content used for the synthesis of ATP which is required for the formation of peptide bonds (Buttery, 1981). The equivalents of four or five ATPs are required per peptide bond formed for the ribosome-dependent peptide bond synthesis and it has been estimated that 1.08 kcal is used for the synthesis of 1 g of protein (Lobley et al., 1980; Reeds et al., 1980; Chauhan, 2008). Millward et al. (1976a) stated that efficiency of fat and protein deposition change with the dietary source of nutrients. They also stated that protein synthesis from dietary amino acid had 85% efficiency whereas fat synthesis from fatty acid was 99% efficient. In addition, fat deposition from dietary carbohydrate resulted in losses of nearly 15% of energy as heat. Conversion of excess protein into fat had a poor efficiency of nearly 31% of heat would be produced if the conversion occurs via glucose and ketones in the liver (Millward et al., 1976a). However, Geay (1984) estimated efficiencies of metabolic energy utilized for fat and protein deposition to be 0.75 and 0.20 respectively.

1.5 Turnover of body tissues

The continuous synthesis and degradation of body tissues is defined as the tissue turnover and these processes help to release energy as well as nutrients during limited feed supply (Buttery, 1981; Lobley, 2003; Waterlow, 2006). Thus muscles (protein) and fat depots act as reservoirs of nutrients. Turnover of body tissues, especially protein turnover reduces the growth efficiency of the animals under ad libitum intake (Trenkle and Marple, 1983).

Protein turnover rate is associated with metabolic body weight of mature animals and rapid growth rates result in fast protein turnover (Buttery, 1981; Gopinath and Kitts, 1984). The main protein deposit of the body is the skeletal muscle and continuous protein turnover occurs throughout the growth of the animal (McCarthy et al., 1983; Trenkle and Marple, 1983). Protein turnover utilizes a considerable amount of total energy intake (nearly 15%) and energetic efficiency in meat animals can be increased by reducing the rate of protein turnover (Buttery, 1981). The protein synthesis results in greater heat production and nearly 30% of energy is lost as heat (Millward et al., 1976b; Pullar and Webster, 1977; Lobley et al., 1980).

Fat turnover mainly depends on lipid mobilization (lipolysis) and lipid deposition in adipose tissues. Lipid mobilization is very important during feed deprivation and stress periods of the animal life (Jones and Marchello, 1983). The endocrine system highly influences lipolysis as well as age, nutrition, genotype, and physiological stresses change the rate of lipolysis (Baldwin et al., 1973).

1.6 Nutritional energy

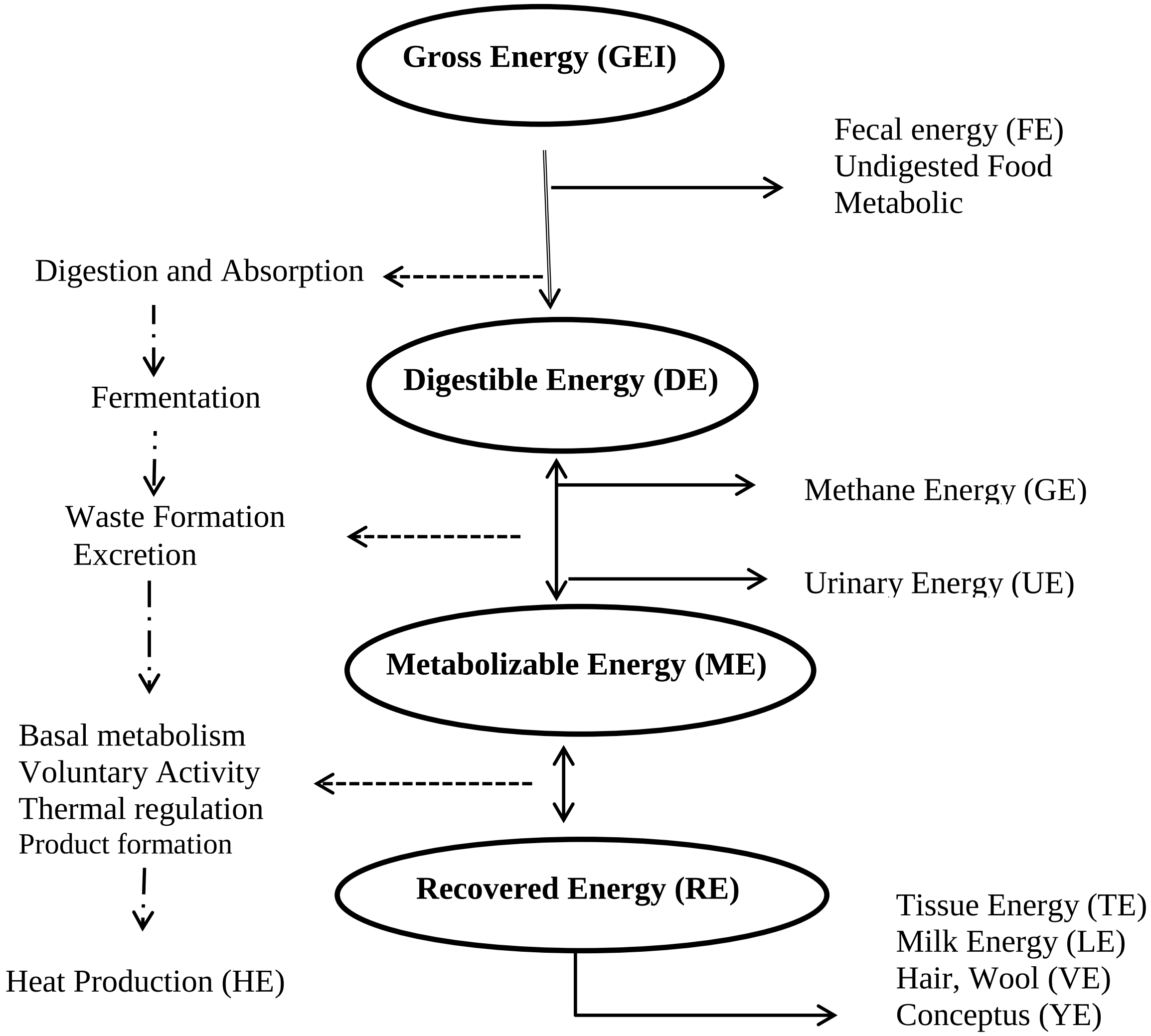
Energy is defined as the potential capacity to do work. It is an abstraction and can be calculated merely in conversion from one form to another (Baldwin and Bywater, 1984). The joule is the most common unit in expressing mechanical, electrical and chemical energy and it can be converted to watt-seconds, ergs and calories according to the requirement (NRC, 2000). In terms of the International Metric System, the joule is described as one kg m^2/sec^2 or 107 ergs (Baldwin and Bywater, 1984). One unit of calorie is equal to the 4.184 joules and it is the approximate heat energy required to increase the temperature of 1g of water from 16.5 °C to 17.5 °C. The joules can be converted to calories and vice versa (NRC, 2000).

In animal energetics the kilocalorie (1 kcal= 1,000 calories) and Mega calorie (1 Mcal =1,000 kcal) are appropriate for use and a calorie represents a small amount of energy (Kleiber, 1972; NRC, 2000). The adiabatic bomb calorimeter which is used to determine the gross energy content of organic matter such as feed, feces and urine accurately, was created by Berthelot (1827 to 1907) and this innovation improved and enhanced the accuracy of energy based research (Ferrell and Oltjen, 2008). Baldwin and Bywater (1984) stated that nutritional energetics mainly emphasises on the quantification of energy transformation especially in two forms as chemical energy and heat energy. Further, they described that the chemical energy provided to animals through feed is converted to heat to support fundamental life processes, stored in chemical form as body reserves, passed to surroundings as in work or conveyed in chemical form to their offspring as in pregnancy and lactation. The first law of thermodynamics which states that “energy can only be transformed from one form to another and cannot be created or destroyed” is used in nutritional measurements and calculations (Ferrell and Oltjen, 2008).

1.7 Energetic efficiency

Use of dietary energy has been subjected to researchers and philosophers since the era of Leonardo da Vinci (1452- to 1519) and they stated that life is basically a controlled combustion process (Ferrell and Oltjen, 2008). The energetic efficiency is primarily described by the partitioning of metabolizable energy (ME) between heat, protein and fat. Energy systems are primarily designed to predict performances and requirements of animals as well as to determine the ME intake partitioning pattern. The experimental data collected through feeding trials at specific points in time or over fixed feeding intervals are used to develop these systems. Hence energy systems are static in nature and empirical in approach (Williams and Jenkins, 2003; Ferrell and Oltjen, 2008). Several models have been developed to calculate net efficiency of metabolic energy utilization for gain in cattle and consequently to estimate daily gain using recovered energy (Williams and Jenkins, 2003).

The terminology of energy utilization which is presently used by most of the feeding systems was developed by the National Research Council (NRC, 1981; Ferrell and Oltjen, 2008). Figure 1.2 represents the energy partitioning pattern in the animal.



Gross Energy (GEI)
Fecal energy (FE)
Undigested Food
Metabolic
Digestion and Absorption
Fermentation
Digestible Energy (DE)
Methane Energy (GE)
Waste Formation
Excretion
Urinary Energy (UE)
Metabolizable Energy (ME)
Basal metabolism
Voluntary Activity
Thermal regulation
Product formation
Recovered Energy (RE)
Tissue Energy (TE)
Milk Energy (LE)
Hair, Wool (VE)
Conceptus (YE)
Heat Production (HE)

Figure 1.2 Energy partitioning pattern in the animal (Ruminant)
Adopted from NRC (1981); Ferrell and Oltjen (2008)

The amount of energy consumed as feed is called gross energy intake and a considerable proportion of it is lost as faecal, gaseous, urinary energy or heat and finally a part of it is recovered as a product. The formation of heat is associated with different biological and physiological processes in the body which include digestion and absorption, fermentation of food, waste formation and excretion, basal metabolism, different voluntary activities, thermal regulation and product formation (NRC, 1981; Ferrell and Oltjen, 2008). Largest energy losses are linked with faecal energy and heat. Net gain of energy is the recovered energy and the product can be identified as body protein and fat, milk, hair, and conceptus (Baldwin and Bywater, 1984; Ferrell and Oltjen, 2008).

1.7.1 Metabolizable energy

Metabolizable energy (ME) is the energy available for animals after subtracting fecal, urinary and gaseous energy losses from digestible energy (Blaxter et al., 1966). As described by the general equation, metabolizable energy (ME) = heat energy (HE) + retained energy (RE), metabolizable energy is a combination of retained energy which is deposited in tissues in animals or products and heat energy which is formed by the animal body (Johnson et al., 2003; Ferrell and Oltjen, 2008). A part of metabolizable energy contributes to maintenance and the other part for gain. Energy requirement for regulating body temperature, essential metabolic processes and energy requirement for physical activities are fulfilled by the metabolizable energy available for maintenance (NRC, 2000). The dietary metabolizable energy efficiency varies with the source, intake level and functions that utilize energy in the animal. The basic starting point of the net energy system is considered as metabolizable energy and the association between energy balance and metabolic energy intake is curvilinear over the entire range of feed intake (Ferrell and Oltjen, 2008).

Blaxter et al. (1966) stated that the relationship between retained energy and metabolizable energy intake (MEI) was curvilinear with approximately two linear relationships, as one below maintenance with partial efficiency symbolized by k_m and another one above maintenance with partial efficiency symbolized by k_g. Figure 1.3 describes this phenomenon while representing ME utilization for maintenance as well as production.

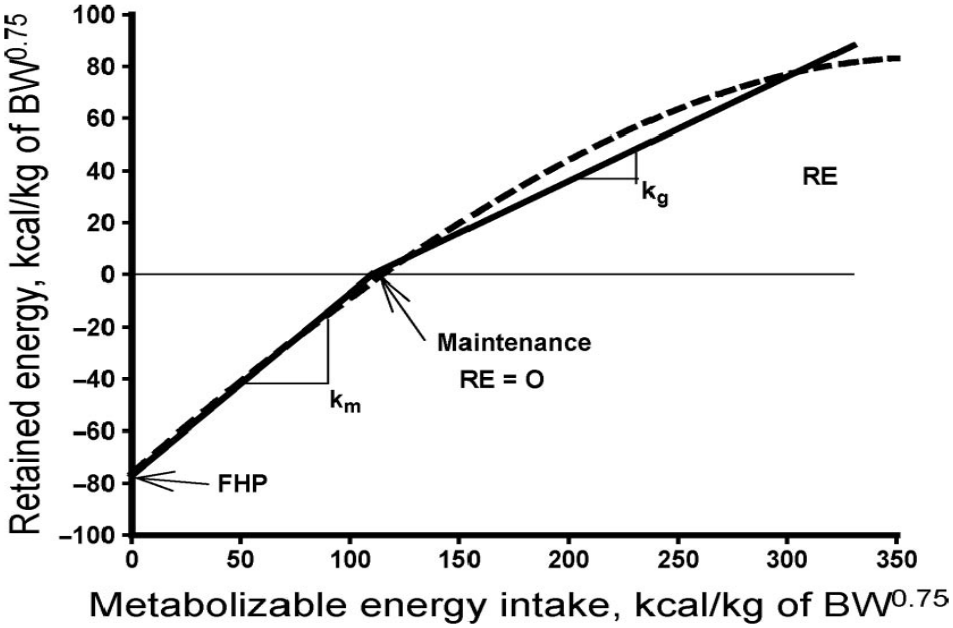


Figure 1.3 Relationship between metabolizable energy intake and retained energy
Source: Ferrell and Oltjen (2008)

In the intersection of the two lines in Figure 1.3, RE become zero and that point is defined as maintenance at which ME=HE. The net energy required for maintenance is defined as fasting heat production (FHP) and it is the energy value at zero ME intake (NRC, 2000; Ferrell and Oltjen, 2008). Lofgreen and Garrett (1968) reported a net energy system called "California Net Energy System

(CNES)" and net energy of feed was separated into two values as net energy maintenance (NE_m) and net energy gain (NE_g). This was an empirical system and was developed using long term, slaughter feeding trial data to calculate energy requirements of both maintenance and growth of growing ruminants. Further they developed two equations using k_m, k_g and ME values as follows;

$NE_m = k_m \times ME$ and

$NE_g = k_g \times ME$

Where, NE_m = Net energy of the feed for maintenance, NE_g = Net energy of the feed for gain, ME= metabolizable energy, k_m = partial efficiency of maintenance, k_g = partial efficiency of gain

When the MEI value is lower than NE_m, NE_g value would be negative and in this situation RE is also a negative value (Garrett and Johnson, 1983; Williams and Jenkins, 2003). At present, all systems use metabolic energy to estimate feed values and use adjustment for different feed levels or planes of nutrition (Ferrell and Oltjen, 2008). Normally, ME is estimated as digestible energy (DE) X 0.82 and NE_m and NE_g values of feed are calculated from ME using following equations.

$NE_m = 1.37ME - 0.138ME^2 + 0.0105ME^3 - 1.12$

$NE_g = 1.42 ME - 0.174ME^2 + 0.0122ME^3 - 1.65$

Where, NE_m = Net energy of the feed for maintenance, NE_g = Net energy of the feed for gain, ME= metabolizable energy (NRC, 2000).

1.7.1.1 Metabolizable energy use for maintenance

Mature beef cattle require 70-75% of metabolizable energy for their maintenance and a large part is dissipated as heat (Ferrell and Jenkins, 1984; Webster, 1985; Okine et al., 2004). Garrett (1980) stated that the maintenance is the state at which neither gain nor loss of energy occurs in the body of an animal and the energy required reaches an equilibrium state while covering the energy cost of essential, minimal muscular activities. In other words metabolizable energy used for maintenance can be defined as the MEI when RE=0 or HE=MEI (Ferrell and Oltjen, 2008).

The energy required for maintenance of steers, heifers, bulls and cows is estimated as 0.077 Mcal x EBW $(kg)^{0.75}$ where, EBW= empty body weight (NRC, 2000). However, empirical adjustment values for the factors such as acclimatization, breed, sex, age, season, physiological state, activity, previous plane of nutrition, body condition, hair coat, temperature, wind, mud, moisture are used to get accurate maintenance values (Garrett, 1980). Heat production for maintenance of the animal varies with MEI levels (Ferrell and Oltjen, 2008). It is the largest loss and influences the biological efficiency (Arango and Van Vleck, 2002). Henrique et al. (2009) stated that a constant animal weight can be maintained for a longer time period by controlling MEI at 31.2 to 35.6 kcal kg^{-1} body mass. It indicates that all the energy consumed has been used for the maintenance. The maintenance energy requirement varies with body weight (Solis et al., 1988), breed, sex, age, season, temperature, physiological state and previous plane of nutrition (NRC, 2000).

Effect of breed type

Different cattle breeds require different amounts of maintenance energy (Solis et al., 1988). Garrett (1971) stated that Holstein steers need 23% more feed to maintain their body energy status than Hereford. At the same time, both bulls and heifers of the Simmental breed required more feed to fulfill energy requirement than the Herefords (Ferrell and Jenkins, 1985). *Bos taurus* breeds of cattle require nearly 10 percent higher maintenance energy than *Bos indicus* breeds (NRC, 2000). The dairy breeds and their crosses have a higher maintenance cost and lower efficiencies of tissue energy exchange than beef breed cattle because they have a higher quantity of metabolically active internal tissues such as internal fat, lean body mass etc. (Solis et al., 1988).

Effect of sex

Although Lofgreen and Garrett (1968) stated that fasting heat production (FHP) and maintenance energy requirements of steers and heifers were not different, Ferrell and Jenkins (1985) found that there was a small difference in FHP between Hereford bulls and Heifers. Further they described that maintenance energy required by bulls of Hereford and Simmental breeds was higher than the same breed heifers by 2% and 16.5% respectively. In general, bulls require 15% more maintenance energy than steers and heifers of same breed (NRC, 2000).

Effect of age and physiological state

Blaxter et al. (1966) stated that the influence of age on maintenance is very small compared to other factors associated with weight. Commonwealth Scientific and Industrial Research Organisation or CSIRO (1990) stated that maintenance energy requirement of the cattle reduces by three percent per year and reported that when cattle reach six years of age they reduce energy requirement by up to 84% of the initial value. However, NRC (2000) suggested that the effect of age on maintenance was not much. Requirement of maintenance energy varies with physiological state and increases with gestation (Kleiber, 1961). In contrast, lactating cows require approximately 20 percent higher maintenance energy compared with non-lactating cows (NRC, 2000).

Effect of temperature

The maintenance energy of a cow is increased during the spring and summer while it is decreased during fall and winter with increasing fatness (Byers and Carstens, 1991). Cattle maintain a constant body temperature by regulating heat production and heat dissipation (NRC, 2000). Normally, animals perform well in a thermonutral zone and a temperature deviation from this zone causes the animal to increase maintenance energy cost. If temperature passes the upper critical temperature (UCT), feed intake is reduced and productivity is decreased. It also increases the metabolic rate and work for dissipating heat. This results in the increase in the energy requirement for maintenance. If the temperature goes below the lower critical temperature (LCT), the animal's metabolic rate increases to maintain body temperature and consequently the maintenance requirement is increased. Increasing of the ambient temperature above the UCT and decreasing temperature below the LCT are the causes of heat stress and cold stress respectively (NRC, 2000).

Nutritional effect

Metabolic rate of cattle changes with the previous plane of nutrition and the level of feed intake (Andersen, 1980; Gray and McCracken, 1980). In addition, fasting heat production (FHP) is decreased with decreased feed intake. Feed restriction causes a reduction in maintenance energy during and after the period of restriction. The effect of the previous plane of nutrition on maintenance is estimated using body condition score in cattle (NRC, 2000).

1.7.1.2 Metabolizable energy use for energy gain (Retained Energy)

Retained energy in beef cattle indicates the energy which is deposited in the tissues as a fat or protein (muscle). In the early stages of growth, both the protein and fat are synthesized and deposited. A small amount of the intake energy is retained as recovered energy and for beef cattle it is normally less than 20% (Baldwin and Bywater, 1984; Ferrell and Oltjen, 2008). Johnson et al. (2003) found that only 16% to 18% of consumed energy is retained in fattening steers. Schake and Riggs (1975) stated that gross empty body energy gain (EBE) efficiency from birth to harvest was 16.7% and approximately 6% gross energy consumed was converted to EBE when the calf was harvested at nearly one year of age. Empty body weight is the summation of fat and fat-free materials and protein mass is considered as 0.22 times that of fat-free matter. Net energy intake above maintenance is primarily used for the visceral and muscle gain and the energy that remains after that, is used for empty body fat gain (Old and Garrett, 1985; Ferrell and Oltjen, 2008). Okine et al. (2004) stated that only 5% of the total life cycle dietary energy consumption is spent for protein gain in beef cattle. Partitioning of net energy for protein and fat changes with breed and plane of nutrition. Old and Garrett (1985) stated that even though Hereford and Charolais had similar energy intakes, Charolais gained more protein (g d^{-1}) than Hereford. Further, they found that although overall ME used for fat gain was 1.72 kcal ME/ kcal of fat, Hereford and Charolais used 1.77 and 1.75 kcal ME respectively. Diet crude protein content changes the efficiency of protein gain and higher protein content results in a higher protein deposition (Old and Garrett, 1985). Webster (1985) stated that the efficiency of conversion of ME into meat can be increased in three ways: decreasing cumulative heat by accelerating growth, reducing energy value of the gains by harvesting a leaner lighter animal and reducing daily heat production.

1.8 Literature Cited

Albrecht, E., F. Teuscher, K. Ender, and J. Wegner. 2006. Growth and breed related changes of marbling characteristics in cattle. J. Anim. Sci. 84:1067-1075.

Allen, C. E. 1976. Cellularity of adipose tissue in meat animals. Fed. Proc. 35:2302–2307.

Andersen, B. B. 1980. Feeding trials describing net requirements for maintenance as dependent on weight, feeding level, sex and genotype. Ann. Zootech. 29:85–92.

Anderson, P. T., W. G. Bergen, R. A. Merkel, and D. R. Hawkins. 1988. The effects of dietary crude protein level on rate, efficiency and composition of gain of growing beef bulls. J. Anim. Sci. 66:1990-1996.

Arango, J. A. and L. D. Van Vleck. 2002. Size of beef cows: Early ideas, new developments. Genet. Mol. Res. 1: 51-63.

Baldwin, R. L., J. R. Reichl, S. Louis, N. E. Smith, Y. T. Yang, and E. Osborne. 1973. Effects of age, pregnancy and lactation on rat, guinea pig and cow adipose enzyme activities and cow adipose metabolism. J. Dairy Sci. 56:340-349.

Baldwin, R. L. and A. C. Bywater. 1984. Nutritional energetics of animals. Ann. Rev. Nutr. 4:101-114.

Berg, R. T. and R. M. Butterfield. 1968. Growth patterns of bovine muscle, fat and bone. J. Anim. Sci. 27:611-619.

Berg, R. T. and R. M. Butterfield. 1976. New concepts of cattle growth. Sydney University Press. Sydney, Australia.

Berg, R. T., B. B. Andersen, and T. Liboriussen. 1978. Growth of bovine tissues. 1. Genetic influences on growth patterns of muscle, fat and bone in young bulls. Anim. Prod. 26:245-258.

Berg, R. T., S. D. M. Jones, M. A. Price, R. Fukuhara, R. M. Buttefield, and R. T. Hardin. 1979. Patterns of carcass fat deposition in heifers, steers and bulls. Can J. Anim. Sci. 59:359-366.

Berg, R. T. and L. E. Walters. 1983. The meat animal: changes and challenges. J. Anim. Sci. 57:133-146.

Bergen, W. G. and R. A. Merkel. 1991a. Body composition of animals treated with partitioning agents: Implications for human health. FASEB J. 5:2951−2957.

Bergen, W. G. and R. A. Merkel. 1991b. Protein accretion. In: A. M. Pearson and T. R. Dutson (Ed.) Growth regulation in farm animals. Advances in Meat Research. 7:169−202.

Bidner, T. P., A. R. Schupp, A. B. Mohamad, N. C. Ramore, R. E. Montgomery, C. P. Bagley, and K. W. McMillin. 1986. Acceptability of beef from Angus-Hereford or Angus Hereford-Brahman steers finished on all-forage or a high energy diet. J. Anim. Sci. 62:381-387.

Blaxter, K. L., J. L. Clapperton, and F. W. Wainman. 1966. Utilization of the energy and protein of the same diet by cattle of different ages. J. Agri. Sci. 67:67-75.

Block, H. C., J. J. McKinnon, A. F. Mustafa, and D. A. Christensen. 2001. Manipulation of cattle growth to target carcass quality. J. Anim. Sci. 79:133–140.

Boyd, D. R. and D. E. Bauman. 1989. Mechanisms of action for somatotropin in growth. Pages 257-293. In Animal Growth Regulation. D. R. Campion, G. J. Hausman and R. J. Martin, eds. Plenum, New York.

Brannang, E. 1971. Studies on monozygous cattle twins. XXIII. The effect of castration and age of castration on the development of single muscles, bone and special sex characters. Swed. J. Agric. Res.1:69-78.

Brethour, J. R. 2000. Using serial ultrasound measures to generate models of marbling and back fat thickness changes in feedlot cattle. J. Anim. Sci. 78:2055–2061.

Brethour, J. R. 2004. The relationship of average back fat thickness of feedlot steers to performance and relative efficiency of fat and protein retention. J. Anim. Sci. 82:3366–3372.

Brody, S. 1946. Bioenergetics and growth. Reinhold Pub. Co. NY.

Brown, J. E., H. A. Fitzburgh, Jr., and T. C. Cartwright. 1976. A comparison of nonlinear models for describing weight-age relationships in cattle. J. Anim. Sci. 42:810-818.

Brown, A. H., P. K. Camfield, R. T. Baublits, F. W. Pohlman, Z. B. Johnson, C. J. Brown, G. T. Tabler, and B. A. Sandelin. 2006. Effects of size and rate of maturing on carcass composition of pasture or feedlot-developed steers. Asian. Aust. J. Anim. Sci. 19:661-671.

Bruce, H. L., J. L. Stark, and S. L. Beilken. 2004. The effects of finishing diet and postmortem ageing on the eating quality of the *M. longissimus thoracis* of electrically stimulated Brahman steer carcasses. Meat Sci. 67:261-268.

Bruns, K. W., R. H. Pritchard, and D. L. Boggs. 2004. The relationships among body weight, body composition and intramuscular fat content in steers. J. Anim. Sci. 82:1315-1322.

Bruns, K. W., R. H. Pritchard, and D. L. Boggs. 2005. The effect of stage of growth and implant exposure on performance and carcass composition in steers. J. Anim. Sci. 83:108–116.

Butterfield, R. M. 1966. Relative growth in beef cattle. Aust. Vet. J. 42:342–343.

Buttery, P. J. 1981. Protein turnover in animal. Trop. Anim. Prod. 6:204-213.

Byers, F. M and G. E. Carstens. 1991. Seasonality of maintenance requirements in beef cows. Energy Metab. Proc. symp. 58:450-453.

Callow, E. H. 1961. Comparative studies of meat. VII. A comparison between Hereford, Dairy Shorthorn and Friesian steers on four levels of nutrition. J. Agr. Sci. Camb. 56:265-282.

Callow, H. 1962. Comparative studies of meat. VIII. The percentage of fat in the fatty and muscular tissues of steers and the iodine number of the extracted fat, as affected by breed and level of nutrition. J. Agric. Sci. Camb. 58:295-307.

Camfield, P. K., A. H. Brown, Z. B. Johnson, C. J. Brown, P. K. Lewis, and L. Y. Rakes. 1999. Effects of growth type on carcass traits of pasture or feedlot developed steers. J. Anim. Sci. 77:2437-2443.

Canfax research services. 2011. Quarterly Report (June). http://www.canfax.ca/Samples/crs_quarterly.pdf. Accessed August, 2012.

Castro-Bulle, F. C. P., P. V. Paulino, A. C. Sanches, and R. D. Sainz. 2007. Growth, carcass quality, protein and energy metabolism in beef cattle with different growth potentials and residual feed intakes. J. Anim. Sci 85:928–936.

Charles, D. D. and E. R. Johnson. 1976. Breed differences in amount and distribution of bovine carcass dissectible fat. J. Anim. Sci. 42:332-341.

Chauhan, B. S. 2008. Principles of biochemistry and biophysics. University science press. Delhi. India.

CSIRO. 1990. Feeding Standards for Australian Livestock. Ruminants. (G. E. Robards and J. C. Radcliffe, Ed.). CSIRO Publications, East Melbourne, Australia.

Dalton, C. 1980. Introduction to Practical Animal Breeding. Granada. London. http://woolshed1.blogspot.com/2009/05/introduction-to-practical-animal_14.html. Accessed February 15, 2012.

DeOliveira, I. M., P. V. R. Paulino, S. C. V. Filho, E. Detmann, M. F. Paulino, L. A. M. Gomide, M. de S. Duarte, and V. R. M. Couto. 2011. Carcass traits of Nellore, F1 Simmental × Nellore and F1 Angus × Nellore steers fed at maintenance or ad libitum with two concentrate levels in the diet. R. Bras. Zootec. 40:2938-2946.

Dikeman, M. E. 2007. Effects of metabolic modifiers on carcass traits and meat quality. Meat Sci. 77:121–135.

Dubeski, P. L., J. L. Aalhus, S. D. M. Jones, A. K. W. Tong, and W. M. Robertson. 1997. Fattening heifers to heavy weights to enhance marbling: Efficiency of gain. J. Anim. Sci. 77:(4) 625-633.

Duckett, S. K. and J. G. Andrae. 2001. Implant strategies in an integrated beef production system. J. Anim. Sci. 79(E. Suppl.):E110–E117.

Elhashmi, A. H., A. El. Amin, and F. A. Omer. 2012. Growth and development of muscles bones and fat of guinea fowl (*Numida meliagris galeata*). J. Anim. Feed Res. 2(1):6-9.

Etherton, T. D. 1989. The mechanisms by which porcine growth hormone improves pig growth performance. Pages 97-105. In Biotechnology and Growth Regulation. R. G. Heap, C. G. Prosser and G. E. Lamming, eds. Butterworths, London.

Ferrell, C. L. and T. G. Jenkins. 1984. Energy utilization by mature, nonpregnant, nonlactating cows of different types. J. Anim. Sci. 58:234-243.

Ferrell, C. L. and T. G. Jenkins. 1985. Energy utilization by Hereford and Simmental males and females. Anim. Prod. 41:53-61.

Ferrell, C. L. and J. W. Oltjen. 2008. ASAS centennial paper: Net energy systems for beef cattle-concepts, application, and future models. J. Anim. Sci. 86:2779-2794.

Fortin, A., S. Simpfendorfer, J. T. Reid, H. J. Ayala, R. Anrique, and A. F. Kertz. 1980a. Effect of level of energy intake and influence of breed and sex on the chemical composition of cattle. J. Anim. Sci. 51:604-614.

Fortin, A., J. T. Reid, A. M. Maiga, D. W. Sim, and G. H. Wellington. 1980b. Effect of level of energy intake and influence of breed and sex on muscle growth and distribution in the bovine carcass. J. Anim. Sci. 51:1288-1296.

Garrett, W. N. 1971. Energetic efficiency of beef and dairy steers. J. Anim. Sci. 32:451-456.

Garrett, W. N. 1980. Energy utilization by growing cattle as determined in 72 comparative harvest experiments. In: L. EMount (Ed.) Energy Metabolism. Cambridge. Proc. 8th Symp., Page 3. EAAP Publ. No. 26 Butterworths, London.

Garrett, W. N. and D. E. Johnson. 1983. Nutritional energetics of ruminants. J. Anim. Sci. 57(Suppl. 2):478−497.

Geay, Y. 1984. Energy and protein utilization in growing cattle. J. Anim. Sci. 58:766-778.

Gerrard, D. E. and A. L. Grant. 2003. Principles of animal growth and development. Kendall/Hunt publishing company. Dubuque, IA.

Goonewardene, L. A., R. T. Berg, and R. T. Hardin. 1981. A growth study of beef cattle. Can. J. Anim. Sci. 6l: 1041- 1048.

Goonewardene, L. A., Z. Wang, R. W. Seneviratne, J. A. Basarab, E. K. Okine, J. Stewart-Smith , J. L. Aalhus, and M. A. Price. 2009. Comparison of growth rates in the tissues of primal cuts of Canadian composites. S. Afr. J. Anim. Sci. 39(5):289-293.

Gopinath, R. and W. D. Kitts. 1984. Growth, N^{τ} -methylhistidine excretion and muscle protein degradation in growing beef steers. J. Anim. Sci. 59:1262-1269.

Gotoh, T., E. Albrecht, F. Teuscher, K. Kawabata, K. Sakashita, H. Iwamoto, and J. Wegner. 2009. Differences in muscle and fat accretion in Japanese Black and European cattle. Meat Sci. 82:300–308.

Gray, R. and K. J. McCracken. 1980. Plane of nutrition and the maintenance requirement. Energy Metab. Proc. Symp. 26:163–167.

Grier, K. 2002. Beef demand and health and food safety risks. George Morris centre. http://www.georgemorris.org/publications/file.aspx?id=f8c382c3-67dc-4692-a400-94caa6e33f64. Accessed August, 2012.

Guenther, J. J. 1974. Physiological maturity evaluation of cattle differing in mature size. Proc. Reciprocal Meat Conf. 27:28-55.

Hammond, J. 1932. Growth and Development of Mutton Qualities in Sheep. Oliver and Boyd, London, UK.

Hand, R., L. A. Goonewardene, B. J. Yaremcio, and R. Westra. 1992. A study on the prevalence of cracked claws among beef cows. Can. J. Anim. Sci. 72:165-168.

Henrique, D. S., A. C. de Queiroz, R. A. M. Vieira, and M. F. Botelho. 2009. Energetic efficiency of protein and body fat retention in crossbred *Bos indicus* and *Bos Taurus* × *Bos indicus* raised under tropical conditions. R. Bras. Zootec. 38(8):1581-1586.

Hicks, R. B., F. N. Owens, D. R. Gill, J. J. Martin, H. G. Dolezal, F. K. Ray, V. S. Hays, and C. A. Strasia. 1987. The effect of harvest date on carcass gain and carcass characteristics of feedlot steers. Oklahoma Agric. Exp. Stn. Res. Rep. MP-119. PP 351–358.

Huxley, J. S. 1932. Problems of relative growth. Lincoln Mac Veagh. The Dial Press, New York.

Johnson, E. R., R. M. Butterfield, and W. J. Pryor. l972. Studies of fat distribution in the bovine carcass. 1. The partition of fatty tissues between depots. Aust. J. Agric. Res. 23:381-388.

Johnson, E. R., D. D. Charles, and D. A. Baker. 2002. The distribution of muscle and bone weight in swamp buffalo (*Bubalus bubalis*), *Bos indicus* and *Bos taurus* Steers. Pertanika J. Trap. Agric. Sci. 25(1):19–26.

Johnson, D. E., C. L. Ferrell, and T. G. Jenkins. 2003. The history of energetic efficiency research: Where have we been and where are we going?. J. Anim. Sci. 81(E. Suppl.):E27-E38.

Johnston, D. J. 2001. Selecting for marbling and its relationship with other important economic traits. What impact does it have?. Pages 88–93. in Proc. Marbling Symp., Coffs Harbour, Australia. Cooperative Research Centre for Cattle and Beef Quality, Armidale, Australia.

Jones, S. D. M., M. A. Price, and R. T. Berg. 1980a. Fattening patterns in cattle. I. Fat partition among the depots. Can. J. Anim. Sci. 60:843-850.

Jones, S. D. M., M. A. Price, and R. T. Berg. 1980b. Fattening patterns in cattle. 2. Fat distribution among the wholesale cuts. Can. J. Anim. Sci. 60:851-856.

Jones, S. J. and J. A. Marchello. 1983. Lipolysis in subcutaneous adipose tissue from cattle varying in frame size and length of time on a finishing diet. J. Anim. Sci. 57:343-348.

Kempster, A. J., A. Cuthbertson, and G. Harrington. 1976. Fat distribution in steer carcasses of different breeds and crosses. 1. Distribution between depots. Anim. Prod. 23:25-34.

Kempster, A. J. 1981. Fat partition and distribution in the carcasses of cattle, sheep and pigs: a review. Meat Sci. 5:83-98.

Kleiber, M. 1961. The Fire of Life. An introduction to animal energetics. Wiley and Sons, New York, London.

Kleiber, M. 1972. Joules vs. calories in Nutrition. J. Nutr. 102:309-312.

Koch, R. M., M. E. Dikeman, D. M. Allen, M. May, J. D. Crouse, and D. R. Campion. 1976. Characterization of biological types of cattle. III. Carcass composition, quality and palatability. J. Anim. Sci. 43:48-62.

Koch, R. M., M. E. Dikeman, and J. D. Crouse. 1982. Characterization of biological types of cattle (cycle III). III. Carcass composition, quality, and palatability. J. Anim. Sci. 54:35-45.

Lawrence, T. L. J. and V. R. Fowler. 1997. Growth of farm animals. CAB International. New York.

Ledger, H. P. 1965. The body and carcass composition of East African ruminants. I. The composition of 'Improved Boran' *Bos indicus* steer carcasses. J. Agric. Sci. 65:261-284.

Leheska, J. M., J. L. Montgomery, C. R. Krehbiel, D. A. Yates, J. P. Hutcheson, W. T. Nichols, M. Streeter, Jr. J. R. Blanton, and M. F. Miller. 2009. Dietary zilpaterol hydrochloride. II. Carcass composition and meat palatability of beef cattle. J. Anim. Sci. 87:1384–1393.

Lobley, G. E., V. Milne, J. M. Lovie, P. J. Reeds, and K. Pennis. 1980. Whole body and tissue protein synthesis in cattle. Brit. J. Nutr. 43:491-502.

Lobley, G. E. 2003. Protein turnover—What does it mean for animal production? Can. J. Anim. Sci. 83:327–340.

Lofgreen, G. P. and W. N. Garrett. 1968. A system for expressing net energy requirements and feed values for growing and finishing beef cattle. J. Anim. Sci. 27:793-806.

López-Campos O., J. A. Basarab, V. S. Baron, J. L. Aalhus, M. Juárez. 2012. Reduced age at slaughter in youthful beef cattle: Effects on carcass merit traits. Can. J. Anim. Sci. 92: 449-463.

Loveday, H. D. and M. E. Dikeman. 1980. Diet energy and adipose composition, lipogenesis and carcass composition. J. Anim. Sci. 51:78–88.

Margeta, V., G. Kralik. G. Kušec, and U. Baulain. 2007. Allometric growth of tissues in pig hams. Poljoprivreda. 13(1):163-166.

May, S. G., H. G. Dolezal, D. R. Gill, F. K. Ray, and D. S. Buchanan. 1992. Effect of days fed, carcass grade traits, and subcutaneous fat removal on postmortem muscle characteristics and beef palatability. J. Anim. Sci. 70:444–453.

McCarthy, F. D., W. G. Bergen, and D. R. Hawkins. 1983. Muscle protein turnover in cattle of differing genetic backgrounds as measured by urinary N^{τ}-methylhistidine excretion. J. Nutr.113:2455–2463.

McMeekan, C. P. 1940. Growth and development in the pig with special reference to carcass quality characters. J. Agr. Sci. 30:276-343.

Millward, D. J., P. J. Garlick, and P. J. Reeds. 1976a. The energy cost of growth. Proc. Nutr. Soc. 35:339-349.

Millward, D. J., P. J. Garlick, D. O. Nnanyelugo, and J. C. Waterlow. 1976b. The relative importance of muscle protein synthesis and breakdown in the regulation of muscle mass. Biochem J. 156(1):185–188.

Mitchell, G. E., A. W. Reed, and S. A. Rogers. 1991. Influence of Feeding Regimen on the Sensory Qualities and Fatty Acid Contents of Beef Steaks. J. Food Sci. 56(4):1102-1103.

Muir, P. D., J. M. Deaker, and M. D. Brown. 1998. Effects of forage- and grain-based feeding systems on beef quality: A Review. New Zealand J. Agric. Res. 41:623-635.

Mukhoty, H. and R. T. Berg. 1973. Influence of breed and sex on muscle weight distribution of cattle. J. Agric. Sci. Camb. 81:317-326.

Nadarajah, K., T. J. Marlowe, and D. R. Notter. 1984. Growth patterns of Angus, Charolais, Charolais x Angus and Holstein x Angus cows from birth to maturity. J. Anim. Sci. 59: 957-966.

National Research Council. 1981. Effect of environment on nutrient requirements of domestic animals. Natl. Acad. Press, Washington, DC.

National Research Council. 2000. Nutrient requirements of beef cattle: Update 2000. 7th ed. Natl. Acad. Press, Washington, DC.

Ntunde, B. N., W. R. Usborne, and G. C. Ashton. 1977. Responses in meat characteristics of Holstein- Friesian males to castration and diet. Can. J. Anim. Sci. 57:449-458.

Okine, E. K., J. A. Basarab, L. A. Goonewardene, and P. Mir. 2004. Residual feed intake and feed efficiency: Differences and implications. Pages 27–38 in Proc. Florida Rumin. Nutr. Symp., Gainesville, FL.

Old, C. A. and W. N. Garrett. 1985. Efficiency of feed energy utilization for protein and fat gain in Hereford and Charolais steers. J. Anim. Sci. 60:766-771.

Owens, F. N., P. Dubeski, and C. F. Hanson. 1993. Factors that alter the growth and development of ruminants. J. Anim. Sci. 71:3138-3150.

Owens, F. N., D. R. Gill, D. S. Secrist, and S. W. Coleman. 1995. Review of some aspects of growth and development of feedlot cattle. J. Anim. Sci. 73:3152-3172.

Patterson, D. L., M. A. Price, and R. T. Berg. 1985. Patterns of muscle, bone and fat accretion in three biological types of feedlot bulls fed three dietary energy levels. Can. J. Anim. Sci. 65:351-361.

Pillen, S. 2010. Skeletal muscle ultrasound. Eur. J. Transl. Myol. 1(4):145–155.

Pitts, G. C. and T. R. Bullard. 1968. Some interspecific aspects of body composition in mammals. Pages 45 – 70. In body composition in animals and man. Natl. Acad. Sci. Washington, DC.

Pomeroy, R. W. 1960. Anatomical distribution of edible tissues in carcass. In recent Advances in Food science, ed. J. Howthorn and Leitch, Butterworths, London.

Preston, R. L. 1971. Effects of nutrition on the body composition of cattle and sheep. Pages 26–41. in Proc. Georgia Nutr. Conf., Atlanta.

Priyanto, R., E. Johnson, and D. G. Taylor. 2009. The growth patterns of carcass tissues within wholesale cuts in fattening steer. J. Indonesian Trop. Anim. Agric. 34:153-158.

Priyanto, R. and E. Johnson. 2011. Muscle growth and distribution in fattening steer of different breeds. Med. Pet. J. Anim. Sci. Tech. 34 (1): 19-22. http://microbiology.journal.ipb.ac.id/index.php/mediapeternakan/article/view/3163/2107. Accessed December 07, 2011.

Pullar, J. D. and A. J. F. Webster. 1977. The energy cost of fat and protein deposition in the rat. Brit. J. Nutr. 37:355-363.

Reeds, P. J, A. Cadenhead, M. F. Fuller, G. E. Lobley, and J. D. McDonald. 1980. Protein turnover in growing pigs: effects of age and food intake. Br. J. Nutr. 43: 445-455.

Sainz, R. D. and E. Hasting. 2000. Simulation of the development of adipose tissue in beef cattle. Pages 175-182. In Modelling Nutrient Utilization in Farm Animals. J. P. McNamara, J. France and D. E. Beever, eds. CAB International, Wallingford, U.K.

Schake, L. M. and J. K. Riggs. 1975. Caloric efficiency of beef production. J. Anim. Sci. 40:561-566.

Schwab, C. R., T. J. Baas, K. J. Stalder, and J. W. Mabry. 2006. Effect of long-term selection for increased leanness on meat and eating quality traits in Duroc swine. J. Anim. Sci. 84:1577–1583.

Seideman, S. C., H. R. Cross, R. R. Oltjen, and B. D. Schanbacher. 1982. Utilization of the intact male for red meat production: A review. J. Anim. Sci. 55:826-840.

Shahin, K. A. and R. T. Berg. 1985. Growth patterns of muscle, fat and bone and carcass composition of double muscled and normal cattle. Can. J. Anim. Sci. 65:279 -294.

Solis, J. C., F. M. Byers, G. T. Schelling, D. W. Forrest, J. F. Baker, and L. W. Greene. 1988. Maintenance requirements and energetic efficiency of cows of different breed types. J. Anim. Sci. 66:764-773.

Stanton, T. L. and J. Whittier. 2006. Estimating cattle performance with net energy. Colorado State University Extension service. Fact sheet 1.167. http://www.ext.colostate.edu/pubs/livestk/01617.html. Accessed October, 2012.

Statistics Canada. 2010. Food statistics –Analysis. http://www.statcan.gc.ca/pub/21-020-x/2009001/t021-eng.htm. Accessed September 10, 2012.

Suess, G. G., W. J. Tyler, and V. H. Brungardt. 1969. Influence of weight and nutrition upon muscle growth and intramuscular fat deposition in Holstein steers. J. Anim. Sci. 29:410-416.

Sussman, M. 1960. Animal growth and development. Prentice-Hall. Englewood Cliffs.

Tatum, J. D., Jr. F. L. Williams, and R. A. Bowling. 1986. Effects of Feeder-Cattle Frame Size and Muscle Thickness on Subsequent Growth and Carcass Development. III. Partitioning of Separable Carcass Fat. J. Anim. Sci. 62:132-138.

Taylor, St. C. S. 1980. Live weight growth from embryo to adult in domesticated mammals. Anim. Prod. 31:223-235.

Trenkle, A. and D. N. Marple. 1983. Growth and development of meat animals. J. Anim. Sci. 57:273-283.

Turner, C. H. 2006. Bone strength: current concepts. Ann. N. Y. Acad. Sci. 1068:429-446.

Van Barneveld, R. J. 2003. Modern pork production—Balancing efficient growth and feed conversion with product quality requirements and consumer demands. Asia Pac. J. Clin. Nutr. 12(Suppl.):S31.

Van Koevering, M. T., D. R. Gill, F. N. Owens, H. G. Dolezal, and C. A. Strasia. 1995. Effect of time on feed on performance of feedlot steers, carcass characteristics, and tenderness and composition of longissimus muscles. J. Anim. Sci. 73:21–28.

Warriss, P. D. 2010. Meat Science: an introductory text. 2nd ed. Cambridge University Press. Cambridge. U. K.

Waterlow, J. C. 2006. Protein turnover. CABI Publishing, Wallingford. U.K.

Webster, A. J. F.1985. Differences in the energetic efficiency of animal growth. J. Anim. Sci. 61:92-103.

Wegner, J., E. Albrecht, I. Fiedler, F. Teuscher, H. J. Papsteinand, and K. Ender. 2000. Growth- and breed-related changes of muscle fiber characteristics in cattle. J. Anim. Sci. 78:1485-1496.

Williams, A. R. 2002. Ultrasound applications in beef cattle carcass research and management. J. Anim. Sci. 80 (E.suppl.2):E183-E188.

Williams, C. B. and T. G. Jenkins. 2003. A dynamic model of metabolizable energy utilization in growing and mature cattle. III. Model evaluation. J. Anim. Sci. 81:1390-1398.

Xiong, Y. L., W. G. Moody, S. P. Blanchard, G. Liu, and W. R. Burris. 1996. Postmortem Proteolytic and Organoleptic Changes in Hot-Boned Muscle from Grass- and Grain-Fed and Zeranol-Implanted Cattle. Food Research International. 29(1):27-34.

Yang, Y. T. and M. A. McElligott. 1989. Multiple action of /3-adrenergic agonists on skeletal muscle and adipose tissue. Biochemistry. 261:1-10.

Chapter 2. Energy partitioning among carcass tissues of different composite types relative to age at harvest

2.1 Introduction

Feed conversion ratio, average daily gain, residual feed intake (metabolic efficiency), carcass characteristics and energetic efficiency of gain are the major components which determine the profit or loss in beef production (Barber et al., 1981; Crews, 2005). The relative proportions of muscle (M), fat (F), and bone influence the quality of the beef carcass and different biological types follow different tissue distribution patterns (Patterson et al., 1985). Crosses of early maturing British breeds, late maturing Continental breeds, combinations of British and Continental crosses and a small percentage of purebreds constitute the Canadian beef industry (Goonewardene et al., 2009). Barber et al. (1981) found a significant difference of M and F deposition among breeds and as such, they suggested a different feeding management for each type so as to reduce feed waste.

Although high dietary energy intake in feedlot increases the weight gain and feed efficiency of cattle, faster F deposition and reduced M deposition could be observed in small and early maturing cattle (Prior et al., 1977). In contrast, large framed and late maturing cattle tend to increase F slightly with respect to energy density of the diet in feedlot (Prior et al., 1977). Hence, an understanding of their carcass composition is important to determine the suitable harvesting ages of different composite types (Goonewardene et al., 2009). In addition, weight, proportions, and distribution of tissues changes with the age (or weight) of cattle are important (Koch and Dikeman, 1977; Jones et al., 1980). The carcass F content and proportion increases while proportions of M and bone decrease as the harvest weight (or age) of the cattle increases (Steen and Kilpatrick, 1995). Hence, the M to F ratio in the animal body decreases as the animal grows. Furthermore, F depots in the body and estimated separable F in the carcass increases with increasing harvest weight (Patterson et al., 1994). Jesse et al. (1976) stated that harvest age and plain of nutrition (energy intake) significantly affects the body F content in beef. In general, the carcass F content and proportion can be reduced by harvesting animals at lighter weights (Steen and Kilpatrick, 2000).

The amount of energy consumed as feed is called gross energy intake (GEI) and considerable proportion of it is lost as faecal energy, gaseous energy, urinary energy or heat, and finally a part of it is recovered as product (Ferrell and Oltjen, 2008). As a greater amount of energy is associated with F deposition (six times higher than M deposition in dry basis without turnover), animals need to use more feed to gain similar amount of body weight at a later stage of life (Warriss, 2010), because at this time predominantly F is deposited. Feed efficiency is reduced when the animal produces more F and less protein (muscle) due to the higher caloric content (9.385 kcal g^{-1}) and lower moisture (10% water) content of F tissues (Brethour, 2004). Understanding the partitioning of energy among different tissues allows a more precise prediction of energy requirements and distinguishing major growth and functional characters of animals with respect to the genetic and environmental conditions (Tess et al., 1984).

The time of harvest of cattle is determined primarily by fatness and bodyweight. In Canada, crossbred cattle of most biological types, on average, are harvested at 18 months of age, ranging between 14 to 21 months of age (Alberta Agriculture and Rural Development, 2011). Each animal has an optimal harvest time (days on feed) which maximizes the profit margins. In addition, carcass quality and meat quality attributes such as weight, back fat thickness, marbling, flavour, juiciness, and tenderness also determine the price paid for beef (Bures and Barton, 2012).

Tenderness is another important quality attribute in beef, and several *ante-mortem* factors such as genotype, production system, age, growth promotants as well as *post-mortem* factors such as carcass suspension, aging time, electrical stimulation have a pronounced effect on the tenderness of the meat (Swatland, 1984; Juárez et al., 2012). Beef tenderness is considerably affected by the age at harvest rather than by early growth (Purchas et al., 2002). Complexity and the amount of collagen (connective tissues) in muscles increase with harvest age thereby reducing tenderness (Arthur, 1995; Rhee et al., 2004). With the increase in the age of an animal, toughness of muscles increases due to forming and increasing collagen cross linkages between collagen helixes to improve the strength of the M (McCormick, 1999; Eyre and Wu, 2005). Hence harvesting younger cattle of different composite types at an optimum time helps to improve the tenderness.

Even though numerous studies have been conducted on optimum harvest times for the early and late maturing biological types on an economic end point, few studies were based on energetic efficiency. Thus, the hypothesis was that all composite types have similar F and M energy deposition patterns and they can be harvested at a similar age. The objectives were 1) to determine the energetic efficiency of producing M and F relative to five composite types representing biological types and 2) to determine optimum harvest times for the different composite types based on energetic efficiency and carcass quality characteristics.

2.2 Materials and methods

Management of the animal

Over two years (2000 and 2001), 176 crossbred steers from five BeefBooster® composite types (M1, M2, M3, M4, and TX) were used to determine the energy requirements for M and F. The foundation breed(s) for M1 was Angus; M2 was Hereford; M3 was small breed types such as Jersey, Longhorn, Shorthorn, Red Poll; M4 was Limousin and Gelbvieh, and TX was Charolais (Rossi et al., 1992; Kress et al., 1996). The animals were spring-born steers which arrived at the Lacombe Research Center, Lacombe, Alberta in early December of 1999 and 2000 at around 7-8 months of age. In 1999, the average weight of calves was 296.6 kg (SD=37) and the average age was 232 (SD=14) days. In 2000, the average weight was 285.4 kg (SD= 39) and the average age was 238 (SD= 14) days. One month before arrival at the Lacombe Research Center, cattle were surgically castrated and treated using a pour-on parasiticide and were vaccinated for IBR, PI3, BVD, *Haemophilus somnus, Pasteurella multocida,* and Clostridial diseases. Growth implants were not used. Radio frequency (RF) transponder buttons (Allflex USA, Inc., Dallas/Fort Worth Airport, Texas 75261-2266, USA) were used for identification of each steer and it was attached 5-6 cm from the base of the right ear. Steers were housed in one large pen 86 m length and 46 m width (44 m^2 per animal) and woodchips and shavings were placed as bedding as needed. Cattle were adapted to feed from the GrowSafe® system and ten individual animal feeding stations were used for feeding. All the animals used were reared under the guidelines of the Canadian Council on Animal Care (1993).

At the beginning, there was a 30 to 40 day pre-trial period and animals were fed with a diet that contained 88% barley silage, 10.4% barley grain, and 1.6% feedlot supplement (as-fed basis) ad libitum. Then gradually the diet was adjusted up to 73.3% grain over 34 days in the pre-trial period. The actual research commenced following the pre-trial period where the animals were fed a diet consisting of 73.3% barley grain, 22.0% barley silage, 1.6% molasses, and 3.1% feed supplement (as-fed basis) ad libitum over 182 days.

Feed samples were collected weekly, pooled monthly and frozen until analyzed. Dry matter content was found by drying a sample in a forced-air oven at 100 °C until it reached a constant weight whereas organic matter content was estimated by making ash of dry samples at 550 °C [Association of Official Analytical Chemists (AOAC), 1980]. The Kjeldahl method was used to estimate the nitrogen content in the feed and crude protein content was calculated by multiplying nitrogen content by 6.25 (Bradstreet, 1965). Six Suffolk sheep (84 ± 5 kg) were used in a digestible trial at the metabolic unit of the University of

Alberta (Edmonton, Canada) to determine the digestible energy content of the feed (Basarab et al., 2003).

Metabolizable energy (ME) content of the feed was calculated using the equation of ME = DE x 0.82 (NRC, 2000). The metabolizable energy of the feed which was fed to calves in 2000 was 11.77 MJ kg^{-1} whereas in 2001 the value was 11.16 MJ kg^{-1}. The net energy (NE) of the feed for maintenance (NE_m) and NE of feed for gain (NE_g) was calculated using $NEm = 1.37\ ME - 0.138\ ME^2 + 0.0105\ ME^3 - 1.12$ and $NE_g = 1.42\ ME - 0.174 ME^2 + 0.0122 ME^3 – 1.65$ (NRC, 2000). The net energy gain of the finishing feed diet in 2000 was 5.18 MJ kg^{-1} and in 2001 was 4.71 MJ kg^{-1} (Table 2.1; Basarab et al., 2003).

Harvest and tissue analysis

The fifteen steers were randomly selected on 1 d (age = 274 d), 71 d (age= 347 d), 99 d (age= 372 d), 127 d (age= 399 d), 155 d (age=427 d) and 183 d (age= 456 d) of the finishing period and three steers from each BeefBooster® strain were slaughtered on the following day at the Lacombe Research Center abattoir. A captive bolt gun was used for stunning steers. Empty body weight was calculated by subtracting gut content weight from slaughter weight. Weights of the warm carcass, right and left halves and weights of all the body parts which were hide, blood, head and tongue, feet, tail, reproductive tract, kidney, liver, heart, spleen, lungs and trachea, bladder, kidney fat, small and large intestine (before and after cleaning), stomach complex (rumen, reticulum, omasum and abomasum before and after cleaning), and F tissues attached to internal body parts of every individual animal were separated and measured.

Table 2.1. Ingredient composition of the finishing diet for steers

	year			
	2000		2001	
	Mean[x]	SD	Mean[x]	SD
Diet ingredients (% as fed basis)				
Barley silage (29.7% dry matter)	22.00		22.00	
Steam rolled barley	73.30		73.30	
Molasses	1.60		1.60	
32% beef supplement	3.10		3.10	
Diet composition[y] (DM basis)				
Dry matter (%)	75.10	1.30	75.60	0.90
Metabolizable energy (MJ kg^{-1})	11.77	0.94	11.16	0.65
NE_m[z] (MJ kg^{-1})	7.84		7.30	
NE_g[z] (MJ kg^{-1})	5.18		4.71	
Crude protein (%)	13.30	0.60	12.00	1.00
Calcium (%)	0.44	0.25	0.71	0.36
Phosphorus (%)	0.37	0.01	0.37	0.02
Acid detergent fibre (%)	11.40	2.10	11.40	2.10
Neutral detergent fibre (%)	25.70	6.00	25.70	6.00
Lignin (%)	2.10	0.50	2.10	0.50
Ash (%)	4.70	1.10	4.70	1.10

[x] Samples of the total mixed finishing diet were collected weekly, pooled and analyzed monthly (*n* = 6).

[y] Diet contains 0.55 mg kg^{-1} Co, 1 mg kg^{-1} I, 13.5 mg kg^{-1} Cu, 42.4 mg kg^{-1} Mn, 48.8 mg kg^{-1} Zn, 4212 IU kg^{-1} vitamin A, 421 IU kg^{-1} vitamin D,4 IU kg^{-1} vitamin E and 17.2 mg kg^{-1} monensin sodium.

[z] Values were calculated using the equations for converting metabolizable energy values to NE_m and NE_g (NRC, 2000).

Source: Basarab et al. (2003)

The offal which is a combination of non-carcass tissues of each animal were grounded separately using a large screw grinder through a 5 mm plate (Autio Company, Route 4, Box 480, Astoria, Oregon 97103, USA). After remixing and re-grounding through an extra pass in the grinder, triplicate subsamples (0.5 kg/ sample) were taken and stored at -20 °C for standard proximate analysis. Cold carcass weights of each right and left halves of the carcass were measured after a 24-hr chill and the left side of each carcass was divided into nine primal cuts; round, loin, flank, short loin, chuck, rib, plate, brisket, and shank. Further each cut was separated into muscle, fat, and bone, and the fat tissues were dissected out into three categories as subcutaneous, intermuscular, and body cavity fat.

All the M, F, and B of the carcass were ground and mixed separately for each animal. Subsamples (0.5 kg) in triplicate were acquired from ground carcass M, F, and B and stored at -25 °C. After removing all the samples from freezer at a later date, they were kept in a 4 °C cooler for 24-hr to determine freezer loss. Moisture loss of each sample was estimated by placing 100 g of grind sample in a gravity convection-drying oven at 105 °C for 24-hr (VWR Scientific Model 1370FM, Mississauga, ON). Average moisture loss of each animal was estimated using triplicate moisture samples. After the dried samples were pulverized to a fine grind, they were analyzed in duplicate to determine crude fat content using petroleum ether extraction (Tecator Soxtec System HT–1043, Tecator Ltd., Hoganas, Sweden) as well as nitrogen content was determined using nitrogen/protein determinator (CNS2000, Leco Corp., St. Joseph, MI). The final mean values of crude fat and nitrogen were calculated omitting highest and lowest from six values and averaging the rest. The mean moisture, F, and protein values were used for proximate analysis. The data and management information of steers were taken from the experiment conducted by Basarab et al. (2003).

Energy calculations for muscle and fat

The feeding event feed intake data obtained from the GrowSafe® System (GrowSafe Systems Ltd., Airdrie, Alberta, Canada) were used to calculate daily feed intake of each animal. The total feed intake during the feedlot period was calculated for each animal. These values were multiplied by the dry matter percentage of the diet to obtain feed dry matter content. The total available ME content of the feed was calculated using ME values which were 11.77 MJ kg^{-1} and 11.16 MJ kg^{-1} for 2000 and 2001 respectively (Basarab et al., 2003) (Table 2.1). In this analysis, we focused on the energy deposition of muscle and fat tissues. The muscle and fat weight of the carcass was used to calculate total deposited energy. The caloric value of fat and protein were 9.385 kcal g^{-1} and 5.539 kcal g^{-1} respectively (Brethour, 2004). Since a calorie is equal to the 4.184 joules (NRC, 2000), these values were converted as 39.267 KJ g^{-1} and 23.175 KJ g^{-1} for fat and protein respectively.

The average carcass muscle and fat gain per day for each animal was determined by dividing tissues weight by the age of the animal. The energy content of the deposited fat and protein was calculated in joules. The energy used for the fat and protein (muscle) gain was calculated using initial and final energy values of each composite type with the relevant number of days in the feedlot.

The day one parameters were used as the initial values (reference) to calculate tissue gain and total energy intake for gain. Total energy deposited was calculated by the summation of energy deposited as muscle and energy deposited as fat. The percentage of metabolizable energy used for protein and fat gain was calculated for different composite types at different time periods (5) in the feedlot.

Energy content of different fat tissues

Fat tissue was further divided into three dissectible depots subcutaneous, intermuscular, and body cavity. The energy content was calculated and the changes of proportions of each depot relative to composite type and harvest age were determined. Likewise the energy for intramuscular fat was determined in the whole carcass.

Calculation of intramuscular fat content in carcass

The muscle which contained the un-dissectible fat tissue from each primal cut of each steer was ground and pooled and subject to proximate analysis for fat, thereby obtaining the percent fat in the component. This tissue component best represented the intramuscular fat content in the half carcass which was dissected into M, F and B. The intramuscular fat in each primal cut was not determined. No data for energy required for intramuscular fat, total intramuscular fat and percent was available at the first harvest day (274 d) and these values were calculated by regressing marbling score on intramuscular fat required, total and percent for each composite type.

Statistical analysis

Analysis of energy in muscle and fat in whole carcass

The data from two consecutive years were pooled for each composite type since the effect of year was not significant ($P > 0.05$). The weight, energy content, and percentage of tissues were calculated for each animal assuming that both halves of the carcass had similar weights and tissue composition. The daily gain of fat and muscle for each animal was calculated by dividing tissue weight by age of the animal. Each animal was considered as an experimental unit and two way ANOVA model was used to determine the effect of composite types, slaughter date, and composite type x slaughter date interaction on the carcass, fat, and muscle tissue weight, energy content, and percentages. The General Linear Model (GLM) in SAS (SAS Inst. Inc., Cary, NC) was used for the analysis. The muscle to fat ratio was calculated with respect to different composite type at different harvest ages. The least squares means for fat and muscle tissue weight, energy content, and percentage as well as energy fat to energy muscle ratio with respect to composite type x harvest age interaction were determined. The values of three steers that exceeded three standard deviations were considered outliers and removed from the analysis. Fisher's LSD method was used for the multiple comparisons ($P < 0.05$). After finding a specific pattern in daily M and F gain, regression analysis was done to determine the regression coefficient and trend of daily M and F growth (gain) against age of the composite types.

2.3 Results

The cold carcass weight and percent M, F, and B expressed as a percentage of the cold carcass weight (M+ F+ B) of each composite type with respect to different harvest ages are shown in Table 2.2. Both composite type and harvest age were significant ($P < 0.01$) for these traits and the interaction was not significant ($P > 0.05$). The carcases weight and the proportion of F in each composite type increased ($P < 0.01$) with harvest age whereas M and B proportions decreased ($P < 0.01$) with age. The carcass weight of both M1 and M2 composite types doubled (100%) within 182 d in feedlot whereas the carcass weights of M3, M4, and TX increased by 93%, 91%, and 78% respectively. The proportion of M in the carcass decreased during the 182 d by 8% for both the M1 and M2 whereas it decreased by 12%, 9%, and 5% for M3, M4, and TX respectively. The proportion of fat increased by 14%, 14%, 17%, 14%, and 10% and proportion of bone decreased by 6%, 5%, 5%, 5%, and 5% during the 182 d in feedlot for M1, M2, M3, M4, and TX respectively. The proportion of bone decreased by almost similar ($P > 0.05$) proportions for all the composites.

The rates of gain of muscle and dissectible fat in kg per day of age are shown in Table 2.3. The average M gain of all the composite types increased with the harvest age and after reaching a peak decreased gradually. The average M gains of different composite types were different at the peak and that value was higher for M1, M2, M4, and TX composite types (around 450 g per day) whereas the values were lower ($P < 0.01$) for M3 the small composite type (around 350 g).

Table 2.2. Carcass traits (least square means) of composite types (CT) at different harvest ages

		Harvest age (days)*					
Trait	CT^y	274 d	347 d	372 d	399 d	427 d	456 d
Carcass weight (kg)	M1	167.40	269.46	271.65	293.06	311.25	331.04
	M2	178.93	235.29	276.56	314.99	339.78	361.71
	M3	135.52	205.47	238.91	251.54	273.83	261.76
	M4	179.27	261.59	285.38	281.51	306.58	342.96
	TX	186.10	271.21	297.35	306.33	331.82	332.26
	SEM	7.96	8.17	10.44	12.64	11.01	9.33
Muscle^x (%)	M1	61.71	56.75	57.21	54.06	53.60	53.54
	M2	62.66	60.62	57.26	55.88	55.04	54.18
	M3	62.11	57.18	55.27	55.68	54.45	49.74
	M4	64.50	60.56	58.96	59.18	57.77	55.13
	TX	63.30	60.48	60.04	59.01	56.14	57.92
	SEM	0.80	1.12	1.17	1.20	0.97	1.05
Fat^x (%)	M1	18.68	27.77	27.38	31.57	32.30	32.34
	M2	17.63	22.34	25.93	29.17	29.97	31.33
	M3	19.57	27.25	29.99	30.21	30.97	36.64
	M4	16.58	22.93	25.78	25.85	27.41	31.11
	TX	17.52	23.83	24.05	24.97	27.69	27.53
	SEM	1.11	1.29	1.36	1.40	1.05	1.18
Bone^x (%)	M1	19.61	15.48	15.40	14.38	14.09	14.12
	M2	19.71	17.05	16.81	14.95	14.99	14.50
	M3	18.32	15.57	14.73	14.11	14.58	13.62
	M4	18.92	16.50	15.26	14.97	14.82	13.76
	TX	19.18	15.69	15.91	16.02	16.17	14.55
	SEM	0.65	0.41	0.45	0.40	0.39	0.37

^{x} proportion of tissue weight compared to total carcass weight.

CT^y M1- composites based on Angus (n= 32, early maturing), M2- composites based on Hereford (n= 34, early maturing), M3- composites of small breeds (n=36, early maturing) M4-composites based on Gelbvieh, Limousin (n=36, late maturing), TX-composites based Charolais dams (n=35, late maturing).

*Harvest age is the average age of composites serially slaughtered at six time points. The differences between harvest ages within CTs were always significant ($P < 0.01$).

Table 2.3. Growth rates (least square means) of muscle and dissectible fat (kg d^{-1}) tissues of composite types at different harvest ages

	Harvest age (days)*						P value ^{z}
CT^{y}	274 d	347 d	372 d	399 d	427 d	456 d	
Muscle gain (kg d^{-1})							
M1	0.388a	0.432a	0.425a	0.394a	0.391a	0.393a	0.56
M2	0.411a	0.407a	0.444a	0.441b	0.431ac	0.425ac	0.44
M3	0.309b	0.339b	0.347b	0.341c	0.341b	0.282b	<0.01
M4	0.408a	0.447ac	0.440a	0.417ab	0.410ac	0.411ac	0.47
TX	0.444a	0.485c	0.488c	0.464db	0.449c	0.432c	0.09
SEM	0.020	0.017	0.015	0.016	0.016	0.013	
Fat gain (kg d^{-1})							
M1	0.116	0.210a	0.203	0.238a	0.235	0.235ab	<0.01
M2	0.115	0.150b	0.199	0.231a	0.220	0.245a	<0.01
M3	0.098	0.163bc	0.189	0.187b	0.195	0.208b	<0.01
M4	0.107	0.169bc	0.193	0.181b	0.195	0.232ab	<0.01
TX	0.123	0.189ac	0.195	0.198ab	0.223	0.207b	<0.01
SEM	0.009	0.010	0.012	0.015	0.014	0.010	

CT^{y} M1- composites based on Angus (early maturing), M2- composites based on Hereford (early maturing), M3- composites of small breeds (early maturing) M4-composites based on Gelbvieh, Limousin (late maturing), TX-composites based Charolais dams (late maturing).

^{z}*P* value refers to harvest age within composite type.

a,b least square means with different letters in columns denote significance differences among composite types for each harvest age ($P < 0.05$). Letters are only shown when means are different ($P < 0.05$).

*Harvest age is the average age of composites serially slaughtered at six time points.

In contrast, F gain was around 100 g per day for all the composite types ($P > 0.05$) at the beginning of feedlot period (274 d) and continuously increased with the age (Table 2.3). The M gain decreased with time since more energy was used for F deposition. Average daily F gain increased by 102%, 113%, 112%, 116%, and 68% for M1, M2, M3, M4, and TX respectively from 274-456 d.

The daily M and F gain for the M1 composite type at different harvest ages is shown in Figure 2.1. The daily M gain increased up to 347 d and after that point it declined and remained constant. Although slight fluctuations were observed, daily dissectible F gain continuously increased over harvest age.

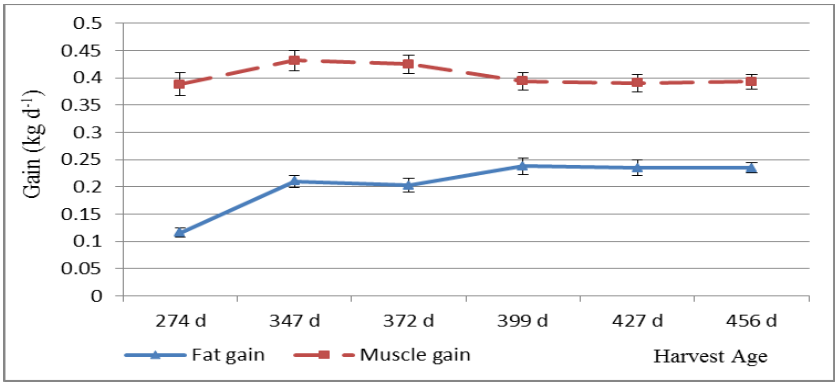


Figure 2.1 Daily muscle and dissectible fat gain for the M1 composite type at different harvest ages

The daily M and F gain for the M2 composite type at different harvest ages is shown in Figure 2.2. The daily M gain increased up to 372 d and after that point it declined with increasing harvest age. Although a slight fluctuation was observed, daily dissectible F gain continuously increased over harvest age.

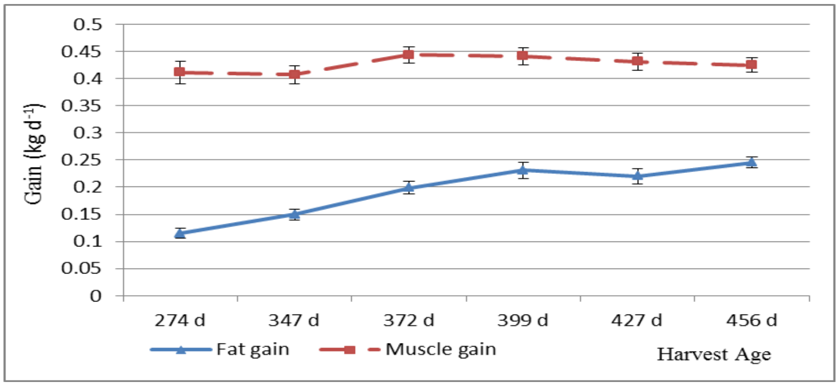


Figure 2.2 Daily muscle and dissectible fat gain for the M2 composite type at different harvest ages

The daily M and F gain for the M3 composite type at different harvest ages is shown in Figure 2.3. The daily M gain increased up to 372 d and it remained constant up to 427 d and declined at 456 d. The daily dissectible F gain continuously increased over harvest age.

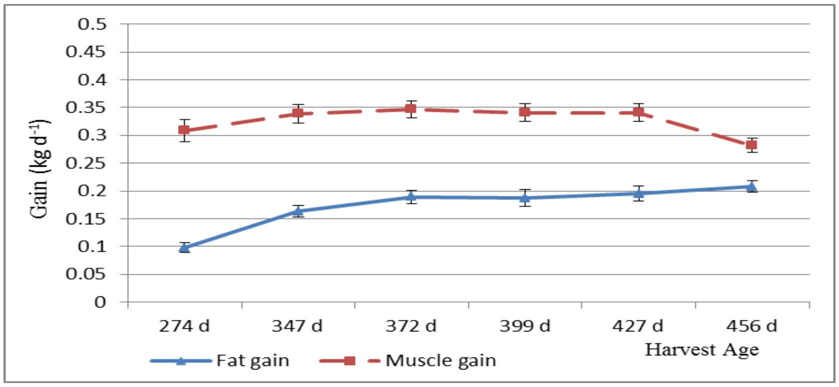


Figure 2.3 Daily muscle and dissectible fat gain for the M3 composite type at different harvest ages

The daily M and F gain for the M4 composite type at different harvest ages is shown in Figure 2.4. The daily M gain increased up to 347 d and it declined with harvest age at a lower rate. The daily dissectible F gain continuously increased over harvest age.

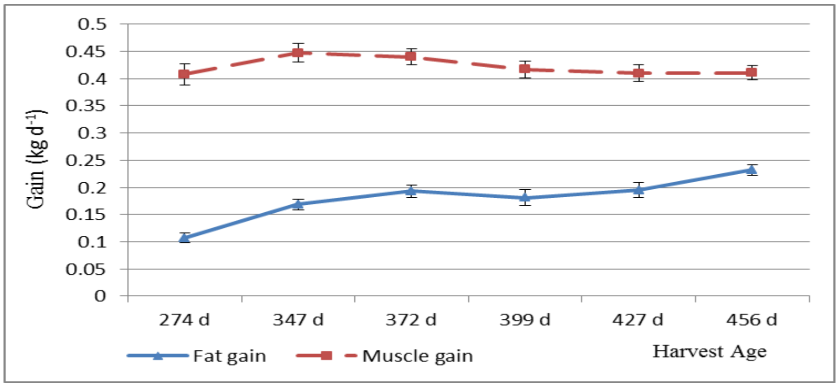


Figure 2.4 Daily muscle and dissectible fat gain for the M4 composite type at different harvest ages

The daily M and F gain for the TX composite type at different harvest ages is shown in Figure 2.5. The daily M gain increased up to 372 d and then declined with increasing harvest age. The daily dissectible F gain increased comparatively at a slower rate over harvest age.

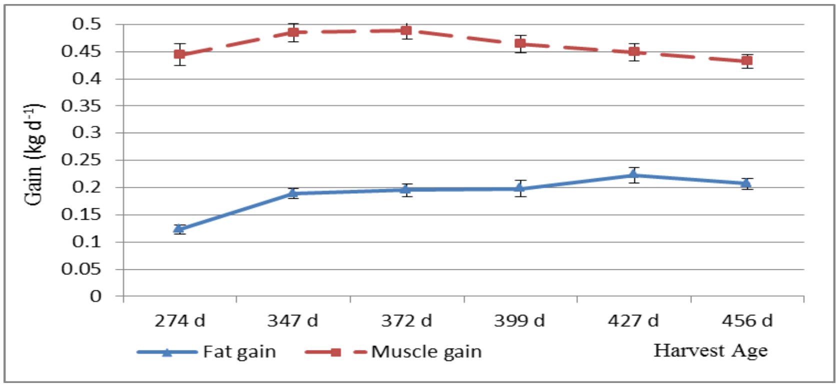


Figure 2.5 Daily muscle and dissectible fat gain for the TX composite type at different harvest ages

The total energy deposited in the tissues (retained energy), energy deposited in muscle, energy deposited in dissectible fat and energy muscle to energy dissectible fat ratio in the carcass is shown in Table 2.4 for the composites at different harvest ages.

The total energy deposition (energy fat + energy protein) increased with the harvest age of the animal with different rates and composite type x harvest day interaction was significant for total energy ($P < 0.05$) (Table 2.4). The total energy deposition more than doubled during the 182 d for all the composite types and energy values increased by 129%, 134%, 126%, 122%, and 100% for M1, M2, M3, M4, and TX respectively. The total energy deposition was numerically higher ($P > 0.1$) for early maturing composite types (M1 + M2) and lower for late maturing (M4 + TX) composite types during 399 – 456 d.

Table 2.4. Comparison of energy used to grow body tissues of composite types at different harvest ages

		Harvest age (days)*					
Trait	CT^y	274 d	347 d	372 d	399 d	427 d	456 d
Total energy (MJ)	M1	3623.85a	6479.71a	6523.86ab	7303.03ac	7809.89ac	8299.38ac
	M2	3834.94a	5370.40b	6493.57ab	7692.73a	8335.13a	8986.97a
	M3	2995.41b	4925.61b	5881.09b	6237.13b	6787.11b	6782.95b
	M4	3856.99a	6025.35a	6792.55a	6713.33bc	7406.57bc	8570.25ac
	TX	4012.50a	6334.66a	6947.14a	7207.64ac	7933.60ac	8063.05c
	SEM	190.05	201.85	286.73	338.48	292.01	237.14
Muscle energy (MJ)	M1	2401.88a	3552.29ac	3602.72a	3664.09ab	3869.33ab	4117.46a
	M2	2601.18a	3303.39a	3663.53a	4073.12ac	4334.31c	4545.89b
	M3	1951.04b	2715.67b	3050.47b	3234.79b	3453.87a	3016.87c
	M4	2671.79a	3673.27ac	3892.04ac	3870.41ac	4102.01bc	4378.26ab
	TX	2727.07a	3809.54c	4138.78c	4178.33c	4313.98c	4451.03ab
	SEM	119.75	139.43	135.27	159.87	148.73	143.68
Fat energy (MJ)	M1	1221.98	2927.42a	2921.14	3638.94	3940.56ac	4181.92ab
	M2	1233.76	2067.01b	2830.04	3619.62	4000.82ac	4441.08a
	M3	1044.37	2209.94bc	2830.62	3002.34	3333.23b	3766.08bc
	M4	1185.20	2352.08bc	2900.51	2842.92	3304.57b	4192.00ab
	TX	1285.44	2525.12ac	2808.36	3029.31	3619.62bc	3612.03c
	SEM	98.59	143.80	215.48	241.28	191.96	185.93
Energy muscle to energy fat ratio	M1	1.99	1.22a	1.24ab	1.02a	0.98a	0.99a
	M2	2.16	1.62b	1.32abc	1.14ab	1.09abc	1.03a
	M3	1.89	1.26a	1.11a	1.11a	1.06ac	0.80b
	M4	2.38	1.58b	1.38bc	1.38bc	1.26b	1.05a
	TX	2.17	1.55b	1.50c	1.43c	1.20bc	1.26c
	SEM	0.17	0.10	0.09	0.10	0.06	0.06

CT^y M1- composites based on Angus (early maturing), M2- composites based on Hereford (early maturing), M3- composites of small breeds (early maturing) M4-composites based on Gelbvieh, Limousin (late maturing), TX-composites based Charolais dams (late maturing).

a,b least square means with different letters in columns denote significance differences among composite types for each harvest age ($P < 0.05$). Letters are only shown when means are different ($P < 0.05$).

*Harvest age is the average age of composites serially slaughtered at six time points. The differences between harvest ages within CTs were always significant ($P < 0.01$).

The energy deposited in both the M and dissectible F tissues increased (*P* < 0.01) with harvest age as body weight increased with the age of an animal (Table 2.4). The M energy increased by 71%, 75%, 55%, 64%, 63% and the F energy in the carcass increased by 242%, 260%, 261%, 254%, 181% for M1, M2, M3, M4, and TX respectively during the 182 d in feedlot. The energy used for M deposition to energy used for F deposition ratio gives a clear picture about the energy partitioning pattern of the composite types (Table 2.4). At the beginning of feedlot period, the ratio was high and all the composite types with the exception of M3 used twice as much energy to deposit muscle than fat (2:1). However with age, the ratio decreased for all the composite types except TX to a ratio of approximately 1:1. M3 composite types reached a 1:1 ratio after 99 d in feedlot, M1 after 127 d, M2 after 155 d, M4 after 182 d and ratio for TX was 1:1.3 at the end of feedlot period (182 d). At 399 d the M: F energy ratio was higher (*P* < 0.05) for late maturing composite types (M4 and TX) compared to early maturing composite types. At the 456 d, the ratio was highest (1.3) for TX (*P* < 0.05) and lowest (0.8) for M3 relative to other composite types.

The proportion of energy used for M accretion decreased (*P* < 0.01) with the age and proportion of energy used for dissectible F deposition increased (*P* < 0.01) with age (Table 2.5). Even on the first day (274 d) in feedlot, the M3 composite type (small breeds) had the lower muscle (protein) energy percentage (65%) and higher fat energy percentage (35%) compared to other composite types. All the other composite types contained more or less similar proportions (*P* > 0.05) of both the muscle and fat energy at 274 d.

Table 2.5. Proportions of energy deposited in muscle and dissectible fat tissues of composite types at different harvest ages

		Harvest age (days)*						*P* value[z]
Trait	CT[y]	274 d	347 d	372 d	399 d	427 d	456 d	
Muscle energy [x] (%)	M1	66.19	54.73a	55.24ab	50.32a	49.52a	49.55a	<0.01
	M2	67.84	61.60b	56.69ab	53.11ab	52.04ab	50.57a	<0.01
	M3	65.24	55.44a	52.18a	52.21a	51.02a	44.51b	<0.01
	M4	69.74	60.96b	57.56b	57.59bc	55.48b	51.16a	<0.01
	TX	68.15	60.14b	59.68b	58.39c	54.50b	55.46c	<0.01
	SEM	1.61	1.69	1.72	1.78	1.30	1.43	
Fat energy [x] (%)	M1	33.81	45.27a	44.76ab	49.68a	50.48a	50.45a	<0.01
	M2	32.15	38.40b	43.31ab	46.89ab	47.96ab	49.43a	<0.01
	M3	34.76	44.56a	47.82a	47.79a	48.98a	55.49b	<0.01
	M4	30.25	39.04b	42.44b	42.41bc	44.52b	48.84a	<0.01
	TX	31.84	39.86b	40.32b	41.61c	45.50b	44.54c	<0.01
	SEM	1.61	1.69	1.72	1.78	1.30	1.43	

[x] proportion of tissue energy compared to total energy.

CT[y] M1- composites based on Angus (early maturing), M2- composites based on Hereford (early maturing), M3- composites of small breeds (early maturing) M4-composites based on Gelbvieh, Limousin (late maturing), TX-composites based Charolais dams (late maturing).

[z] *P* value refers to harvest age within composite type.

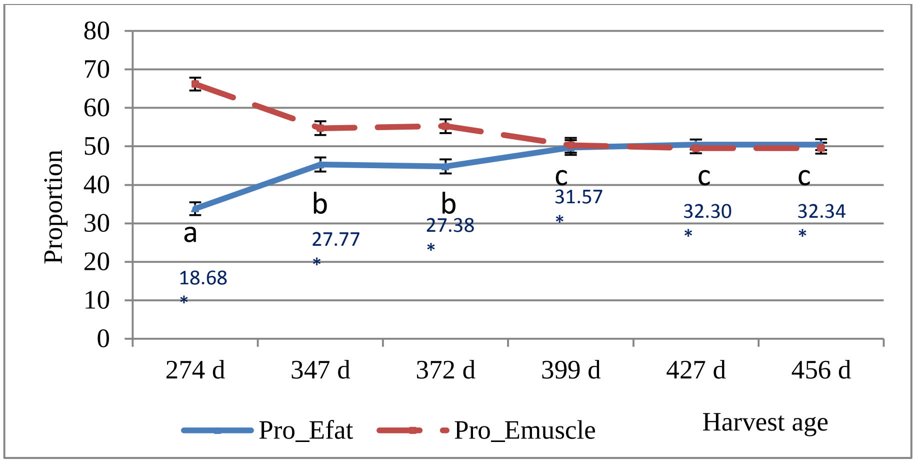
a,b least square means with different letters in columns denote significance differences among composite types for each harvest age ($P < 0.05$). Letters are only shown when means are different ($P < 0.05$).

*Harvest age is the average age of composites serially slaughtered at six time points.

At the 399 d, the fat energy percentage was lower ($P < 0.05$) and muscle energy percentage was higher ($P < 0.05$) for late maturing composite types (M4 and TX) than early maturing composite types (M1 and M3) (Table 2.5). After this period, M4 composites also increased the usage of energy for fat deposition and at the 456 d, the fat energy percentage was lower and protein energy percentage was higher ($P < 0.05$) for TX compared to all the other composite types. Late maturing composite types fattened more slowly compared to early maturing composite types. The muscle energy as a proportion of total energy decreased by 25%, 25%, 32%, 27%, 19% and fat energy as a percentage of total energy increased by 49%, 54%, 60%, 61%, 40% for M1, M2, M3, M4, and TX respectively during the 182 d in feedlot.

The Figures 2.6 - 2.10 represent the changes in the proportion of dissectible fat and muscle energy in composite types with harvest age. According to the Figure 2.6 – 2.10, each composite type has shown a specific point where the proportion (%) of energy from M and F intersect and at that point energy used for fat deposition is equal to the energy used for protein deposition. Beyond this equilibrium point, proportion of energy used for F deposition increased while the proportion of energy used for M deposition decreased. Therefore, beyond the point of intersection or equilibrium point as more of the energy is used for the fat deposition, energetic efficiency of muscle deposition is reduced. Early maturing composite types reached the equilibrium point at an earlier age whereas later maturing composites took more time to reach that specific point. Based on energetic efficiency of M deposition the equilibrium point for each composite indicates a optimum harvest age at which a composite should be harvested beyond which proportionately more energy will be utilized for fat synthesis and less for M.

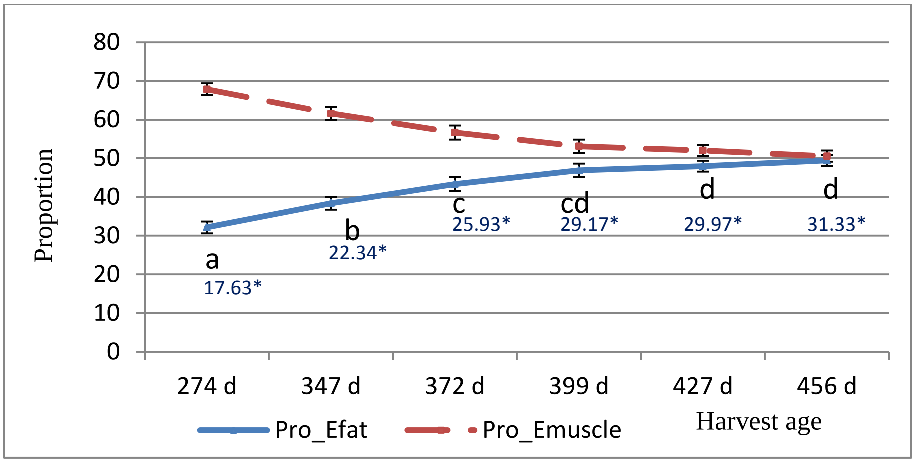
The proportion of muscle energy decreased with harvest age while the proportion of fat energy increased and two lines for muscle and fat energy intersected at 399 d for M1 (Figure 2.6). Hence, they can be harvested at around 399 d to maximize the proportion of muscle. However, if a fatter carcass is required, they can be harvested after 399 d.



* Percentages of fat weight in the carcass.
a,b least square means with different letters denote significance differences in harvest ages ($P < 0.05$).

Figure 2.6 Proportion of energy used for muscle (Pro_Emuscle) and fat (Pro_Efat) deposition at different harvest ages for the M1 composite type

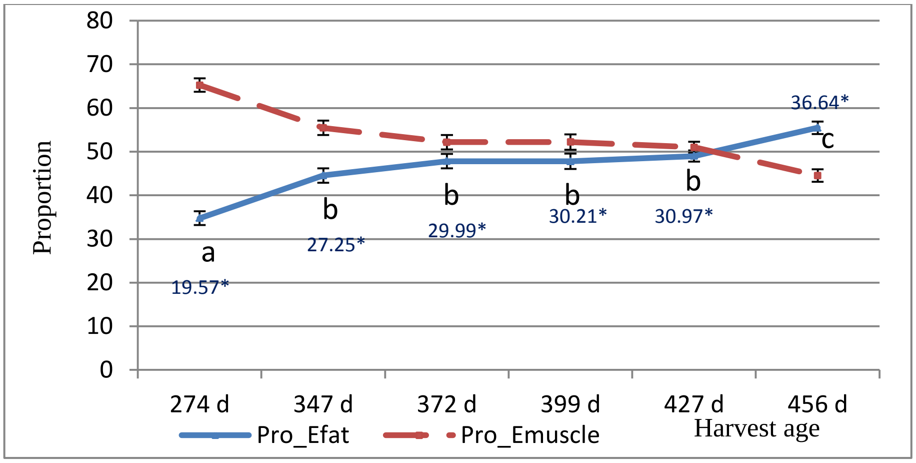
The proportion of muscle energy decreased with harvest age while the proportion of fat energy increased and two lines for muscle and fat energy intersected at 456 d for M2 (Figure 2.7). The proportions of fat energy at different harvest ages which were demarcated by similar letters were not different ($P > 0.05$). The proportion of fat energy at 399 d, 427 d and 456 d was not different ($P > 0.05$) for M2 composite type and therefore, they can be harvested at 399 d or 427 d to maximize the proportion of muscle. However, if a fatter carcass is required, they can be harvested after 427 d.



*Percentages of fat weight in the carcass.
a,b least square means with different letters denote significance differences in harvest ages (*P* < 0.05).

Figure 2.7 Proportion of energy used for muscle (Pro_Emuscle) and fat (Pro_Efat) deposition at different harvest ages for M2 composite type

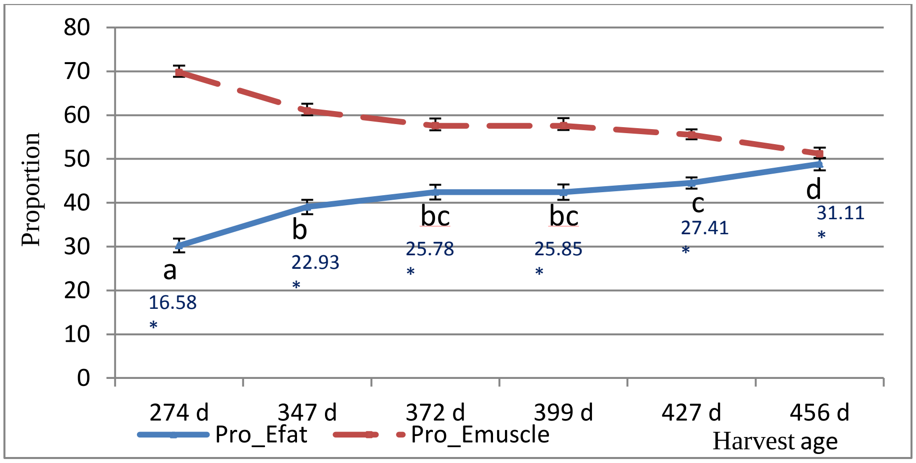
The proportion of muscle energy decreased with harvest age while the proportion of fat energy increased and the two lines for muscle and fat energy intersected at about 427 d for M3 (Figure 2.8). The proportion of fat energy at 372 d, 399 d and 427 d was not significantly different (*P* > 0.05) for M3 composite type and they can therefore be harvested at 372 d or 399 d to maximize the proportion of muscle. However, if a fatter carcass is required, they can be harvested after 427 d.



*Percentages of fat weight in the carcass.
a,b least square means with different letters denote significance differences in harvest ages ($P < 0.05$).

Figure 2.8 Proportion of energy used for muscle (Pro_Emuscle) and fat (Pro_Efat) deposition at different harvest ages for M3 composite type

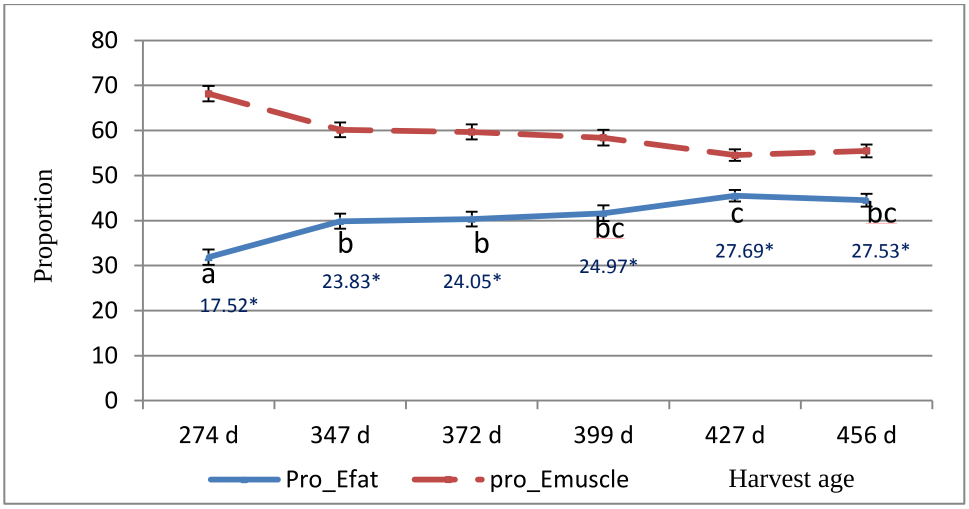
The proportion of muscle energy decreased with harvest age while the proportion of fat energy increased slowly and two lines for muscle and fat energy intersected at 456 d for M4 (Figure 2.9). Hence, they can be harvested at 456 d to maximize the proportion of muscle. However, if a fatter carcass is required, they can be harvested after 456 d.



*Percentages of fat weight in the carcass.
a,b least square means with different letters denote significance differences in harvest ages ($P < 0.05$).

Figure 2.9 Proportion of energy used for muscle (Pro_Emuscle) and fat (Pro_Efat) deposition at different harvest ages for M4 composite type

The proportion of muscle energy decreased with harvest age while the proportion of fat energy increased at a lower rate and the lines had not intersected for TX even at 456 d (Figure 2.10). The proportion of muscle energy was more than 50% at the end of the period (456 d). Hence, they can be fed to more than 456 days to maximize the proportion of muscle in the carcass.



*Percentages of fat weight in the carcass.
a,b least square means with different letters denote significance differences in harvest ages ($P < 0.05$).

Figure 2.10 Proportion of energy used for muscle (Pro_Emuscle) and fat (Pro_Efat) deposition at different harvest ages for TX composite type

The proportion of metabolizable energy contributed to total energy, muscle, and fat energy deposition in the carcass is shown in Table 2.6. At 347 d, nearly one third of metabolizable energy was deposited in the tissues and the ratio of retained energy to metabolizable energy reduced with increasing harvest age. This retained energy: metabolizable energy ratio decreased by 37.99%, 26.32%, 18.41%, and 32.00% for M1, M3, M4, and TX respectively from 347 d to 456 d.

Table 2.6. Utilization of metabolizable energy (MJ) for muscle and dissectible fat accretion

	Harvest age (days)*					
CT^{y}	347 d	372 d	399 d	427 d	456 d	*P* value^{z}
Retained energy: Metabolizable energy (%)						
M1	39.22a	31.16	28.51	27.61ac	24.32ac	< 0.01
M2	24.24b	26.25	29.05	27.78ac	26.92a	0.30
M3	32.29ac	31.90	29.65	28.04a	23.79bc	0.07
M4	30.73bc	30.62	24.76	23.74bc	25.07ab	<0.01
TX	32.00ac	28.69	25.54	22.89b	22.08c	<0.01
SEM	2.58	2.16	1.94	1.39	0.97	
Muscle energy: Metabolizable energy (%)						
M1	15.82	12.88	9.79	9.58	8.89a	0.03
M2	11.09	10.47	11.12	10.69	10.10a	0.90
M3	12.91	12.11	11.86	11.12	6.68b	<0.01
M4	14.20	12.78	10.33	9.59	9.08a	0.03
TX	14.94	13.89	11.77	9.32	9.46a	0.02
SEM	1.97	1.16	1.20	0.85	0.65	
Fat energy: Metabolizable energy (%)						
M1	23.40ad	18.28	18.72a	18.03a	15.43a	< 0.01
M2	13.15c	15.78	17.93a	17.09ab	16.82a	0.13
M3	19.38bd	19.79	17.80a	16.92ab	17.11a	0.72
M4	16.54bc	17.84	14.43ab	14.15bc	15.98a	0.25
TX	17.06bc	14.80	13.77b	13.57c	12.61b	0.33
SEM	1.92	1.84	1.48	1.02	0.92	

CT^{y} M1- composites based on Angus (early maturing), M2- composites based on Hereford (early maturing), M3- composites of small breeds (early maturing) M4- composites based on Gelbvieh, Limousin (late maturing), TX-composites based Charolais dams (late maturing).

^{z}*P* value refers to harvest age within composite type.

a,b least square means with different letters in columns denote significance differences among composite types for each harvest age ($P < 0.05$). Letters are only shown when means are different ($P < 0.05$).

*Harvest age is the average age of composites serially slaughtered at six time points

However, the retained energy: metabolizable energy ratio of M2 shows a deviation from other composite types and this increased slightly. This may be due to only small animals remaining at 456 d and the loss of randomness.

The metabolizable energy used for fat deposition was higher than that for muscle deposition and metabolizable energy: fat and muscle ratios decreased with age of the animal. Muscle energy to metabolizable energy ratio decreased by a slightly higher percentage compared to fat energy to metabolizable energy and the ratio decreased by 44%, 9%, 48%, 36%, 37% for M1, M2, M3, M4, and TX respectively during the 347 d to 456 d period. Fat energy: metabolizable energy ratio decreased by 34%, 11%, 3%, and 26% for M1, M3, M4, and TX and increased by 28% for M2 during the 347 d to 456 d period. The energy conversion was higher for early maturing composite types (29%) than later maturing composite types (27%), because late maturing composite types have a larger frame size and more energy is required for maintenance. However, the M2 composite type deviated from the pattern that other composites followed. The M1, M3, M4 and TX composite types reached their peak energy conversion at 347 d and M2 at 399 d.

Energy distribution among different dissected fat depots

The energy deposited in BC, SC and IM fat depots increased ($P < 0.01$) with harvest age as body fat weight increased with the age of an animal (Table 2.7). The BC fat energy was similar for all the composites at each harvest age with the exception at 399 d. However, the amount of energy deposited in both SC and IM fat depots in early maturing composites (M1 + M2) was numerically higher than the late maturing composites (M4 + TX) at the later stage (399 d – 456 d) in the feedlot.

Table 2.7. Comparison of energy used to grow different dissected fat tissues of composite types at different harvest ages

		Harvest age (days)*					
Fat tissue	CT^{y}	274 d	347 d	372 d	399 d	427 d	456 d
Body cavity energy (MJ)	M1	110.26	246.28	274.55	304.08ab	337.17	350.78
	M2	139.53	218.06	263.56	340.05b	344.61	346.86
	M3	103.66	203.93	253.14	265.18a	334.82	304.32
	M4	112.56	224.61	272.77	238.21a	291.49	336.39
	TX	120.00	234.82	274.08	290.05ab	337.17	302.88
	SEM	11.36	20.24	20.12	22.45	26.04	15.51
Subcutaneous energy (MJ)	M1	355.29	910.99a	933.29	1110.46	1187.43a	1280.36ab
	M2	337.43	598.43b	895.91	1105.75	1244.29a	1422.24a
	M3	310.73	664.13b	846.59	896.85	917.27b	1233.76ab
	M4	319.37	697.90b	910.21	839.78	965.18b	1297.63a
	TX	369.11	724.87b	753.40	828.53	1037.95ab	1055.75b
	SEM	39.92	53.62	77.21	91.23	77.05	80.98
Intermuscular energy (MJ)	M1	756.44	1770.15a	1713.29	2224.38	2415.96	2550.77ab
	M2	756.80	1250.52b	1670.57	2173.81	2411.93	2671.98b
	M3	629.97	1341.88bc	1730.88	1840.30	2081.14	2228.00a
	M4	753.27	1429.57bc	1717.53	1764.91	2047.90	2557.97bc
	TX	796.33	1565.44ac	1780.88	1910.72	2244.49	2253.39ac
	SEM	52.20	84.78	132.56	146.58	113.87	111.79

CT^{y} M1- composites based on Angus (early maturing), M2- composites based on Hereford (early maturing), M3- composites of small breeds (early maturing) M4-composites based on Gelbvieh, Limousin (late maturing), TX-composites based Charolais dams (late maturing).

a,b least square means with different letters in columns denote significance differences among composite types for each harvest age ($P < 0.05$). Letters are only shown when means are different ($P < 0.05$).

*Harvest age is the average age of composites serially slaughtered at six time points. The differences between harvest ages within CTs were always significant ($P < 0.01$).

The energy usage for the different dissected fat tissues (subcutaneous, body cavity, and intermuscular fat) as a proportion of total fat in the carcass is shown in Table 2.8 relative to each composite type at different harvest times. On average, 9% of total fat energy (Table 2.4) was deposited as BC fat during the study period (Table 2.8). The energy deposited as BC fat was low compared to IM and SC fat. Average BC fat energy proportion was similar for all the composite types throughout the feeding period, though M2 had higher ($P < 0.05$) percentage on 274 d (Table 2.8). Even though some fluctuations were observed, the BC fat energy percentage decreased during 182 d for all the composite types by 7%, 31%, 18%, 15%, and 10% for M1, M2, M3, M4, and TX respectively and this decline was significant ($P < 0.05$) only for the M2 and M3 composites.

On average, 25-30% of the total fat energy shown in Table 2.4 was deposited as SC fat (Table 2.8). Although the proportion of energy for SC fat followed an irregular pattern, proportions increased for all the composite types with increase in harvest age (Table 2.8). Although it was not significant ($P > 0.05$) the proportion of energy for SC fat was slightly higher for early maturing composite types (M1+M2) at 427 d than late maturing composite types (M4+TX). However, at the end of the study period the deposition of SC fat energy was slightly higher for all the composite types except TX. The SC fat energy increased by 6%, 17%, 10%, 20%, and 2% for M1, M2, M3, M4, and TX respectively within 182 d and it was significant ($P < 0.05$) only for the M2 and M3 composite types.

Table 2.8. Comparison of proportions of energy used to grow different dissected fat tissues of composite types at different harvest ages

		Harvest age (days)*						
Fat tissue	CT[y]	274 d	347 d	372 d	399 d	427 d	456 d	*P* value[z]
Body cavity energy%[x]	M1	9.04a	8.34	9.40	8.43	8.56	8.44	0.35
	M2	11.25b	10.45	9.49	9.51	8.65	7.80	<0.01
	M3	9.87a	9.27	9.05	8.79	10.07	8.08	<0.01
	M4	9.54a	9.58	9.45	8.46	8.84	8.10	0.22
	TX	9.33a	9.39	9.68	9.61	9.29	8.41	0.45
	SEM	0.37	0.62	0.45	0.49	0.52	0.32	0.34
Subcutaneous energy%[x]	M1	28.74	31.14	31.88a	30.50	29.93	30.52	0.59
	M2	27.29	28.94	31.58a	30.46	31.09	32.04	0.03
	M3	29.57	29.98	29.79a	29.87	27.57	32.61	0.04
	M4	25.77	29.72	31.42a	29.32	29.12	30.85	0.12
	TX	28.46	28.39	26.71b	27.10	28.53	29.17	0.66
	SEM	1.58	1.00	1.11	1.26	1.05	1.06	
Intermuscular energy %[x]	M1	62.22	60.51	58.71a	61.07	61.51	61.04	0.46
	M2	61.46	60.61	58.93a	60.03	60.27	60.15	0.79
	M3	60.56	60.75	61.16ab	61.34	62.37	59.31	0.47
	M4	64.69	60.70	59.13a	62.22	62.04	61.05	0.09
	TX	62.21	62.23	63.61b	63.29	62.18	62.42	0.77
	SEM	1.56	0.96	1.19	1.05	1.01	0.94	

[x] proportion of different fat tissues relative to total fat.

CT[y] M1- composites based on Angus (early maturing), M2- composites based on Hereford (early maturing), M3- composites of small breeds (early maturing) M4-composites based on Gelbvieh, Limousin (late maturing), TX-composites based Charolais dams (late maturing).

[z] *P* value refers to harvest age within composite type.

a,b least square means with different letters in columns denote significance differences among composite types for each harvest age ($P < 0.05$). Letters are only shown when means are different ($P < 0.05$).

*Harvest age is the average age of composites serially slaughtered at six time points.

The IM fat percentage in the body of all the composite types within the entire feeding period was higher (*P* < 0.01) and the average proportion was 61% (Table 2.8) of total dissectible fat energy (Table 2.4). Hence, higher amount of energy was spent on the deposition of IM fat. The IM fat percentage was slightly higher for TX throughout the feedlot period and the fat energy deposition was similar (*P* > 0.05) in all composites except 372 d of harvest age (Table 2.8). The decreasing pattern of IM fat energy proportion was irregular among the composite types and the proportion decreased by 2%, 2%, 2%, 6% in M1, M2, M3, M4 respectively and increased by 0.33% in the TX.

Energy deposition in intramuscular (chemically determined) fat tissue

As the harvest age increased, the intramuscular fat energy, total intramuscular and percent intramuscular fat increased (Table 2.9). The intramuscular fat energy increased with harvest day or age from 425.25 MJ at 274 d to 1057.62 MJ at 456 d which was about 2.50 times pooled for all composites. The total intramuscular fat in the carcass increased by 150% pooled for all composites and percent intramuscular fat per unit of muscle increased from 6-16% pooled for all composites. Like in the other fat depots (Table 2.7), the energy required to produce intramuscular fat increased with harvest day and this was generally consistent in all composite types.

Table 2.9. Comparison of energy used to grow intramuscular fat, intramuscular fat in carcass, percent intramuscular fat in muscle and marbling scores in composite types at different harvest ages

		Harvest age (days)*						
Trait	CT[y]	274 d[z]	347 d	372 d	399 d	427 d	456 d	*P* value[x]
Intramuscular fat energy (MJ)	M1	452.44	670.20	837.36	983.10	996.64	1114.03a	< 0.01
	M2	451.12	627.46	778.23	980.57	1094.42	1191.29a	< 0.01
	M3	363.18	529.48	710.45	803.71	876.43	824.26b	< 0.01
	M4	435.47	648.10	746.97	850.61	885.62	1068.53a	< 0.01
	TX	424.06	677.34	789.44	923.90	1036.15	1090.01a	< 0.01
	SEM	33.39	60.73	47.25	63.26	68.09	56.80	
Intramuscular fat weight[m] (kg)	M1	11.52	17.07	21.32	25.04	25.38	28.37a	< 0.01
	M2	11.49	15.98	19.82	24.97	27.87	30.33a	< 0.01
	M3	9.25	13.48	18.09	20.47	22.32	20.99b	< 0.01
	M4	11.09	16.50	19.02	21.66	22.55	27.21a	< 0.01
	TX	10.80	17.25	20.10	23.53	26.39	27.75a	< 0.01
	SEM	0.85	1.55	1.20	1.61	1.73	1.45	
Intramuscular fat[y] %[n]	M1	11.12	11.10	13.67a	15.63	15.18	16.01	< 0.01
	M2	9.96	11.29	12.03ab	14.22	15.14	15.44	< 0.01
	M3	10.99	11.68	13.63a	14.70	15.04	16.11	< 0.01
	M4	9.66	10.50	11.33b	13.05	12.73	14.43	< 0.01
	TX	6.08	10.76	11.28b	13.02	14.09	14.53	< 0.01
	SEM	0.51	1.14	0.50	0.79	0.75	0.70	
Marbling score	M1	306	432	478	491a	490	541	< 0.01
	M2	312	418	416	445ab	474	473	< 0.01
	M3	328	410	451	455ab	485	458	< 0.01
	M4	308	411	410	431ab	418	446	< 0.01
	TX	250	412	410	418b	451	450	< 0.01
	SEM	23	17	19	16	22	30	

CT[y] M1- composites based on Angus (early maturing), M2- composites based on Hereford (early maturing), M3- composites of small breeds (early maturing) M4-composites based on Gelbvieh, Limousin (late maturing), TX-composites based Charolais dams (late maturing).

[m] calculated as a total for the carcass.

[n] calculated as a percent of muscle (g kg^{-1}).

[z] calculated by regression.

a,b least square means with different letters in columns denote significance differences among composite types for each harvest age ($P < 0.05$). Letters are only shown when means are different ($P < 0.05$).

*Harvest age is the average age of composites serially slaughtered at six time points.

The regression equations of marbling score on intramuscular fat for each composite type that were used to predict intramuscular fat at the first harvest day (274 d) are shown in Table 2.10. The dependent variable was intramuscular fat and independent variable was marbling score.

Table 2.10. Regression equations to predict intramuscular fat on the first harvest day (274 d) by composite type

CT^y	Equation	SE	*P* value	R^2 (%)
M1	Y = 5.583 + 0.018 Marbling score	0.0059	< 0.01	30%
M2	Y = 1.536 + 0.027 Marbling score	0.0082	< 0.01	33%
M3	Y = 2.494 + 0.026 Marbling score	0.0097	< 0.01	24%
M4	Y = 2.885 + 0.022 Marbling score	0.0094	< 0.05	20%
TX	Y = -3.324 + 0.038 Marbling score	0.0100	< 0.01	39%

Y is the dependent variable and indicates predicted intramuscular fat percentage and marbling score is the independent variable.

CT^y M1- composites based on Angus (early maturing), M2- composites based on Hereford (early maturing), M3- composites of small breeds (early maturing) M4-composites based on Gelbvieh, Limousin (late maturing), TX-composites based Charolais dams (late maturing).

The regression of marbling score on intramuscular fat pooled for all composite types was:

$$\text{Predicted intramuscular fat} = 2.43 + 0.025 \text{ marbling score}$$
$$(P < 0.01, \text{SE} = 0.0020, R^2 = 0.48)$$

The correlation between marbling score and intramuscular fat was 0.69 ($P < 0.01$) pooled for all composite types.

2.4 Discussion

Differences in carcass tissue weight, percentage of muscle, fat, and bone were observed (Table 2.2) between composites and across harvest ages. Carcass, muscle, and fat weights increased with the days in the feedlot and the proportions of muscle and bone decreased while the proportion of fat increased. Carcass weight is known to linearly increases with increasing days in the feedlot (May et al., 1992). Berg and Butterfield (1968) found that carcass weight and fat percentage continuously increased while both M and B percentages decreased as harvest weight increased. Also Shahin and Berg (1985) found that the different tissues in the animal had different growth patterns and harvest age greatly influenced the carcass composition. Furthermore, Owens and Gardner (2000) stated that increased harvest age was associated with increased body weight and fat percentage as well as decreased muscle percentage. Therefore, our study agreed with the literature cited.

Different breeds follow different growth patterns (Nadarajah et al., 1984; Patterson et al., 1985) and the body composition of the cattle varied with frame size and biological type. Koch et al. (1976) reported that the carcass weights were different for different breeds: Jersey had lower carcass weight, Hereford and Angus had medium carcass weight and Charolais, Simmental, and Limousin had heavier carcass weights. Carcass weight was higher for late maturing breeds (Berg and Butterfield, 1968; Fox and Black, 1984) and they also observed similar growth patterns as in the current study with composites. McEwen et al. (2007) found that Charolais cattle were heavier at all the ages compared to Angus. In the present study, we also found differences in carcass weight between composite types: early maturing (M1+ M2+ M3) cattle had lower carcass weights (average 262.11 kg) and late maturing composites (M4 +TX) had higher carcass weights (average 281.86 kg) during the 182 d period (Table 2.2). Therefore, the different composites have different growth patterns and harvest age greatly influenced carcass composition.

Even though muscle percentage increased at early ages, as the fattening began both the muscle and bone percentages decreased (Table 2.2). Bone is an early developing tissue and muscle is intermediate in development (Berg and Butterfield, 1968). The bone growth ceases after epiphyseal growth of the bones and growth presumably stops at the mature age after it reaches its optimum length (Owens et al., 1993). Therefore, the bone percentage decreased with the harvest age of the animal as they came close to their mature age and size. The proportion of bone (percentage) was not significantly different among composite types (Table 2.2) and Patterson et al. (1985) stated that breed differences on bone distribution was less pronounced and the differences in percentage of bones were smaller at a constant weight. The TX (Charolais) composite in the current study had slightly higher bone (4% higher) than other composites while other composites had similar proportions of bone. Also Koch et al. (1976) stated that Simmental and Charolais crosses contained slightly higher proportion of bone compared to Angus, Hereford, Jersey, South Devon and Limousin.

Beef scientists have mainly focused on M and F deposition ignoring the value of B in the carcass since M and F tissues have a significant effect on carcass value (Trenkle and Marple, 1983). Results in this study showed that TX has a tendency to deposit more M than the early maturing composite types. The average proportion of muscle in the carcass of early maturing composites was 5% lower than the proportion of muscle of late maturing composites (Table 2.2) during the study period. Hence, the total lean in the carcass can be increased by the selection of large framed cattle. Eversole et al. (1981) also stated that the large framed or late maturing cattle had a higher lean content than Angus and Hereford breeds (early maturing) and Shahin and Berg (1985) stated that the proportion of muscle decreased due to higher proportions of fat and an earlier fattening pattern of early maturing composite types. Therefore, composite types (breeds) have a strong influence on the M and F composition in the carcass.

During finishing period, fat accretion is more closely related to harvest age than harvest weight (Owens et al., 1995). In this study, carcass fat increased with progressing harvest age (Table 2.2) whereas the proportion of carcass muscle (protein) was inversely related to fat percentage and decreased with increasing harvest age. Similar results were found by Jesse et al. (1976), Johnson et al. (1996) and Bruns et al. (2004). Adipose tissue is the most variable tissue in the animal body (Eversole et al., 1981) and it is a late developing tissue (Berg and Butterfield, 1968; Dubeski et al., 1997). In this study, increase in the average proportion of fat from 274 d to 399 d was 24% and 22% and increase in the average proportion of fat from 399 d to 456 d was 32%, 27% for early and late maturing composites respectively. These results could be explained by the fact that fat growth is slow until the animal reaches approximately one half of its physiological maturity followed by a dramatic increase in F at the later stage of the growth (Trenkle and Marple, 1983). Jess et al. (1976) stated that greatest change in fat content occurred after the carcass reached 341 kg in weight and in our study the greatest change occurred before they reached 250 kg of carcass weight in all the composite types. The reason might be the high energy content in the present study diet compared to the study reported by Jess et al. (1976). The amount of fat at protein maturity (maximum protein mass) is 36% and when percentage of the body fat reaches 52%, the body protein accretion of cattle ceases (Owens et al., 1995). Therefore, fat tissue accumulation is highly influenced by the harvest age of the cattle.

Early maturing composites had proportionately more fat than late maturing types at any carcass weight. Angus and Hereford cattle fatten at lighter weights and these British composite types produced the fattest carcasses compared to late maturing composites such as Charolais (Berg and Butterfield, 1968; Shahin and Berg, 1985; Dubeski et al., 1997). In our study, the highest carcass fat percentage change was observed between 274 d – 347 d and it was 49%, 27%, 39%, 38% and 36% for M1, M2, M3, M4 and TX respectively. Jones and Marchello (1983) stated that the small framed cattle deposited fat at a faster rate and quicker than medium or large framed animals since the lipolytic (fat degradation) rates were lower in small framed cattle. Late maturing composites reached 30% of carcass fat which is considered optimum to obtain an ideal carcass (Goonewardene et al., 2012) at later harvest ages (beyond 456 d) compared to early maturing composites (399 d). Since late maturing cattle require longer time on feed to finish, McEwen et al. (2007) fed Charolais cattle for 214 d compared to Angus which were fed for 143 d in feedlot to obtain AAA quality grade carcasses. May et al. (1992) stated that feeding Angus x Hereford crossbred steers (early maturing) beyond 112 days in feedlot is inefficient since they reached maximum meat quality at this harvest point. In this study we found that early maturing cattle reached to optimum fat percentage around 127 days in feedlot and feeding beyond this point is energetically inefficient. Because current feedlot management emphasises to maximize profit, feeding high energy diets after reaching a normal harvest weight is inefficient and prolongs feeding to produce extremely fat carcass which are discounted based on yield grade increases the cost of production (Dubeski et al., 1997). If price signals for AAA and prime are high and discounts for over fat carcasses low or non-existent, then feedlot managers will over fatten (yield grade 3) cattle to obtain maximum profit. However, this depends on feed price and input costs. Steen and Kilpatrick (2000) also stated that the more effective way to reduce carcass fat of the cattle reared even on high forage diets is to reduce harvest weight. Carcass fat composition is highly influenced by composite type. Therefore, early maturing composites types can be harvested at early ages and late maturing composite types at a later age based on the level of fat in the carcass. The signals for what feedlot managers do come from our (US) grading price system, the cost of inputs and the CAN:US dollar exchange. Therefore to reduce fat in our grading system would need to change and reward lean instead of marbling as intramuscular fat.

Growth rates of M and F were different across harvest ages of composite types (Table 2.3). The average daily gains of the cattle slowdown with increasing days on feed and after they reach a plateau gradually decline and a similar pattern was found by Dubeski et al. (1997) and Bruns et al. (2004). As animals grow, the proportionality of tissue changes and tissue growth rates slows (Bruns et al., 2004). In the current study, differences of daily gains were observed for composite types and the average carcass gain per day of age was 0.73, 0.74, 0.59, 0.71, and 0.77 kg d^{-1} for M1, M2, M3, M4, and TX respectively. The breed differences of daily gain was found by Barber et al. (1981) and the average daily live weight gain was higher (1.11 kg d^{-1}) for Charolais and was lower (1.01 kgd^{-1}) for Angus around 299 days and 279 days respectively, that were fed with 60% grain. With a 64% dressing percentage, the reference daily carcass gain was around 0.65 kg d^{-1} and 0.71 kg d^{-1} for Angus and Charolais respectively (Barber et al., 1981). However, the carcass gains that resulted for different composite types were higher in our study as cattle were fed with a higher concentrate feed (73% grain as-fed basis). Dubeski et al. (1997) also found that Hereford cattle were lighter at an earlier age and had higher daily gains than Angus.

Generally, growth rates are higher at lighter weights than at heavier body weights since there is a greater deposition of M verses F at lighter weights (McEwen et al., 2007). The average muscle gain decreased or remained constant after it reached a plateau with increase in harvest age and the average fat gain increased continuously with the harvest age (Figure 2.1 – 2.5). Though the average F gain was around 100 g for all the composite types at 274 d, the fat gain increased by 102%, 113%, 112%, 116%, and 68% for M1, M2, M3, M4, and TX respectively within 182 d (Table 2.3). The regression coefficient of muscle gain (kg d^{-1}) to harvest age (d) was -5.59 x10^{-5}, 9.8x10^{-5}, -4.7x10^{-5}, -1.1x10^{-4}, -1.5 x10^{-4} and the regression coefficient of fat gain (kg d^{-1}) to harvest age (d) was 6.3x 10^{-4}, 7.2 x 10^{-4}, 5.2x10^{-4}, 5.8x10^{-4}, 4.5x10^{-4} for M1, M2, M3, M4, and TX respectively. The regression coefficients for muscle gain were negative except for M2 and the coefficient values were almost near to zero. However, regression coefficient values for the fat gain were positive and the fat gain increased with harvest age for all the composite types. Furthermore, the regression coefficient value for fat gain was higher by 21% for early maturing composites than later maturing composites.

Energy utilization

Based on energetic efficiency of producing M and F in composites, we reject the null hypothesis that energetic efficiency of M and F deposition is similar in composites at different harvest times.

The difference between body tissue synthesis and degradation is called the net gain of an animal (Owens et al., 1993). The net energy intake above the maintenance energy is primarily used for muscle tissue and visceral growth, following usage of energy for fat tissue deposition (Ferrell and Oltjen, 2008). Total retained energy is the summation of accretion of energy in the form of M and F (Owens et al., 1995). Differences were observed between composites for total energy, muscle energy, fat energy, and muscle energy: fat energy ratio across different harvest ages (Table 2.4). The net energy had doubled within the 182 d feeding period for all the composite types. The highest net energy gain per day was reached at different harvest ages by composite types as well as at peak, they reached averages of 41.04 MJ d^{-1} (71 d), 31.03 MJ d^{-1} (127 d), 30.07 MJ d^{-1} (99 d), 30.9 MJ d^{-1} (71 d), and 33.17 MJ d^{-1} (71 d) for M1, M2, M3, M4 and TX respectively. The net energy gain per day for the cattle was estimated as 40.2 MJ d^{-1} (9.61 Mcal d^{-1}) (Tedeschi et al., 2004) and our results are comparable. The total energy (MJ) per kg of carcass increased with the harvest age and this value was around 21 MJ kg^{-1} carcass for all the composite types except M3 at the 274 d where the value was higher for M3 (22 MJ kg^{-1} carcass) since they had a higher proportion of fat. At the end of study period (456 d) the energy per unit weight of carcass increased up to 25 MJ kg^{-1} of carcass except in TX (24 MJ kg^{-1} carcass). The energy per unit weight of carcass increased by 16%, 16%, 17%, 16% and 13% for M1, M2, M3, M4 and TX respectively during the 182 d period.

When the proportion of F increases in the body, total energy in the carcass increases (NRC, 2000) since the caloric value of F (low moisture) is higher compared to M (higher moisture content). The fat tissue consists of 85% fat, 10% water and 5% ash whereas muscle contains 22% protein, 73% water and 5% ash and the energy deposited in 1 g of fat is 9.385 kcal and the energy deposited in 1g of protein is 5.539 kcal (Brethour, 2004). There is little information available on energy values of F and M growth in composite types of cattle across different harvest ages. However, muscle and fat energy distribution in the carcass followed the fat and muscle weight distribution pattern in the carcass. Hence, total energy in tissues and energy distribution pattern was analyzed using both energy per gram of tissue and total mass of tissue. In the current study, the calculated values of total energy increased with the age of animals since more fat was accumulated with the advanced harvest age. Both muscle energy and fat energy increased with the harvest age since the growth of the cattle occurred continuously (Table 2.4). However, the energy used for muscle deposition to fat deposition ratio (Table 2.4) decreased with the days in the feedlot since most of the energy was partitioned to deposit F. Owens et al. (1995) also found that the cattle harvested at a lighter weight had higher M to F ratio than the cattle harvested at heavier weights. However, the energy muscle to energy fat ratio was higher by 23% at 456 d for late maturing composites than early maturing composites since they used more energy for muscle deposition even at the later days in the feedlot.

The proportion of dissectible fat energy deposited in the carcass increased whereas the proportion of muscle energy decreased with the increase in harvest age (Table 2.5). There was a specific equilibrium point for each composite type that used equal amounts of energy for both M and dissectible F deposition and beyond this point more energy was used to deposit F in the body which has very little carcass value (Figure 2.6 – 2.10). The sufficient fatness required for US choice grade is reached by the cattle at 25-35% of carcass fat (Dikeman et al., 1985). The optimum fat suitable for ideal carcass is around 25-31% of total tissue (Goonewardene et al., 2012). According to the current study results, the different composite types accumulated that optimum fat at different harvest ages. As shown in Figures 2.6-2.10 the total fat in the carcass reached 30% at different harvest ages for the composites and at that point fat energy almost reached 50% of the total deposited energy. This point might be the maximum point to harvest each composite type to get leaner carcasses since after this point more energy deposited as fat and feeding beyond this point is inefficient. However, cattle can be harvested beyond that maximum point to obtain fatty carcass. Different composite types have different equilibrium points for harvest to obtain leaner carcass such as 399 d for M1, 399 d or 427 d for M2, 372 d or 399 d for M3, 456 d for M4, and TX can be fed more than 456 days until approximately reach 50% of energy deposited as fat. Selecting optimum days to harvest different composite types helps to improve the quality of beef and conform to consumer demands for beef with less fat. However, we couldn't find any research on the optimum harvest ages that are recommended for different composite types based on energetic efficiency from literature and this may be the first study that addressed this particular topic.

Many researchers have focused on reducing saturated fats in human diets, as they are linked with heart disease, cancer, stroke, diabetes and atherosclerosis (Doyle, 2004). Level of fatness in beef influences the fatty acid composition and carcasses of leaner and lighter animals contain a higher polyunsaturated: saturated fatty acid ratio than carcasses from fatty and heavier cattle (De Smet et al., 2004). The accumulation of excess fat increases the cost of production and the energy content or caloric value of meat while reducing consumer acceptance and per capita consumption of beef. As stated by Dikeman (1984) beef consumption has reduced due to diet health controversies and the high caloric content of beef with excess fat. He further stated that consumer confidence and the demand of beef can be increased by marketing beef with less fat. Dikeman et al. (1985) also stated that harvesting Angus and Hereford at lighter weight is economical, efficient in feed utilization, and carcasses contained less amounts of fat. Also Jones and Marchello (1983) stated that the 30% of cattle body weight or 80% of their body calories are in the form of fat at market weight. Fat synthesis is energetically expensive compared to protein synthesis and feeding to choice grade results fatty carcasses and it is deemed to be energetically inefficient (Dikeman et al., 1985). Therefore, we suggest that desirable carcasses of early maturing composite types can be achieved by feeding grains minimally for 127 d and the optimum harvest age varies for different composite types. Therefore, consumer demand for less fat in beef can be accommodated, production cost can be lowered and more energy diverted to M production by reducing the harvest age of the early maturing composites.

Metabolizable energy (ME) represents the total energy available for an animal and part of it contributes to maintenance of the body and processes and another part contributes to tissue deposition in the body (Williams and Jenkins, 2003a). Approximately 73% of ME is used for maintenance and rest is used for the product formation (Johnson et al., 2003). Eating, chewing, and rumination processes in cattle use 10% to 33% of the total metabolizable energy taken from forages (Carstens and Kerley, 2009). The current study shows that ME used for the total energy, muscle, and fat energy deposition changed with the harvest age for the different composites (Table 2.6). Furthermore, we found that average ME used for the maintenance was 70%, 73%, 70%, 73%, and 74% for M1, M2, M3, M4, and TX respectively and these values are comparable with that in the literature. The TX composite showed the largest ME requirement and this could be explained by its large and heavy body size and they reached puberty at a later age and a large mass is associated with the higher maintenance cost (Owens et al., 1993). During 182 d in feedlot, energy requirements for maintenance increased at different rates by 24%, 12%, 8%, and 14.5% for M1, M3, M4, and TX respectively due to increasing body weight. The Maintenance energy requirement of different breeds may also vary between 10-30 % due to genetic effects (Cardenas-Medina et al., 2010).

The average percentages of energy retained from metabolizable energy were 30%, 27%, 29%, 27%, 26% and this percentage decreased by 38%, 26%, 18%, and 31% for M1, M3, M4 and TX respectively and the percentage increased slightly for M2 during 182 d period in feedlot (Table 2.6). The energy retained in the body decreased with feeding days since maintenance requirement increased. The cattle at an advanced stage of fattening had higher maintenance energy cost due to heavy body mass (Berg and Butterfield, 1968). On average, cattle have retained 29% of ME fed over the 182 d in feedlot. Williams and Jenkins (2003b) found that Angus x Hereford crossbred steers fed with a feed containing 3.2 Mcal kg^{-1} ME and finished at 530 kg retained 26.5% of ME over the finishing period. Dikeman (1984) stated that only 20% -25% of nutrients consumed by animals were used for production and the remaining 75% to 80% was used for the maintenance of beef cow herds. In the current study, a higher percentage of energy from ME retained was observed for cattle composites compared to previous studies. Cardenas-Medina et al. (2010) stated that only 5.2%- 13.4% of the total energy acquired during life time of beef cattle was recovered at the time of harvest. However, in our study early maturing composites had higher (29%) energy conversion rate than late maturing cattle (27%).

The current study (Table 2.6) showed that average ME deposited as fat was higher (17%) compared to ME deposited as muscle (11%). The metabolizable energy used for fat deposition was 1.5 times (48%) higher than the muscle deposition and ratios decreased with the age. However, these values changed with the age of harvest and composite types. Williams and Jenkins (2003b) also stated that both the muscle and fat efficiency percentages relative to ME changed with the days in the feedlot. Early maturing composite types used more ME energy for F deposition (18%) than late maturing composite types (15%) and late maturing composite types used 8% more ME for muscle deposition even at the end of 182 d in feedlot compared to early maturing cattle. However, for all the composite types, ME energy used for M and F tissue deposition decreased with the time since the maintenance requirement increases with the age and body size of cattle (Owens et al., 1993).

Based on energetic efficiency of M and F deposition we have established that diverse composites should be harvested at different ages in order to obtain a carcass that has maximum muscle and optimum fat. Furthermore, from an energy utilization point of view producing excessive amounts of fat which will be trimmed at retail, amounts to a waste of feed energy. Traditionally, feedlots sort harvest cattle by weight and heavier cattle are harvested first. Our study shows that sorting based on biological type is as important as sorting based on body weight and some consideration be given to this type of harvest cattle management. As consumer trends move to accommodate less fat in beef, biological type or genetic make-up will become a more important consideration of optimum harvest ages for beef cattle in Canada.

Energy distribution among different fat depots

The growth and energy distribution of fat depots follows different patterns (Table 2.7) and energy deposited in all the fat depots increased as total fat energy increased rapidly with the increase in harvest age of animal. On the first day (274 d) in feedlot, the proportion of BC fat energy was around 10% (Table 2.8). However, with the increase in days in feedlot, the proportion of energy used for BC fat declined and the decline was significant for early maturing composites. Owens and Gardner (2000) stated that BC (internal fat) fat decreases with increasing carcass weight due to early maturity of these tissues and thus confirms our findings. Body cavity fat is usually removed at retail when beef is sold in cuts (Miller et al., 1995).

The proportion of SC fat energy was the second highest (28%) in the body on the first day in the feedlot and the percentage of energy used for fat deposition in the depot increased with the increase in age of harvest (Table 2.8) and similar results were found by Hicks et al. (1987), Brethour (2000), and Bruns et al. (2004). Owens and Gardner (2000) also found that SC fat thickness increased with the increase in carcass weight. The SC fat energy percentage was slightly higher for small composite types (average 30%) even on the first day in the feedlot since they deposited more fat in the body at early ages compared to other composite types (average 28%). Subcutaneous fat (back fat) is usually trimmed to 6 mm (hot- fat trimming) in the carcass and it is a waste product (Miller et al., 1995). There is an energy cost to produce this fat and a dollar cost to trim this fat. It is estimated that it costs $ 27.42 per head (> 16.5% trimmable fat) to trim fat from the carcass at retail (Ritchie, 2000; Goonewardene et al., 2012).

The current study showed that the proportion of IM fat energy (62%) was higher than the energy compared to all other fat depots in all the composite types on the first day in the feedlot (Table 2.8). However with the increase in the days in feedlot, the proportion of IM energy reduced gradually. Previous studies done by Callow (1962), Johnson et al. (1972), and Trenkle and Marple (1983) also showed higher IM fat followed by SC and BC fat. Also the fat energy in both IM and BC depots decreased and energy deposited as SC fat increased with the advancement of the age of cattle. The IM fat depots grew earlier and had higher proportions than SC fat (Callow, 1962; Johnson et al., 1972). The SC: IM fat energy ratio represents the degree of intensity for selection for harvest (Shahin and Berg, 1985) and this ratio increases with progressing harvest age (Owens and Gardner, 2000). The IM fat proportion declined and SC fat proportion increased with increasing total separable fat (Tatum et al., 1986). During the 182 d period the SC: IM fat energy ratio increased by 8%, 20%, 13%, 27% and 2% for M1, M2, M3, M4, and TX respectively (Table 2.7). The change was lower for M1 and

M3 than expected, since they had higher SC: IM ratio (0.47) at 274 d, and the change was higher for M4 since the ratio was lower (0.39) at the 274 d.

Although not significant, the current study showed differences in energy distribution patterns of fat tissues for composite types. Late maturing composite types used more energy to deposit IM and BC fat than early maturing composite types which used more energy to deposit SC fat at an earlier age. However, statistically all the composite types had similar SC and IM fat energy proportions with the exception at 372 d. When steers fatten, F deposition changes and significant differences can be observed among steers of different breeds (Jones et al., 1980; Tatum et al., 1986). Larger frame size cattle contain lower proportions of SC fat and higher proportion of BC and IM fat than early maturing British breeds (Berg and Walter, 1983). Late maturing crosses such as Charolais, Simmental and Limousin had the lowest percentage of trim fat (SC) whereas Jersey (early maturing crosses) had the highest percentage of trim fat (Koch et al., 1976). Jones et al. (1980) found that Hereford cattle contained a greater percentage of subcutaneous fat compared to dairy breeds which had more internal fat. Therefore, our study based on energetics of fat partitioning agrees with those in the literature, which relate to fat distribution in depots.

Energy deposition in intramuscular fat tissue

There are no values for energy requirements for intramuscular fat in the literature. The intramuscular fat component also contained a little fat from the intercostals and brisket which could not be physically dissected. However, for the whole carcass this was the best estimate of intramuscular fat. Averaged for all composites, SC fat energy increased by 348% for the 182 days in the feedlot where intramuscular fat energy increased by 250% for the same time frame.

Previous research has shown the percent intramuscular fat to be between 2-12% in 32 muscles in AA Angus beef carcasses (Jeremiah et al., 2003). Also Savell et al. (1986) reported intramuscular fat values in the rib eye ranging from 1.77% to 10.42% in beef carcasses. In Japanese Black Angus and Black Angus crosses, the intramuscular fat in the rib eye ranged from 11.8 to 24.7% (Kuchida et al., 2000). Indurain et al. (2009) have reported intramuscular marbling fat values in the rib eye of Spanish cattle of 1.67% (range 0.63-4.22%). Most studies on intramuscular (marbling) fat that is reported in the literature are confined to the rib eye as quality grade of the carcass is determined based on rib eye marbling. In the US grading system, select quality grade needs to have between 2.3-3.99% intramuscular fat, choice and choice+ between 4.0 and 9.89% intramuscular fat and prime between 9.9-12.0% and greater intramuscular fat in the rib eye (Greiner, 2002). The results from our study on intramuscular fat in the carcass appear to be slightly higher than values reported in the literature. However, there have been no studies in the literature that have evaluated either the energy requirements or intramuscular fat in the entire carcass.

Turnover of energy in tissues

It is also well established that as cattle get older, heavier and more mature, they put on proportionately more F compared to M and the energy of putting on F is higher than for M (Koontz et al., 2000). Actual protein synthesis efficiency of the animal is approximately half of the theoretical protein synthesis whereas the fat synthesis efficiency of the animal is similar to the theoretical fat synthesis (Owens et al., 1995). The reason is that continuous rapid protein turnover reduces the efficiency of protein synthesis (Owens et al., 1995). Kielanowski (1976) found that the heat loss from deposition of 1 kg of M and F as 7.4 Mcal and 3.8 Mcal whereas Pullar and Webster (1977) reported values of 7.0 Mcal and 3.4 Mcal for M and F respectively. They used rats and pigs for these calculations. However, Reeds et al. (1982) estimated that heat produced from fat accretion from fatty acids, carbohydrates and protein was 0.14, 1.87 and 3.78 Mcal kg^{-1} respectively, whereas heat production during deposition of protein was 1.08 Mcal kg^{-1}. They further estimated that a minimum of 17% and 1% of daily energy losses occurred through protein and fatty acid synthesis respectively. However, these values can be affected by the feed and digestion processes (Trenkle and Marple, 1983) and when dietary nutrients are biochemically transformed to body tissues, a considerable amount of energy is lost as a heat from the body (Trenkle and Marple, 1983). The efficiency of ME use for fat synthesis was higher (60-80%) than the efficiency of protein synthesis (10-40%) as more energy is utilized for protein synthesis (Garrett, 1980). In the literature, protein turnover has been evaluated or measured in specific muscles and rates of turnover differ between muscles. Therefore, the turnover values for protein cannot be correctly represented in the whole carcass (McCarthy et al., 1983), and cannot be applied to the energetics of the whole carcass undertaken in our study.

Economics and consumer demand

The feed represents a major cost in producing beef and feed cost per unit of beef produced influences profitability (Baker et al., 2006). The average loss for an animal in return is $1 per day when actual harvest date changes from optimum (Koontz et al., 2000). Beef producers need to focus on reducing fatness in their products and this will lead to a reduced fat intake compared to lean intake (Fredeen et al., 1981). Production of F is expensive compared to M (Dikeman, 1984). Production of excess fat by the current feeding and marketing system can lead to increased production costs and thereby price of beef compared to other protein sources (Dikeman, 1984). The lower consumption of animal fat reduces the number of chronic or degenerative diseases and obesity while increasing the life expectancy. Since fat is a high caloric source, consumer demand is higher for the beef with less fat (Harper, 1982). The production of beef with less fat increases the efficiency of beef production greatly (Dikeman, 1984).

Compared to chicken and pigs which are harvested after eight and 90 days of post inflection respectively, cattle are harvested at 84% of their mature age and the longer the time after the inflection point approximately 259 -278 days, the less the efficiency (Goonewardene et al., 2005). This reduces energetic efficiency while increasing the cost of production. Further extending harvest age increases the risk of sickness, death and can reduce the tenderness which has a direct influence on consumer demand for beef (Goonewardene et al., 2005). Dikeman (1984) stated that cattle can be harvested at an earlier stage on the growth curve with less body fat content without any significant effect on palatability. He further stated that harvesting cattle in the early stage of fattening enhances production efficiency, processing efficiency, beef nutritional status, and sensory traits.

Feeding cattle after they reached an optimum fat level is a waste of feed and money. The current price of a kilogram of barley grain is $ 0.25 (ACPC, 2012) and it contained 3.03 Mcal kg^{-1} or 12.68 MJ kg^{-1} of ME (NRC, 2000). Hence, the cost of 1 MJ of ME energy in barley is $ 0.02. However, the diet used in the study contained 73.3% of barley grain and then cost of 1 MJ of feed becomes $0.015. The maximum harvest age to obtain lean carcass for M1 composite is around 399 d. When we feed them up to 456 d, this was 57 days more than their optimum harvest age and they deposited 542.98 MJ of fat energy. The average conversion efficiency of ME to fat energy of M1 during 399 d to 456 d was 17.39% and thereby in total 3122.36 MJ of ME is required to deposit 542.98 MJ of fat energy. Hence, the cost of barley for producing extra fat in M1 would be about $ 46.83 per head. The extra cost of keeping cattle more than suitable harvest age (57 days more) would be $ 71.30 and $ 66.30 for M2 and M3 respectively. Most of this fat is trimmed during the fabrication. In addition to that, the extra cost involves the removal, transportation and disposal of extra fat leading to increases in the cost of production.

2.5 Conclusions

In summary, the harvest age of cattle varies with the composite type as energetic efficiency of muscle production is reduced with the harvest age. Each composite type has an optimum harvest age to obtain lean meat and beyond this equilibrium point more energy is diverted to form fat. Also, after the threshold point higher proportion of metabolizable energy is used to produce fat which has a low economic value. Harvesting cattle after this equilibrium point can increase the caloric value and the fat content in the carcass as well as increase the cost of production. Highest amount of fat energy was deposited in IM fat depots followed by SC, intramuscular and BC fat and the proportions of energy deposited in both IM and BC depots decreased while the energy in SC and intramuscular fat depots increased with increase in harvest age. According to the results, it can be suggested that the best harvest age to obtain energetically efficient leaner beef for M1 is 399 d, M2 is 399 d or 427 d, M3 is 372 d or 399 d, M4 is 456 d and TX can be fed to more than 456 days. These results are however only applicable for a calf-fed beef production system but not for a yearling-fed system under the present energy feeding system.

2.6 Literature cited

Alberta Agriculture and Rural Development (ARD). 2011. Capturing benefits by reducing beef emissions. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/cl14131/$file/182-AlbertaOffset-Beef.pdf?OpenElement. Accessed July, 2012.

Alberta Canola Producers Commission (ACPC). 2012. Weekly feed grain prices. http://canola.ab.ca/feedgrains.aspx. Accessed November 15, 2012.

Arthur, P. F. 1995. Double muscling in cattle: a review. Aust. J. Agric. Res. 46:1493-1515.

Association of Official Analytical Chemists. 1980. Official methods of analysis. 13th ed. AOAC, Washington, DC.

Baker, M. J., L. O. Tedeschi, D. G. Fox, W. R. Henning, and D. J. Ketchen. 2006. Using ultrasound measurements to predict body composition of yearling bulls. J. Anim. Sci. 84:2666–2672.

Barber, K. A., L. L. Wilson, J. H. Ziegler, P. J. Levan, and J. L. Watkins. 1981. Charolais and Angus steers harvested at equal percentages of cow weight 1. Effects of harvest weight and diet energy density on carcass traits. J. Anim. Sci. 52:218-231.

Basarab, J. A., M. A. Price, J. L. Aalhus, E. K. Okine, W. M. Snelling, and K. L. Lyle. 2003. Residual feed intake and body composition in young growing cattle. Can. J. Anim. Sci. 83:189-204.

Berg, R. T. and R. M. Butterfield. 1968. Growth patterns of bovine muscle, fat and bone. J. Anim. Sci. 27:611-619.

Berg, R. T. and L. E. Walters. 1983. The meat animal: changes and challenges. J. Anim. Sci. 57:133-146.

Bradstreet, R. B. 1965. The Kjeldahl method for organic nitrogen. Academic Press, New York, NY.

Brethour, J. R. 2000. Using serial ultrasound measures to generate models of marbling and back fat thickness changes in feedlot cattle. J. Anim. Sci. 78:2055–2061.

Brethour, J. R. 2004. The relationship of average back fat thickness of feedlot steers to performance and relative efficiency of fat and protein retention. J. Anim. Sci. 82:3366-3372.

Bruns, K. W., R. H. Pritchard, and D. L. Boggs. 2004. The relationships among body weight, body composition and intramuscular fat content in steers. J. Anim. Sci. 82:1315-1322.

Bures, D. and L. Barton. 2012. Growth performance, carcass traits and meat quality of bulls and heifers harvested at different ages. Czech J. Anim. Sci. 57(1):34-43.

Callow, H. 1962. Comparative studies of meat. VIII. The percentage of fat in the fatty and muscular tissues of steers and the iodine number of the extracted fat, as affected by breed and level of nutrition. J. Agric. Sci. 58:295-307.

Canadian Council on Animal Care. 1993. Guide to the care and use of experimental animals. In E. D. Olfert, B. M. Cross, and A. A. McWilliams, eds. Vol. 1. CCAC, Ottawa, ON.

Cardenas-Medina, J. V., J. C. Ku-Vera, and J. G. Magana-Monforte. 2010. Estimation of metabolizable energy requirements for maintenance and energetic efficiency of weight gain in *Bos taurus* and *Bos indicus* cows in Tropical Mexico. J. Anim. Vet. Adv. 9(3):522-528.

Carstens G. E. and M. S. Kerley. 2009. Biological basis for variation in energetic efficiency of beef cattle. Pages 124-131. Proc. Beef improvement federation 41st annual research Symp. Sacramento, California, USA.

Crews, D. H., Jr. 2005. Genetics of efficient feed utilization and national cattle evaluation: A review. Genet. Mol. Res. 4:152–165.

DeSmet, S., K. Raes, and D. Demeyer. 2004. Meat fatty acid composition as affected by fatness and genetic factors: a review. Anim. Res. 53:81-98.

Dikeman, M. E. 1984. Cattle production systems to meet future consumer demands. J. Anim. Sci. 59:1631-1643.

Dikeman, M. E., K. N. Nagele, S. M. Myers, R. R. Schalles, D. H. Kropf, C. L. Kastner, and F. A. Russo. 1985. Accelerated versus conventional beef production and processing. J. Anim. Sci. 61:137-150.

Doyle, E. 2004. Saturated fat and beef fat as related to human health. A review of scientific literature. Food Research Institute, University of Wisconsin, Madison,WI. http://www.wisc.edu/fri/briefs/satfat.pdf. Accessed August, 2012.

Dubeski, P. L., J. L. Aalhus, S. D. M. Jones, A. K. W. Tong, and W. M. Robertson. 1997. Fattening heifers to heavy weights to enhance marbling: Efficiency of gain. J. Anim. Sci. 77:(4) 625-633.

Eversole, D. E., W. G. Bergen, R. A. Merkel, W. T. Magee, and H. W. Harpster. 1981. Growth and muscle development of feedlot cattle of different genetic backgrounds. J. Anim. Sci. 53:91-101.

Eyre, D. R. and J. J. Wu. 2005. Collagen crosslinks. Top. Curr. Chem. 247:207-229.

Ferrell, C. L. and J. W. Oltjen. 2008. ASAS CENTENNIAL PAPER: Net energy systems for beef cattle-Concepts, application, and future models. J. Anim. Sci. 86:2779-2794.

Fox, D. G. and J. R. Black. 1984. A system for predicting body composition and performance of growing cattle. J. Anim. Sci. 58:725-739.

Fredeen, H. T., A. H. Martin, and P. J. L'hirondelle. 1981. Tissue composition of Canada A beef carcasses and implications in estimating dietary intake of fat and lean. Can. J. Anim. Sci. 61:883-891.

Garrett, W. N. 1980. Factors influencing energetic efficiency of beef production. J. Anim. Sci. 51:1434–1440.

Goonewardene L. A., Z. Wang, E. K. Okine, M. A. Price, J. A. Basarab, Jr. D. H. Crew, P. Ramsey, K. L. Lyle, N. French, and S. S. Moore. 2005. A comparison of growth, efficiency and maturing patterns of meat. J. Anim. Veter. Adv. 4: 825-830.

Goonewardene, L. A., Z. Wang, R. W. Seneviratne, J. A. Basarab, E. K. Okine, J. Stewart-Smith, J. L. Aalhus, and M. A. Price. 2009. Comparison of growth rates in the tissues of primal cuts of Canadian composites. S. Afr. J. Anim. Sci. 39(5): 289-293.

Goonewardene, L. A., J. A. Basarab, Z. Wang, M. A. Price, P. Ramsey, T. Marx, J. Aalhus, R. W. Seneviratne, W. G. N. P. Yalingasinghe, and E. K. Okine. 2012. Tissue distribution in primal cuts of Canadian beef composites and opportunities for harvesting younger and leaner cattle. Int. J. Anim. Veter. Adv. 4(1):1-15.

Greiner, S. P. 2002. The relationship between marbling and intramuscular fat. Virginia Cooperative Extension. Livestock Newsletter Archive. Virginia Polytechnic Institute and State University. http://www.sites.ext.vt.edu/newsletter-archive/livestock/aps-02_12/aps-171.html. Accessed on January, 2013.

Harper, A. E. 1982. Meat Animal Fat in Human Nutrition. Proc. Int. Syrup. on Meat Sci. and Tech- nol., Univ. of Nebraska, Lincoln.

Hicks, R. B., F. N. Owens, D. R. Gill, J. J. Martin, H. G. Dolezal, F. K. Ray, V. S. Hays, and C. A. Strasia. 1987. The effect of harvest date on carcass gain and carcass characteristics of feedlot steers. Oklahoma Agric. Exp. Stn. Res. Rep. MP-119:351–358.

Indurain, G., T. R. Carr, M. V. Goñi, K. Insasti, M. J. Berain. 2009. The relationship of carcass measurements to carcass composition and intramuscular fat in Spanish beef. Meat Sci. 82:155-161.

Jeremiah, L. E., M. E. R. Dugan, J. L. Aalhus, and L. L. Gibson. 2003. Assessment of the chemical and cooking properties of the major beef muscles and muscle groups. Meat Sci. 65:985–992.

Jesse, G. W., G. B. Thompson, J. L. Clark, H. B. Hedrick, and K. G.Weimer. 1976. Effects of ration energy and harvest weight on composition of empty body and carcass gain of beef cattle. J. Anim. Sci. 43:418–425.

Johnson, H. R., R. M. Butterfield, and W. J. Pryor. l972. Studies of fat distribution in the bovine carcass. 1. The partition of fatty tissues between depots. Aust. J. Agric. Res. 23:381-388.

Johnson, B. J., P. T. Anderson, J. C. Meiske, and W. R. Dayton. 1996. Effect of combined trenbolone acetate and estradiol implant on feedlot performance, carcass characteristics, and carcass composition of feedlot steers. J. Anim. Sci. 74:363–371.

Johnson, D. E., C. L. Ferrell, and T.G. Jenkins. 2003. The history of energetic efficiency research: Where have we been and where are we going?. J. Anim. Sci. 81(E. Suppl.):E27-E38.

Jones, S. D. M., M. A. Price, and R. T. Berg. 1980. Fattening patterns in cattle. I. Fat partition among the depots. Can. J. Anim. Sci. 60:843-850.

Jones, S. J. and J. A. Marchello. 1983. Lipolysis in subcutaneous adipose tissue from cattle varying in frame size and length of time on a finishing diet. J. Anim. Sci. 57:343-348.

Juárez, M., J. A. Basarab, V. S. Baron, M .Valera, I. L. Larsen, J. L. Aalhus. 2012. Quantifying the relative contribution of *ante-* and *post-mortem* factors to the variability in beef texture. Animal **6**: 1878-1887.

Kielanowski, J. 1976. Energy cost of protein deposition. In: D. J. A. Cole (Ed.) Protein metabolism and nutrition. Page 207. E. A. A. P. Pub. Butterworths, London.

Koch, R. M., M. E. Dikeman, D. M. Allen, M. May, J. D. Crouse, and D. R. Campion. 1976. Characterization of biological types of cattle. III. Carcass composition, quality and palatability. J. Anim. Sci. 43:48- 62.

Koch, R. M. and M. E. Dikeman. 1977. Characterization of biological types of cattle. V. Carcass wholesale cut composition. J. Anim. Sci. 45:30-42.

Koontz, S. R., D. L. Hoag, J. L. Walker, and J. R. Brethour. 2000. Returns to market timing and sorting of fed cattle. NCR-134 Conf. on Applied price analysis, forecasting and market risk management, Chicago, IL.

Kress, D. D., K. C. Davis, and M. W. Tess. 1996. Adjusting scrotal circumference of yearling beef bulls in five composites. Can. J. Anim. Sci. 76:189–191.

May, S. G., H. G. Dolezal, D. R. Gill, F. K. Ray, and D. S. Buchanan. 1992. Effect of days fed, carcass grade traits, and subcutaneous fat removal on postmortem muscle characteristics and beef palatability. J. Anim. Sci. 70:444–453.

Kuchida, K., S. Kono, K. Konishi, L. D. Van Vleck, M. Suzuki, and S. Miyoshi. 2000. Prediction of crude fat content of longissimus muscle of beef using the ratio of fat area calculated from computer image analysis: Comparison of regression equations for prediction using different input devices at different stations. J. Anim. Sci. 78:799–803.

McCarthy, F. D., W. G. Bergen, and D. R. Hawkins. 1983. Muscle protein turnover in cattle of differing genetic backgrounds as measured by urinary N^{τ}-methylhistidine excretion. J. Nutr.113:2455–2463.

McCormick, R. J. 1999. Extracellular modification to muscle collagen: Implications for meat quality. Poultry Sci. 78:785–791.

McEwen, P. L., I. B. Mandell, G. Brien, and C. P. Campbell. 2007. Effects of grain source, silage level, and harvest weight endpoint on growth performance, carcass characteristics, and meat quality in Angus and Charolais steers. Can. J. Anim. Sci. 87:167–180.

Miller, M. F., D. B. Bawcom, C. K. Wu, M. K. Meade, and C. B. Ramsey. 1995. Microbiology of hot-fat-trimmed beef. J. Anim. Sci. 73:1368-1371.

Nadarajah, K., T. J. Marlowe, and D. R. Notter, 1984. Growth patterns of Angus, Charolais, Charolais x Angus and Holstein x Angus cows from birth to maturity. J. Anim. Sci. 59:957-966.

NRC. 2000. Nutrient requirements of beef cattle. 7th rev. ed. Update 2000. Natl. Acad. Press, Washington, DC.

Owens, F. N., P. Dubeski, and C. F. Hanson. 1993. Factors that alter the growth and development of ruminants. J. Anim. Sci. 71:3138-3150.

Owens, F. N., D. R. Gill, D. S. Secrist, and S. W. Coleman. 1995. Review of some aspects of growth and development of feedlot cattle. J. Anim. Sci. 73:3152-3172.

Owens, F. N. and B. A. Gardner. 2000. A review of the impact of feedlot management and nutrition on carcass measurements of feedlot cattle. J. Anim. Sci. 77:1-18.

Patterson, D. L., M. A. Price, and R. T. Berg. 1985. Patterns of muscle, bone and fat accretion in three biological types of feedlot bulls fed three dietary energy levels. Can. J. Anim. Sci. 65:351-361.

Patterson, D. C., C. A. Moore, and R. W. J. Steen. 1994. The effects of plane of nutrition and harvest weight on the performance and carcass composition of continental beef bulls given high forage diets. Anim. Prod. 58:41-47.

Prior, R . L., R. H. Kohlmeier, L. V. Cundiff, M. E. Dikeman, and J. D. Crouse. 1977. Influence of dietary energy and protein on growth and carcass composition in different biological types of cattle. J. Anim. Sci. 45:132-146.

Pullar, J. D. and A. J. F. Webster. 1977. The energy cost of fat and protein deposition in the rat. Brit. J. Nutr. 37:355-363.

Purchas, R. W., D. L. Burnham, and S. T. Morris. 2002. Effects of growth potential and growth path on tenderness of beef longissimus muscle from bulls and steers. J. Anim. Sci. 80:3211-3221.

Reeds, P. J., K. W. J. Wahle, and P. Haggarty. 1982. Energy costs of protein and fatty acid synthesis. Proc. Nutr. Soc. 41:155-159.

Rhee, M. S., T. L. Wheeler, S. D. Shackelford, and M. Koohmaraie. 2004. Variation in palatability and biochemical traits within and among eleven beef muscles. J. Anim. Sci. 82:524-550.

Ritchie, H. D. 2000. Why is efficiency so important to the beef industry?. Limousin Focus Symposium, Stillwater, OK.

Rossi, D. J., D. D. Kress, M. W. Tess, and P. J. Burfening. 1992. Correcting bias from the standard linear adjustment of weaning weight to an age-constant basis for beef calves. J. Anim. Sci. 70:1333-1341.

Savell, J. W., H. R. Cross, and G. C. Smith. 1986. Percentage ether extractable fat and moisture content of beef *longissimus* muscle related to USDA marbling score. J. Food Sci. 51:838−840.

Shahin K. A and R. T. Berg. 1985. Growth patterns of muscle, fat and bone and carcass composition of double muscled and normal cattle. Can. J. Anim. Sci. 65:279 -294.

Steen, R. W. J. and D. J. Kilpatrick. 1995. Effects of plane of nutrition on harvest weight on the carcass composition of serially harvested bulls, steers and heifers of three breed crosses. Livest. Prod.Sci. 43:205–213.

Steen, R. W. J. and D. J. Kilpatrick. 2000. The effects of the ratio of grass silage to concentrate in the diet and restricted dry matter intake on the performance and carcass composition of beef cattle. Livest. Prod. Sci. 62:181-192.

Swatland, H. J. 1984. Structure and development of meat animals. Prentice-Hall Publications Inc., Englewood Cliffs, NJ, USA.

Tatum, J. D., Jr. F. L. Williams, and R. A. Bowling. 1986. Effects of feeder-cattle frame size and muscle thickness on subsequent growth and carcass development. III. Partitioning of separable carcass fat. J. Anim. Sci. 62:132-138.

Tedeschi, L. O., D. G. Fox, and P. J. Guiroy. 2004. A decision support system to improve individual cattle management. 1. A mechanistic, dynamic model for animal growth. Agric. Systems. 79:171–204.

Tess, M. W., G. E. Dickerson, J. A. Nienaber, J. T. Yen, and C. L. Ferrell. 1984. Energy costs of protein and fat deposition in pigs fed ad libitum. J. Anim. Sci. 58:111-122.

Trenkle, A. and D. N. Marple. 1983. Growth and development of meat animals. J. Anim. Sci. 57:273-283.

Warriss, P. D. 2010. Meat Science: an introductory text. 2nd ed. Cambridge University Press, Cambridge, U.K.

Williams, C. B. and T. G. Jenkins. 2003a. A dynamic model of metabolizable energy utilization in growing and mature cattle. II. Metabolizable energy utilization for gain. J. Anim. Sci. 81:1382-1389.

Williams, C. B. and T. G. Jenkins. 2003b. A dynamic model of metabolizable energy utilization in growing and mature cattle. III. Model evaluation. J. Anim. Sci. 81:1390-1398.

Chapter 3. Influence of Canadian cattle composite types and harvest age on tissue energy distribution of primal cuts

3.1 Introduction

The value of a beef carcass changes with the distribution of tissues in each meat cut (Pabiou et al., 2011). The final value of an animal depends on tissue composition of both the whole carcass as well as primal and sub primal cuts (Apple et al., 1999). Furthermore, retail values change relative to the type, tissue composition and eating quality of the retail cuts within the primal and sub primal cuts (Koch et al., 1982; Morris et al., 1999). There is genetic variation in the distribution of primal cuts in the carcass and the tissue composition changes with the type of breed (Pabiou et al., 2011). Evaluation of the carcass and sub primal compositions of different breeds or breed crosses is valuable in improving the efficiency of beef production (Wheeler et al., 1997). Navajas et al. (2010) also stated that the assessment of carcass composition in primal cuts is important for research and genetic improvement of carcass quality.

Traditionally, carcass dissection was used to determine the composition of primal cuts and currently new technique such as digital image analysis is being pursued to predict the composition of beef cuts (Pabiou et al., 2011). As dissection of the carcass into primal cuts is a time consuming and expensive procedure, researchers are looking for the new methods to evaluate and predict the composition of cuts and total carcass (Hanson, 1999). Increasing consumer demand for leaner beef products has changed the retail and packing segments in the beef industry and many of the packers trim and remove excess fat in the primal and sub primal cuts at the retail market (Ahmed et al., 1992; Miller et al., 1995). However, harvesting leaner cattle is more advantageous than harvesting fatty, lightly muscled cattle that require trimming of excess fat (Savell et al., 1989).

There is little information available on the primal cuts tissue composition and caloric values associated with producing M and F in beef primal cuts. In the present study, we hypothesised that tissue composition and energy deposition would be similar for primal cuts of BeefBooster® composites (CT) relative to harvest age or harvest time. The objective was to determine energy conversion into muscle and fat relative to primal cuts of composite types at different ages of harvesting.

3.2 Materials and methods

The data were collected from 173 crossbred steers from five BeefBooster® strains where foundation breeds were Angus (M1), Hereford (M2), various small breeds (M3), Limousin and Gelbvieh (M4) and Charolais (TX) (Kress et al., 1996) to determine the energetic values of muscle and fat tissues in primal cuts. Each group consisted of 18 steers from the same BeefBooster® strain. Data were obtained for two consecutive years (2000 and 2001). Ninety spring born calves averaging 232 (SD=14) days of age arrived in the feedlot early December 1999 and another ninety spring born calves averaging 238 (SD= 14) days of age arrived in early December 2000 at the Lacombe Research Center. They were treated and cared for under the guidelines established by the Canadian Council on Animal Care (1993). Animals were fed ad libitum twice daily a diet containing 73.3% barley grain, 22% barley silage, 1.6% molasses and 3.1% feedlot supplement (32% crude protein) on an as fed basis during 182 d finishing period. Samples of the feed were analyzed to estimate the dry matter, metabolize energy, crude protein, calcium, phosphorous (AOAC, 1980), acid detergent fibre, neutral detergent fibre, and lignin (Robertson and Van Soest, 1981).

Animals were serially harvested at 1 d, 71 d, 99 d, 127 d, 155 d, and 183 d of the finishing period. Fifteen animals, three from each genetic strain, were randomly selected for harvest at each slaughter date. Four calves died prior to harvest in 2001 and data for three animals were excluded as outliers (two standard deviation away from mean). Animals were harvested after they reach 274, 347, 372, 399, 427, and 456 days of age, on average, and 1, 71, 99, 127, 155, and 183 days in feedlot respectively. All the steers were measured for weight, hip height, body condition score, ultrasound back fat thickness, longissimus thoracic area and marbling score at entry to feedlot and again before harvest.

After harvest, hide and all the organs were separated and weighed. Then each carcass was divided into two halves as right and left as well as they weighed. After a 24-hr chill, cold carcass measurements were taken and the left side of each carcass was divided into nine primal (wholesale) cuts (Figure 3.1) as chuck, brisket, rib, plate, short loin, flank, loin, round and shank according to the procedures explained by Jones et al. (1984). Those cuts were separated into fat, bone and muscle and in addition, fat was further divided into body cavity (BC), subcutaneous (SC) and intermuscular (IM) fat (Basarab et al., 2003). Intramuscular fat was not determined in the nine primal cuts of the carcass.

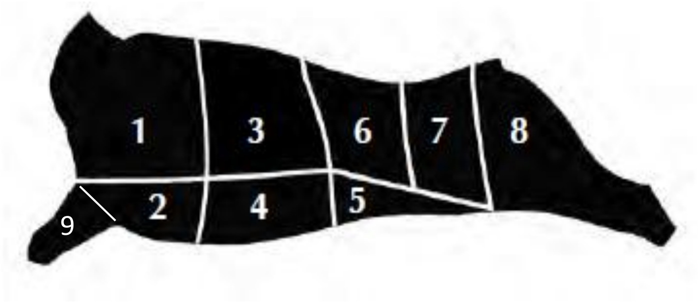


Figure 3.1 Primal cuts of a beef carcass

1.Chuck, 2.Brisket, 3.Rib, 4.Plate, 5.Flank, 6.Short loin, 7.Loin (Sirloin), 8.Round, and 9.Shank

Source: Beef and pork whole animal buying guide (2009)

The management of cattle and research procedure was same as chapter 2 and was cited in a paper by Basarab et al. (2003).

Calculating energy of different tissues

The energy deposited as muscle (protein) and dissectible fat in the primal cuts were calculated using weights of muscle and fat as well as caloric values which are 39.267 KJ g^{-1} and 23.175 KJ g^{-1} for fat and muscle, respectively (Brethour, 2004). The data from two different years were pooled together since age and initial weight at first day in feedlot was not significant for all the CTs ($P > 0.05$). The total energy was calculated by summing energy deposited as fat and muscle in each carcass. The proportion of energy deposited as muscle and fat in each cut as well as the proportion of energy deposited in each cut compared to total energy deposited (muscle + fat) in the body was determined. Further, energy deposited in different dissectible fat depots (BC, SC, IM) in each cut as well as the proportion (%) of energy deposited in different fat tissues related to total dissectible fat energy in each cut were determined. SC: BC+IM ratio was calculated for each primal cut. The data were pooled for the two years. All the data were analysed using GLM procedure of SAS (SAS Inst. Inc., Cary, NC). The composite type and age at harvest were considered as fixed effects and significance was declared at $P < 0.05$. The statistical analysis was conducted within each primal cut and least square means and standard errors were determined. Fisher's LSD method was used for the multiple comparisons ($P < 0.05$)

3.3 Results

The total energy deposited in each primal cut in the different composites by harvest age is shown in Table 3.1. In all cuts, the total energy deposited increased ($P < 0.01$) with the increase in harvest age. This is a reflection of the increase in the amounts of M and F with age. Differences between composites in the energy deposited were observed for the major primal cuts (chuck and round) at all harvest ages with the exception of the rib, loin, and short loin (Table 3.1). The chuck had the highest total caloric value (averaged over all harvest ages 1857.40 MJ) whereas the shank had the lowest total caloric value (averaged over all harvest ages 162.25 MJ) compared to all the other cuts of all the CTs.

Table 3.1. Total energy (MJ) deposited (least squares means) in the primal cuts

		Harvest age (days)*						
Primal cut	CT^y	274 d	347 d	372 d	399 d	427 d	456 d	*P* value^z
Chuck	M1	1038.20a	1875.95a	1875.91ab	2074.15ab	2208.84ac	2454.78a	<0.01
	M2	1053.86a	1546.16b	1866.26ab	2191.32a	2399.59a	2471.09a	<0.01
	M3	846.25b	1437.12b	1691.27b	1770.54b	1939.12b	1974.16b	<0.01
	M4	1078.92a	1766.26a	1938.19a	1939.44ab	2114.73bc	2437.90a	<0.01
	TX	1130.37a	1799.57a	2020.53a	2134.57a	2307.56ac	2339.66a	<0.01
	SEM	53.81	64.34	86.22	104.77	77.62	77.99	
Round	M1	943.71a	1459.88a	1469.96a	1525.14a	1568.09ab	1677.72a	<0.01
	M2	1020.76a	1301.92b	1530.96a	1702.86a	1772.51a	1921.97b	<0.01
	M3	755.77b	1088.78c	1247.55b	1281.66b	1357.00b	1324.36c	<0.01
	M4	1062.47a	1414.53ab	1558.33a	1527.14a	1634.72ab	1797.16ab	<0.01
	TX	1077.88a	1505.62a	1604.09a	1620.32a	1657.55a	1764.48ab	<0.01
	SEM	47.06	52.69	60.94	72.43	102.24	61.47	
Rib	M1	318.14	626.42a	635.33	773.54	805.06a	814.68a	<0.01
	M2	335.30	514.15bc	619.44	745.36	824.62a	859.66a	<0.01
	M3	275.59	488.61b	610.57	662.95	691.32b	694.64b	<0.01
	M4	321.79	575.29ac	671.84	643.01	709.78b	813.40a	<0.01
	TX	363.89	586.78a	656.25	686.82	767.04ab	780.14ab	<0.01
	SEM	20.78	23.68	39.67	32.86	35.15	29.36	
Loin	M1	318.77a	537.93a	549.30	559.78	657.05a	650.43b	<0.01
	M2	342.97a	438.49b	537.73	638.11	678.77a	718.19a	<0.01
	M3	259.04b	411.13b	501.40	525.14	548.07b	531.07c	<0.01
	M4	321.76a	506.27a	556.91	535.31	622.58ab	709.43a	<0.01
	TX	342.06a	523.68a	586.06	568.08	667.00a	672.70ab	<0.01
	SEM	16.21	17.19	21.32	30.48	28.92	18.17	
Short loin	M1	253.83	419.34a	469.95	480.17	557.29ab	558.25	<0.01
	M2	268.71	351.42b	469.72	526.26	604.57b	627.54	<0.01
	M3	224.34	347.37b	429.08	452.27	492.29a	504.84	<0.01
	M4	268.63	428.32a	478.66	457.86	503.65a	565.47	<0.01
	TX	293.62	421.48a	475.86	470.65	567.23ab	550.74	<0.01
	SEM	18.17	19.34	23.70	22.82	26.47	25.83	
Plate	M1	233.33	454.90ac	475.55	622.82	697.19	697.49ad	<0.01
	M2	258.80	362.32b	444.44	618.55	682.15	817.34b	<0.01
	M3	204.35	340.88b	436.58	507.79	585.14	564.64c	<0.01
	M4	257.80	399.16abc	502.99	517.73	580.43	723.46ab	<0.01
	TX	238.27	448.16c	489.03	553.01	623.74	614.52cd	<0.01
	SEM	16.79	20.50	31.42	36.52	48.69	36.87	
Brisket	M1	212.61	448.14a	413.30	505.01a	545.07	527.38a	<0.01
	M2	211.21	329.82b	386.04	502.13a	529.16	635.48b	<0.01
	M3	172.45	308.17b	354.70	373.63b	436.64	426.29c	<0.01
	M4	228.56	406.94a	436.38	429.95ab	450.29	588.10ab	<0.01
	TX	223.40	424.76a	433.76	453.15ab	528.35	515.49a	<0.01
	SEM	18.47	26.84	36.33	30.89	36.55	30.90	

Flank	M1	199.38	504.73a	471.26	585.67	593.76	743.17a	<0.01
	M2	218.83	381.20b	484.05	571.39	657.45	699.87ab	<0.01
	M3	173.20	386.14b	482.57	506.27	565.06	614.13b	<0.01
	M4	183.41	376.02bc	472.09	482.56	607.76	733.69a	<0.01
	TX	228.63	445.08ab	511.11	540.98	611.02	637.95b	<0.01
	SEM	15.95	27.94	31.55	42.41	48.09	32.02	
Shank	M1	105.89ab	152.44a	163.29a	176.75	177.54	175.53ac	<0.01
	M2	125.29ac	144.93a	154.93a	196.75	186.31	235.83b	<0.01
	M3	84.41b	117.40b	127.35b	156.88	172.47	148.82a	<0.01
	M4	134.70c	152.56a	177.15a	180.34	182.64	201.64bc	<0.01
	TX	114.39ac	179.53c	170.45a	180.06	204.11	187.37c	<0.01
	SEM	8.67	8.21	8.17	11.49	13.4	13.16	

CT[y] M1- composites based on Angus (early maturing), M2- composites based on Hereford (early maturing), M3- composites of small breeds (early maturing) M4-composites based on Gelbvieh, Limousin (late maturing), TX-composites based Charolais dams (late maturing).

[z]*P* value refers to differences in harvest age within composite type and primal cut.

a,b least square means within column and primal cuts with different letters differ ($P < 0.05$). Letters are only shown when means are different ($P < 0.05$).

*Harvest age is the average age of composites serially slaughtered at six time points.

The total energy in most of the cuts more than doubled for all the composites in the loin (107%), short loin (115%), chuck (127%), rib (146%), brisket (157%), and plate (186%) between 274 d – 456 d. Highest total energy change was observed for the flank which was 2.5 times higher (245%) and lowest total energy change was observed for the shank (68%) followed by the round (74%) over the 182 d period. The average total energy deposited in cuts as a percentage of total energy in the carcass were 3%, 6%, 7%, 7%, 7%, 8%, 10%, 23%, and 29% for the shank, brisket, flank, plate, short loin, loin, rib, round, and chuck respectively. All the CTs followed the similar energy partitioning pattern among primal cuts during the study period. However, the total energy as a proportion of total energy in the carcass decreased for the short loin, loin, round, and shank by 3%, 7%, 21%, 24% and proportions of other primal cuts such as the chuck, rib, brisket, plate, and flank increased by 2%, 10%, 15%, 28%, and 55% during 182 d period. The total energy values in the carcasses were calculated by summing all the energy values in primal cuts.

The total energy deposited in the small framed CTs were lower ($P < 0.05$) compared to the intermediate and large framed CTs. Even though at 274 d both intermediate framed (M1+M2) early maturing cattle and large framed late maturing (M4+TX) cattle had a similar amount of total energy deposited in all the cuts, at the end of trial period TX cattle had lower total energy for all the cuts compared to M2 and M4. On the first day in feedlot (274 d), the ratio of total energy of the major cuts (chuck+ round+ rib+ loin+ short loin) to total energy of other cuts was 3.82, 3.71, 3.72, 3.79, and 3.98 whereas on the last day of the study (456 d) those ratios were 2.87, 2.76, 2.86, 2.81, and 3.1 for M1, M2, M3, M4, and TX CTs respectively. Hence, the ratios decreased by 25%, 26%, 23%, 26%, and 22% relative to M1, M2, M3, M4, and TX CTs respectively.

The energy deposited as muscle and the energy deposited as dissectible fat in primal cuts are shown in the Table 3.2 and Table 3.3 respectively. The total energy deposited as M and F increased ($P < 0.01$) with harvest age in all the composites as M and F growth occurs with the increase in age of cattle. The average muscle energy change of composites in the round, short loin, shank, loin, rib, plate, brisket, chuck, flank was 48%, 54%, 55%, 63%, 68%, 74%, 75%, 77% and 128% respectively during the 182 d period (Table 3.2).

Table 3.2. Energy deposited in muscle tissue (MJ) of primal cuts

		Harvest age (days)*					
Primal cut	CT^{y}	274 d	347 d	372 d	399 d	427 d	456 d
Chuck	M1	696.74a	1077.74ab	1099.06a	1124.83ac	1153.35ab	1312.64a
	M2	728.47a	990.66b	1097.58a	1212.53ab	1325.25bc	1355.13a
	M3	578.45b	819.32c	925.31b	969.50c	1092.79a	946.94b
	M4	770.81a	1126.47a	1192.90ac	1152.27ab	1243.27b	1352.04a
	TX	791.11a	1128.63a	1250.38c	1290.86b	1375.37c	1366.10a
	SEM	36.78	43.35	46.08	52.56	43.42	50.22
Round	M1	726.96a	989.30a	1021.38a	1001.17a	1051.07	1101.28a
	M2	789.35a	958.99a	1071.06a	1163.86b	1200.47	1261.50a
	M3	569.65b	763.39b	834.46b	876.95a	908.31	802.63b
	M4	828.44a	1047.52a	1114.88a	1092.32b	1140.22	1186.96a
	TX	830.97a	1098.81a	1162.47a	1171.89b	1079.81	1214.22a
	SEM	37.62	44.35	38.61	47.43	85.69	42.19
Rib	M1	197.82ab	304.43a	312.40	313.33ab	341.45ab	339.28a
	M2	219.86a	292.16a	312.22	338.82ac	373.21a	382.70c
	M3	174.28b	244.11b	280.73	298.03b	302.05b	268.99b
	M4	219.70a	317.96a	289.38	329.40abc	345.77a	368.64ac
	TX	231.01a	322.91a	357.82	358.29c	373.58a	395.06c
	SEM	11.49	14.14	25.12	13.07	15.57	13.03
Loin	M1	216.36a	317.41ac	302.39a	310.36ab	357.05a	349.33a
	M2	237.47a	286.14a	318.15b	375.28c	382.85a	399.08b
	M3	167.94b	244.11b	268.68a	282.74a	295.72b	259.87c
	M4	231.44a	338.20c	346.70bc	332.95bc	367.87a	383.78ab
	TX	240.28a	336.50c	366.17c	358.13bc	388.73a	395.21b
	SEM	10.78	12.61	13.22	18.29	16.59	12.70
Short loin	M1	169.64ab	228.97ab	245.66ab	235.46a	257.55a	259.56a
	M2	181.54a	220.01bc	248.25ab	272.08bc	296.09bc	308.69b
	M3	142.14b	192.66c	212.59b	219.55a	243.34a	211.51c
	M4	189.57a	255.54a	266.36ac	267.29c	268.83ab	275.94ab
	TX	198.75a	254.46a	283.97c	273.00c	302.05c	298.65b
	SEM	9.60	11.24	12.34	10.13	11.11	12.50
Plate	M1	133.12ab	187.26ac	195.97ac	210.99	238.55	236.23a
	M2	147.55a	166.24a	188.74ab	222.48	239.54	283.05b
	M3	109.85b	133.03b	161.45b	186.33	194.83	161.76c
	M4	149.56a	182.93ac	213.98ac	218.77	229.13	251.99ab
	TX	130.52ab	198.69c	225.42c	228.66	241.02	241.49a
	SEM	8.38	7.52	10.54	12.77	18.07	13.14

Brisket	M1	98.26ab	170.75a	157.59ab	169.83a	176.75ab	176.59a
	M2	106.76a	140.29ab	157.04ab	186.95a	191.15ac	196.22a
	M3	79.26b	110.00b	126.69a	137.51b	154.96b	118.97b
	M4	114.95a	152.49a	170.41b	182.31a	174.90bc	205.64a
	TX	110.31a	179.99a	183.24b	179.07a	209.50a	199.00a
	SEM	8.65	13.87	10.79	10.76	11.54	14.38
Flank	M1	88.81a	179.28a	162.78	185.77	183.55	231.13a
	M2	101.82ac	148.48ab	168.34	190.50	206.35	212.44a
	M3	70.45b	131.17b	160.06	164.39	167.94	159.68b
	M4	91.00a	148.01bc	179.68	173.66	207.50	225.19a
	TX	109.57c	169.95ac	191.74	196.22	206.57	217.54a
	SEM	5.80	10.35	11.69	12.26	15.10	8.52
Shank	M1	74.16	97.15a	105.49a	112.35	110.00	111.40a
	M2	88.37	100.43a	102.16a	110.62	119.40	147.09b
	M3	59.02	77.87b	80.50b	99.81	93.94	86.52c
	M4	76.32	104.13ac	117.73a	121.44	124.53	128.08a
	TX	84.54	119.58c	117.58a	122.21	137.35	123.76a
	SEM	7.07	6.40	5.52	9.23	10.39	6.44

CT^y M1- composites based on Angus (early maturing), M2- composites based on Hereford (early maturing), M3- composites of small breeds (early maturing) M4-composites based on Gelbvieh, Limousin (late maturing), TX-composites based Charolais dams (late maturing).

a,b least square means within column and primal cuts with different letters differ ($P < 0.05$). Letters are only shown when means are different ($P < 0.05$).

*Harvest age is the average age of composites serially slaughtered at six time points.The differences between harvest ages within CTs were always significant ($P < 0.01$).

Higher fat energy changes compared to muscle energy change were observed in all the primal cuts of the composites (Table 3.3). The fat energy more than doubled for all of the cuts such as the shank (105%), round (163%), loin (206%), brisket (234%), chuck (240%), short loin (241%), rib (291%), plate (329%) and flank (345%) during the 182 d period.

Table 3.3. Energy deposited in the dissected fat tissue (MJ) of primal cuts

		Harvest age (days)*					
Primal cut	CT	274 d	347 d	372 d	399 d	427 d	456 d
Chuck	M1	341.46	798.22a	776.86	949.32	1055.49a	1142.14
	M2	325.39	555.49b	768.69	978.79	1074.34a	1115.96
	M3	267.80	617.80b	765.97	801.04	846.33c	1027.22
	M4	308.11	639.79b	745.28	787.17	871.46bc	1085.86
	TX	339.27	670.94b	770.15	843.71	932.19ac	973.56
	SEM	26.55	42.78	57.79	72.39	47.53	56.12
Round	M1	216.75ab	470.57ac	448.58	523.98	517.01	576.44ab
	M2	231.41a	342.93bc	459.89	539.00	572.04	660.47b
	M3	186.12b	325.39b	413.09	404.71	448.69	521.73a
	M4	234.03a	367.01bc	443.45	434.81	494.50	610.21ab
	TX	246.91a	406.80c	441.62	448.43	577.75	550.26a
	SEM	14.06	23.30	31.92	37.16	34.69	31.27
Rib	M1	120.31	321.99a	322.93	460.21a	463.61a	475.39
	M2	115.44	221.99b	307.22	406.54ac	451.41ac	476.96
	M3	101.31	244.50b	329.84	364.92bc	389.27bc	425.65
	M4	101.05	257.33b	382.46	313.61b	364.00b	444.76
	TX	132.88	263.87b	298.43	328.53b	393.45bc	385.08
	SEM	13.03	17.65	45.58	26.96	25.58	25.90
Loin	M1	102.41	220.52a	246.91	249.42	300.00	301.10
	M2	104.71	152.36b	219.58	262.83	295.91	319.11
	M3	91.10	167.01b	232.72	242.41	252.35	271.20
	M4	90.31	168.06b	210.21	202.36	254.71	325.65
	TX	101.78	187.17ab	219.89	209.95	278.27	277.49
	SEM	7.95	13.99	16.13	18.66	15.84	16.96
Short loin	M1	84.19	190.37a	224.29	244.71	299.74	298.69
	M2	87.17	131.41b	221.46	254.19	308.48	318.85
	M3	82.20	154.71ab	216.49	232.72	248.95	293.32
	M4	79.06	172.77a	212.30	190.58	234.82	289.53
	TX	94.87	167.01ab	191.88	197.64	265.18	252.09
	SEM	11.28	12.92	15.86	17.88	20.58	20.61
Plate	M1	100.21	267.64a	279.58	411.83a	458.64	461.25ab
	M2	111.26	196.07b	255.71	396.07ab	442.62	534.29a
	M3	94.50	207.85bc	275.13	321.46bc	390.31	402.88bc
	M4	108.25	216.23bc	289.00	298.95c	351.31	471.46ab
	TX	107.75	249.48c	263.61	324.34abc	382.72	373.03c
	SEM	12.13	17.02	25.88	29.80	35.17	30.05

Brisket	M1	114.35	277.38a	255.71	335.18a	368.32	350.78ac
	M2	104.45	189.53b	229.00	315.18a	338.01	439.27b
	M3	93.19	198.17bc	228.01	236.12b	281.67	307.33a
	M4	113.61	254.45ac	265.97	247.64b	275.39	382.46bc
	TX	113.09	244.76ab	250.52	274.08ab	318.85	316.49ac
	SEM	11.99	21.52	28.94	23.72	26.96	24.11
Flank	M1	110.58	325.44a	308.48	399.89	410.21	512.04
	M2	117.02	232.72b	315.71	380.89	451.10	487.43
	M3	102.75	254.97b	322.51	341.88	397.12	454.45
	M4	92.41	228.01b	292.41	308.90	400.26	508.51
	TX	119.06	275.13ab	319.37	344.76	404.45	420.42
	SEM	12.15	21.80	25.53	33.48	37.35	29.68
Shank	M1	31.73	55.29ac	57.80	64.40	67.54	64.14
	M2	36.91	44.50ab	52.77	86.13	66.91	88.74
	M3	25.39	39.53b	46.86	57.07	78.53	62.30
	M4	58.38	48.43ab	59.42	58.90	58.11	73.56
	TX	29.84	59.95c	52.88	57.85	66.75	63.61
	SEM	10.96	3.81	4.56	10.84	10.05	7.55

CT^{y} M1- composites based on Angus (early maturing), M2- composites based on Hereford (early maturing), M3- composites of small breeds (early maturing) M4-composites based on Gelbvieh, Limousin (late maturing), TX-composites based Charolais dams (late maturing).

a,b least square means within column and primal cuts with different letters differ ($P < 0.05$). Letters are only shown when means are different ($P < 0.05$).

*Harvest age is the average age of composites serially slaughtered at six time points.The differences between harvest ages within CTs were always significant ($P < 0.01$).

The muscle energy to fat energy ratios (E-muscle: E-fat) of the primal cuts are shown in Table 3.4. E-muscle: E-fat ratios of all the primal cuts except shank changed significantly ($P < 0.01$) in all the CTs with increasing harvest age. The composite type differences were observed ($P < 0.05$) in E-muscle: E-fat ratios in primal cuts at some harvest ages as follows: in the chuck at all the harvest ages except 274 d and 399 d, in the round at all the harvest ages except 274 d and 427 d, in the rib at all the harvest ages except 274 d and 372 d, in the loin at all the harvest ages, in the short loin and plate at all the harvest ages except 274 d, in the brisket at all the harvest ages except 274 d-372 d, in the flank only at 456 d, and in the shank only at 427 d and 456 d. At the 456 d, E-muscle: E-fat ratio in primal cuts of the small composite type was lowest ($P < 0.05$), TX had highest ($P < 0.05$) and other CTs had comparatively lower or equal ratios.

Table 3.4. Changes of energy muscle: energy fat ratio in the primal cuts with harvest ages

		Harvest age (days)*						
Primal cut	CT^y	274 d	347 d	372 d	399 d	427 d	456 d	*P* value ^{z}
Chuck	M1	2.06	1.36a	1.42ab	1.20	1.09a	1.16a	0.01
	M2	2.30	1.80b	1.47ab	1.25	1.24ab	1.22ac	<0.01
	M3	2.17	1.37a	1.23a	1.26	1.31bc	0.93b	<0.01
	M4	2.76	1.77b	1.63b	1.52	1.44bc	1.26ac	<0.01
	TX	2.37	1.73bc	1.68b	1.59	1.49c	1.45c	<0.01
	SEM	0.26	0.11	0.11	0.12	0.07	0.08	
Round	M1	3.34	2.12a	2.31ab	1.93a	2.06	1.92a	<0.01
	M2	3.44	2.82b	2.34ab	2.19ab	2.11	1.93a	<0.01
	M3	3.09	2.43ab	2.06b	2.23ab	2.09	1.55b	<0.01
	M4	3.58	2.89b	2.58a	2.55bc	2.32	1.96a	<0.01
	TX	3.42	2.74b	2.68a	2.71c	1.90	2.25c	<0.01
	SEM	0.18	0.17	0.15	0.16	0.18	0.10	
Rib	M1	1.68	0.95a	0.98	0.69a	0.74a	0.72ab	0.01
	M2	2.05	1.34b	1.03	0.86ab	0.83ab	0.82b	<0.01
	M3	1.76	1.02ac	0.88	0.83ab	0.79a	0.63a	<0.01
	M4	2.46	1.24bc	0.92	1.06bc	0.96b	0.84b	<0.01
	TX	1.81	1.27bc	1.26	1.16c	0.98b	1.05c	<0.01
	SEM	0.27	0.09	0.12	0.08	0.05	0.06	
Loin	M1	2.13ac	1.48a	1.24a	1.25a	1.20a	1.20ab	<0.01
	M2	2.33ab	1.93ab	1.45ab	1.45ab	1.30ab	1.27a	<0.01
	M3	1.89a	1.51a	1.20a	1.22a	1.18a	0.96b	<0.01
	M4	2.62b	2.02b	1.70b	1.67b	1.47b	1.44ab	<0.01
	TX	2.42bc	1.90ab	1.70b	1.77b	1.41b	1.46a	<0.01
	SEM	0.16	0.15	0.11	0.13	0.07	0.09	
Short loin	M1	2.11	1.22a	1.10a	0.98a	0.88a	0.87ab	<0.01
	M2	2.24	1.72b	1.13a	1.09a	0.97ab	1.00ac	<0.01
	M3	1.81	1.26a	1.02a	0.97a	0.99ab	0.73b	<0.01
	M4	2.67	1.51ab	1.26ab	1.46b	1.16b	0.96ab	<0.01
	TX	2.21	1.60b	1.52b	1.45b	1.17b	1.23c	<0.01
	SEM	0.26	0.12	0.09	0.12	0.07	0.08	

Plate	M1	1.36	0.70ab	0.70ab	0.51a	0.52ac	0.52a	<0.01
	M2	1.49	0.85a	0.76ab	0.58ab	0.54ab	0.54a	<0.01
	M3	1.18	0.66b	0.62b	0.60ab	0.51a	0.40b	<0.01
	M4	1.46	0.85a	0.75ab	0.74b	0.66b	0.54a	<0.01
	TX	1.24	0.83a	0.88a	0.75b	0.65bc	0.66c	<0.01
	SEM	0.15	0.05	0.06	0.07	0.04	0.04	
Brisket	M1	0.88	0.61	0.61	0.51a	0.48a	0.52a	<0.01
	M2	1.04	0.76	0.75	0.60ac	0.57ab	0.46ab	<0.01
	M3	0.86	0.57	0.59	0.60ac	0.56a	0.39b	<0.01
	M4	1.12	0.66	0.66	0.74b	0.65b	0.54ac	<0.01
	TX	1.01	0.75	0.76	0.69bc	0.66bc	0.63c	<0.01
	SEM	0.11	0.07	0.06	0.05	0.03	0.04	
Flank	M1	0.84	0.55	0.54	0.47	0.45	0.46ac	<0.01
	M2	0.88	0.64	0.55	0.50	0.47	0.44abc	<0.01
	M3	0.71	0.54	0.51	0.50	0.44	0.36b	<0.01
	M4	1.09	0.65	0.63	0.57	0.53	0.45ac	<0.01
	TX	0.98	0.63	0.61	0.59	0.52	0.52c	<0.01
	SEM	0.09	0.04	0.05	0.04	0.04	0.03	
Shank	M1	2.32	1.76	1.83	1.77	1.64ac	1.79ab	<0.01
	M2	2.40	2.27	1.96	1.60	1.77ab	1.70ab	<0.01
	M3	2.39	2.03	1.81	1.84	1.52a	1.43a	0.02
	M4	2.04	2.20	2.07	2.07	2.18b	1.83b	0.86
	TX	2.83	2.08	2.27	2.16	2.12bc	2.03b	0.07
	SEM	0.23	0.17	0.19	0.18	0.18	0.13	

CT[y] M1- composites based on Angus (early maturing), M2- composites based on Hereford (early maturing), M3- composites of small breeds (early maturing) M4-composites based on Gelbvieh, Limousin (late maturing), TX-composites based Charolais dams (late maturing).

[z] *P* value refers to differences in harvest age within composite type and primal cut.

a,b least square means within column and primal cuts with different letters differ ($P < 0.05$). Letters are only shown when means are different ($P < 0.05$).

*Harvest age is the average age of composites serially slaughtered at six time points.

The average changes of the E-muscle: E-fat ratio during 182 d were 0.45, 0.47, 0.64, 0.81, 1.01, 1.13, 1.14, 1.25, and 1.45 for the flank, brisket, shank, plate, loin, chuck, rib, short loin, and round respectively. The changes were higher for the major primal cuts compared to other primal cuts. The round had the highest change in E-muscle: E-fat ratio and the lowest deposition of fat energy (Table 3.3) among the major cuts over the period.

The muscle and fat energy deposited in each cut as a percentage of total energy in the whole carcass is shown in Table 3.5 and Table 3.6 respectively. The fat and muscle energy content in most cuts compared to total energy in the carcass changed significantly ($P < 0.01$) with days in the feedlot. On the first day in feedlot (274 d), the round in all the CTs had the highest muscle energy percentage (20%) compared to total energy in the carcass (E-muscle: E-carcass) and it decreased with the time whereas at the end of the trial period (456 d) the chuck had the highest muscle energy percentage (15%) compared to other cuts. Nearly 1/5th of total carcass energy was deposited as muscle energy in the round. As expected, the shank had the lowest muscle (2%) and fat energy (1%) content compared to total energy throughout the 182 d period. The E-muscle: E-carcass ratio decreased by 20%, 21%, 22%, 24%, 26%, 30%, 31%, and 33% in the chuck, brisket, plate, rib, loin, shank, short loin, and round, respectively, and the ratio increased by 2% in the flank during 182 d. There was a significant effect ($P < 0.05$) of CTs on the muscle energy distribution among the primal cuts (Table 3.5).

Table 3.5. Muscle energy proportions relative to total energy in the whole carcass (E-muscle: E-carcass ratio)

		Harvest age (days)*						
Primal Cut	CT^{y}	274 d	347d	372d	399d	427d	456d	*P* value^{x}
Chuck	M1	19.17	16.61a	16.84ab	15.42a	14.83a	15.79ac	<0.01
	M2	18.94	18.47bc	16.99ab	15.77ab	15.91ab	15.06ab	<0.01
	M3	19.34	16.69a	15.82b	15.66a	16.13ab	13.99b	<0.01
	M4	20.22	18.70c	17.59a	17.16bc	16.83b	15.81ac	<0.01
	TX	19.79	17.81ac	18.02a	18.03c	17.41b	17.00c	0.05
	SEM	0.62	0.52	0.51	0.53	0.54	0.50	
Round	M1	20.06ab	15.23a	15.66ab	13.72a	13.44	13.25a	<0.01
	M2	20.61ab	17.87b	16.59a	15.18ab	14.42	14.03a	<0.01
	M3	19.03b	15.57a	14.27b	14.14a	13.42	11.83b	<0.01
	M4	21.60a	17.38b	16.46a	16.29b	15.43	13.86a	<0.01
	TX	20.76a	17.37bc	16.79a	16.40b	13.52	15.13c	<0.01
	SEM	0.57	0.58	0.50	0.59	1.01	0.40	
Rib	M1	5.44	4.67	4.79	4.34	4.38	4.08a	<0.01
	M2	5.73	5.45	4.82	4.41	4.48	4.26a	<0.01
	M3	5.82	5.00	4.79	4.77	4.45	3.98a	<0.01
	M4	5.72	5.28	4.37	4.91	4.69	4.32a	0.03
	TX	5.78	5.09	5.16	5.00	4.74	4.93b	0.05
	SEM	0.17	0.18	0.36	0.20	0.18	0.17	
Loin	M1	5.96	4.91	4.64	4.24a	4.57	4.20ab	<0.01
	M2	6.19	5.35	4.93	4.90bc	4.60	4.45a	<0.01
	M3	5.63	4.98	4.61	4.56ac	4.37	3.83b	<0.01
	M4	6.02	5.62	5.14	4.94c	4.97	4.49a	<0.01
	TX	6.02	5.31	5.29	4.99c	4.91	4.93c	<0.01
	SEM	0.15	0.18	0.22	0.18	0.18	0.16	
Short loin	M1	4.66	3.54	3.77	3.26a	3.30	3.12a	<0.01
	M2	4.74	4.09	3.84	3.56ab	3.56	3.44ab	<0.01
	M3	4.76	3.94	3.65	3.56ab	3.61	3.13a	<0.01
	M4	4.91	4.23	3.94	3.98b	3.64	3.23a	<0.01
	TX	4.97	4.02	4.11	3.81b	3.83	3.72b	<0.01
	SEM	0.12	0.16	0.19	0.16	0.15	0.16	
Plate	M1	3.67	2.90	3.00	2.91	3.02	2.84a	<0.01
	M2	3.87	3.11	2.92	2.91	2.87	3.15a	<0.01
	M3	3.66	2.72	2.74	3.00	2.88	2.38b	<0.01
	M4	3.92	3.04	3.15	3.24	3.08	2.93a	<0.01
	TX	3.25	3.13	3.25	3.19	3.08	3.02a	0.86
	SEM	0.19	0.13	0.13	0.15	0.20	0.15	

Brisket	M1	2.69	2.62	2.42	2.33	2.24a	2.13ab	0.03
	M2	2.77	2.61	2.42	2.44	2.30a	2.17ab	0.24
	M3	2.64	2.26	2.17	2.21	2.29a	1.75a	<0.01
	M4	2.99	2.52	2.52	2.70	2.37ab	2.40b	0.12
	TX	2.74	2.83	2.62	2.51	2.64b	2.48b	0.55
	SEM	0.17	0.20	0.12	0.12	0.10	0.15	
Flank	M1	2.47	2.74	2.50	2.55	2.34	2.78a	0.07
	M2	2.67	2.77	2.58	2.47	2.47	2.37bc	0.36
	M3	2.38	2.68	2.76	2.64	2.48	2.35b	0.89
	M4	2.34	2.46	2.65	2.58	2.79	2.63ac	0.01
	TX	2.75	2.68	2.75	2.74	2.62	2.71a	0.71
	SEM	0.14	0.15	0.14	0.12	0.16	0.09	
Shank	M1	2.06	1.50	1.63	1.56	1.39	1.35ac	0.01
	M2	2.30	1.88	1.59	1.46	1.44	1.64b	0.01
	M3	1.97	1.61	1.38	1.61	1.40	1.27a	0.01
	M4	2.01	1.72	1.75	1.81	1.68	1.49bc	0.25
	TX	2.11	1.90	1.70	1.72	1.75	1.54c	0.06
	SEM	0.18	0.10	0.10	0.13	0.13	0.08	

CT[y]M1- composites based on Angus (early maturing), M2- composites based on Hereford (early maturing), M3- composites of small breeds (early maturing) M4-composites based on Gelbvieh, Limousin (late maturing), TX-composites based Charolais dams (late maturing).

[x]*P* value refers to differences in harvest age within composite type and primal cut.

a,b least square means within column and primal cuts with different letters differ ($P < 0.05$). Letters are only shown when means are different ($P < 0.05$).

*Harvest age is the average age of composites serially slaughtered at six time points.

The muscle energy proportion of the major cuts such as the chuck, round, rib, loin, and short loin compared to total energy in the body (whole carcass) decreased by a higher proportion ($P < 0.01$) for M1, M2, M3, and M4 composites and decreased at a lower proportion ($P < 0.05$) for TX composite type with the increase in harvest age. At 399 d, E-muscle: E-carcass proportions of major cuts (chuck + round+ rib+ loin+ short loin) was numerically lower for small composite types M3 and M1 compared to the larger CTs. At 456 d, E-muscle: E-carcass ratio of major cuts was lower ($P < 0.05$) for all the other CTs compared to TX.

The dissectible fat energy deposited in all the primal cuts except the shank expressed as a proportion of total energy in the carcass (E-fat: E-carcass) increased ($P < 0.05$) for all the CTs with increasing the age at harvest (Table 3.6). The E-fat: E-carcass was highest for the chuck and lowest for the shank at all the harvest ages. At 274 d, E-fat: E-carcass ratio (Table 3.6) of all the cuts except the flank and brisket were lower than the E-muscle: E-carcass ratio (Table 3.5). Muscle in these cuts is growing at a faster rate than fat in relation to the whole carcass. The E-fat: E-carcass ratio was higher than E-muscle: E-carcass ratio in both the flank and brisket even at the beginning of study since they contained higher amounts of fat tissues. Some major cuts such as the chuck, rib, loin, and short loin increased in the E-fat: E-carcass ratio with the increasing harvest age and at 456 d they almost exceed or reached the E-muscle: E-carcass ratios. These are the cuts where fat growth is pronounced as more energy is used to grow fat. However, E-fat: E-carcass ratio of the round increased slightly with age of harvest and for the TX it was not different ($P > 0.05$), because this is the leanest primal among the major cuts. In the plate the E-fat: E-carcass ratio increased ($P < 0.05$) with age of harvest and reached or exceeded the ratio of E-muscle: E-carcass. The E-fat: E-carcass ratio increased by 18%, 36%, 50%, 53%, 55%, 76%, 93%, and 99% in the round, loin, brisket, chuck, short loin, rib, plate, and flank, respectively, and the ratio decreased by 13% in the shank within 182 d.

Table 3.6. Fat energy proportions relative to total energy in the whole carcass (E-fat: E-carcass ratio)

		Harvest age (days)*						
Primal cut	CT^{y}	274 d	347 d	372 d	399 d	427 d	456 d	*P* value^{x}
Chuck	M1	9.44	12.37a	11.90	12.91	13.64a	13.77ab	<0.01
	M2	8.48	10.33b	11.73	12.67	12.90ab	12.42ac	<0.01
	M3	8.96	12.41a	12.95	12.73	12.43b	15.19b	<0.01
	M4	7.81	10.63b	10.93	11.79	11.76b	12.65ac	<0.01
	TX	8.45	10.57b	11.09	11.59	11.73b	11.97c	<0.01
	SEM	0.50	0.53	0.53	0.65	0.49	0.52	
Round	M1	6.02	7.26	6.85	7.16	6.56	6.94	<0.01
	M2	6.05	6.37	7.08	6.98	6.87	7.34	<0.01
	M3	6.19	6.54	7.01	6.45	6.62	7.69	<0.03
	M4	6.08	6.09	6.48	6.46	6.66	7.12	<0.06
	TX	6.13	6.45	6.34	6.19	7.24	6.79	0.16
	SEM	0.24	0.29	0.28	0.30	0.28	0.27	
Rib	M1	3.33	4.97a	4.94	6.33a	5.97a	5.74ab	<0.01
	M2	3.00	4.11bc	4.70	5.26b	5.41ab	5.30ac	<0.01
	M3	3.36	4.96a	5.57	5.84a	5.71a	6.29b	<0.01
	M4	2.54	4.28b	5.50	4.68bc	4.91b	5.19ac	<0.01
	TX	3.29	4.16b	4.26	4.49c	4.94bc	4.76c	0.02
	SEM	0.26	0.24	0.49	0.24	0.26	0.28	
Loin	M1	2.83ac	3.43	3.80ac	3.40ab	3.84	3.64ab	0.01
	M2	2.76ab	2.84	3.39ab	3.40ab	3.56	3.56ab	<0.01
	M3	3.05a	3.36	3.94c	3.88a	3.72	3.99b	<0.01
	M4	2.32b	2.79	3.07b	3.03b	3.42	3.80ab	<0.01
	TX	2.53bc	2.96	3.16b	2.89b	3.49	3.42a	<0.01
	SEM	0.17	0.21	0.17	0.18	0.14	0.17	
Short loin	M1	2.31	2.95	3.44ab	3.35ab	3.87	3.60a	<0.01
	M2	2.26	2.43	3.41ab	3.30ab	3.69	3.54a	<0.01
	M3	2.71	3.15	3.66a	3.73a	3.68	4.33b	<0.01
	M4	1.99	2.86	3.13bc	2.84bc	3.18	3.38a	<0.01
	TX	2.34	2.64	2.77c	2.72c	3.34	3.10a	0.03
	SEM	0.23	0.20	0.19	0.19	0.25	0.21	
Plate	M1	2.77	4.16	4.29	5.63a	5.81a	5.57a	<0.01
	M2	2.88	3.65	3.92	5.14ab	5.30ab	5.95a	<0.01
	M3	3.15	4.20	4.58	5.11ab	5.73ac	5.91a	<0.01
	M4	2.78	3.59	4.26	4.44b	4.71b	5.47a	<0.01
	TX	2.65	3.93	3.79	4.44b	4.83bc	4.61b	<0.01
	SEM	0.26	0.24	0.28	0.27	0.34	0.28	

Brisket	M1	3.17	4.26	3.92	4.59	4.68	4.24	0.02
	M2	2.70	3.50	3.47	4.09	4.04	4.88	<0.01
	M3	3.10	4.02	3.82	3.75	4.14	4.52	<0.01
	M4	2.87	4.21	3.90	3.68	3.70	4.45	0.02
	TX	2.78	3.87	3.56	3.76	4.01	3.92	0.03
	SEM	0.23	0.31	0.31	0.22	0.25	0.26	
Flank	M1	3.05	5.01ab	4.74ab	5.43	5.26	6.18ab	<0.01
	M2	3.06	4.33bc	4.80ab	4.93	5.39	5.46ac	<0.01
	M3	3.40	5.12a	5.52a	5.40	5.81	6.66b	<0.01
	M4	2.32	3.79c	4.28b	4.61	5.39	5.93abc	<0.01
	TX	2.93	4.33bc	4.58b	4.73	5.06	5.18c	<0.01
	SEM	0.25	0.27	0.29	0.29	0.37	0.32	
Shank	M1	0.89	0.85	0.88	0.87	0.85	0.77	0.63
	M2	0.96	0.83	0.81	1.10	0.80	0.99	0.41
	M3	0.85	0.80	0.78	0.90	1.15	0.91	0.36
	M4	1.52	0.80	0.88	0.87	0.78	0.85	0.27
	TX	0.74	0.95	0.77	0.80	0.85	0.78	0.29
	SEM	0.28	0.07	0.06	0.12	0.13	0.08	

CT^y M1- composites based on Angus (early maturing), M2- composites based on Hereford (early maturing), M3- composites of small breeds (early maturing) M4-composites based on Gelbvieh, Limousin (late maturing), TX-composites based Charolais dams (late maturing).

^{x}*P* value refers to differences in harvest age within composite type and primal cut.

a,b least square means within column and primal cuts with different letters differ ($P < 0.05$). Letters are only shown when means are different ($P < 0.05$).

*Harvest age is the average age of composites serially slaughtered at six time points.

There were no differences ($P > 0.05$) in E-fat: E-carcass ratios among CTs in the round, brisket and shank, and CTs had similar ratios at each harvest age. However, at 399 d small CTs and M1 had higher ($P < 0.05$) E-fat: E-carcass ratio in the loin, rib, plate compared to other CTs. At 456 d, small CTs had the highest ($P < 0.05$) E-fat: E-carcass ratio and TX had lower ratios ($P < 0.05$) in all the cuts except the round, brisket and shank.

The proportions of energy deposited as F and M (expressed as %) in each primal cut is shown in Tables 3.7 and Table 3.8 respectively. The proportion of energy deposited as muscle decreased (P < 0.05) and the proportion of energy deposited as fat increased (P < 0.01) during the 182 d period in the primal cuts except shank of all the CTs. At 399 d, the composite type effect is prominent and after 399 d, M4 gained a significant amount of fat. During the 125 d period from 274 d to 399 d, the proportion of muscle energy decreased in primal cuts as follows: in the chuck proportion changed by 19%, 20%, 19%, 17%, and 13%: in the round by 15%, 11%, 9%, 8%, and 6%: in the rib by 35%, 30%, 29%, 26%, and 17%: in the loin by 18%, 15%, 16%, 14%, and 10%: in the short loin by 26%, 24%, 23%, 18%, and 14%: in the plate by 40%, 37%, 31%, 28%, and 24%: in the brisket by 27%, 25%, 19%, 18%, and 19%: in the flank by 29%, 28%, 20%, 30%, and 24%: in the shank by 9%, 18%, 8%, -10%, and 8% in the M1, M2, M3, M4, and TX respectively (Table 3.7).

During the 274 d to 399 d period the proportion of fat energy in primal cuts increased as follows: in the chuck percentage changed by 38%, 44%, 41%, 45%, and 31%: in the round by 49%, 38%, 28%, 30%, and 20%: in the rib by 57%, 59%, 50%, 60%, and 31%: in the loin by 38%, 35%, 31%, 36%, and 24%: in the short loin by 53%, 50%, 41%, 46%, and 30%: in the plate by 54%, 51%, 36%, 40%, and 29%: in the brisket by 23%, 26%, 16%, 19%, and 19%: in the flank by 24%, 25%, 14%, 31%, and 23%: in the shank by 20%, 43%, 19%, -16%, and 23% in the M1, M2, M3, M4, and TX respectively (Table 3.8).

Table 3.7. Muscle energy proportions (%) relative to total energy in primal cuts

		Harvest age (days)*						*P* value^z
Primal cut	CT^y	274 d	347 d	372 d	399 d	427 d	456 d	
Chuck	M1	66.99	57.36a	58.58ab	54.42	52.14b	53.33a	<0.01
	M2	69.08	64.16b	59.15ab	55.49	55.32ab	54.79ab	<0.01
	M3	68.34	57.42a	54.93b	55.22	56.45ac	48.00c	<0.01
	M4	72.02	63.73b	61.67a	59.42	58.86ac	55.53ab	<0.01
	TX	70.11	62.73b	62.05a	60.85	59.72c	58.75b	<0.01
	SEM	1.72	1.67	1.70	2.00	1.20	1.57	
Round	M1	76.90	67.64a	69.57ab	65.65a	67.25	65.52a	<0.01
	M2	77.25	73.68b	69.99ab	68.48ab	67.73	65.68a	<0.01
	M3	75.44	70.41ab	67.01b	68.52ab	66.91	60.66b	<0.01
	M4	78.02	74.00b	71.76a	71.51b	69.80	66.05ac	<0.01
	TX	77.11	72.78b	72.51a	72.59b	62.36	69.01c	0.03
	SEM	0.92	1.43	1.28	1.49	3.03	1.15	
Rib	M1	62.16	48.50a	49.40	40.66a	42.42a	41.64ab	<0.01
	M2	65.82	57.03b	50.61	45.77a	45.26ac	44.87a	<0.01
	M3	63.47	50.19ac	46.51	45.14a	43.96a	38.75b	<0.01
	M4	69.44	55.26bc	44.85	51.18b	48.75bc	45.47a	<0.01
	TX	63.98	55.26bc	54.81	52.84b	49.07bc	50.94c	<0.01
	SEM	2.41	1.93	3.88	1.94	1.51	1.70	
Loin	M1	67.81ab	58.94	55.13a	55.50a	54.34a	53.72ab	<0.01
	M2	69.49a	65.47	59.14ac	58.90ac	56.41ac	55.69b	<0.01
	M3	64.99b	59.80	53.89a	54.16a	53.90a	49.06a	<0.01
	M4	72.18a	66.78	62.48c	62.02c	59.19c	54.03ab	<0.01
	TX	70.42a	64.37	62.47c	63.39c	58.45c	59.02b	<0.01
	SEM	1.57	2.13	1.90	2.00	1.28	1.84	
Short loin	M1	67.00	54.56a	52.28ab	49.40a	46.60a	46.43ab	<0.01
	M2	67.99	62.96b	52.95ab	51.81a	49.12ab	49.68bc	<0.01
	M3	63.86	55.47ac	50.12a	48.94a	49.51ab	42.09a	<0.01
	M4	71.51	59.92ab	55.72b	58.37b	53.47b	48.84b	<0.01
	TX	68.23	60.64bc	59.64c	58.6b	53.50b	54.46c	<0.01
	SEM	2.49	1.98	1.72	2.04	1.73	1.87	
Plate	M1	57.12	41.29ab	41.16	34.13a	34.28ac	34.03a	<0.01
	M2	57.91	45.97a	43.05	36.25ab	35.10ab	34.71a	<0.01
	M3	53.78	39.38b	37.81	37.20ab	33.52a	28.72b	<0.01
	M4	58.61	45.94a	42.70	42.10b	39.80b	35.01a	<0.01
	TX	55.26	44.78a	46.39	42.18b	38.85bc	39.51c	<0.01
	SEM	2.71	1.74	2.03	2.15	1.71	1.49	

Brisket	M1	46.28	37.94	38.14	33.83a	32.54a	33.83ac	<0.01
	M2	50.04	42.87	42.12	37.26ac	36.34ab	30.74ab	<0.01
	M3	46.10	35.94	36.55	37.36ab	35.74ac	27.96b	<0.01
	M4	51.60	38.30	39.39	42.26b	39.15bc	34.92ac	<0.01
	TX	49.91	42.36	42.76	40.27bc	39.76b	38.70c	0.02
	SEM	2.58	2.66	2.25	1.72	1.32	1.84	
Flank	M1	44.99	35.45	34.77	32.00	30.79	31.26a	<0.01
	M2	46.69	39.07	35.34	33.38	31.78	30.47a	<0.01
	M3	41.25	34.62	33.29	33.08	30.24	26.35b	<0.01
	M4	51.19	39.41	38.56	36.01	34.25	30.82a	<0.01
	TX	48.69	38.42	37.46	36.86	34.02	34.36a	<0.01
	SEM	2.52	1.80	1.97	1.68	1.60	1.39	
Shank	M1	69.89	63.52	64.63	63.77	61.95	63.78a	0.01
	M2	70.37	69.30	66.13	57.59	63.84	62.55ab	0.12
	M3	69.96	66.38	63.90	64.10	55.99	58.53b	0.11
	M4	60.98	68.27	66.61	67.36	68.33	64.14a	0.80
	TX	73.86	66.65	68.74	67.84	67.35	66.49a	0.13
	SEM	4.84	1.89	1.86	3.84	3.84	1.70	

CT^{y} M1- composites based on Angus (early maturing), M2- composites based on Hereford (early maturing), M3- composites of small breeds (early maturing) M4-composites based on Gelbvieh, Limousin (late maturing), TX-composites based Charolais dams (late maturing).

^{z}*P* value refers to differences in harvest age within composite type and primal cut.

a,b least square means within column and primal cuts with different letters differ ($P < 0.05$). Letters are only shown when means are different ($P < 0.05$).

*Harvest age is the average age of composites serially slaughtered at six time points.

Table 3.8. Fat energy proportions (%) relative to total energy in primal cuts

		Harvest age (days)*						
Primal cut	CT^{y}	274 d	347 d	372 d	399 d	427 d	456 d	*P* value^{z}
Chuck	M1	33.01	42.64a	41.42ab	45.58	47.86b	46.67a	<0.01
	M2	30.92	35.84b	40.85ab	44.51	44.68ab	45.21ab	<0.01
	M3	31.66	42.58a	45.07b	44.78	43.55ac	52.00c	<0.01
	M4	27.98	36.27b	38.33a	40.58	41.14ac	44.47ab	<0.01
	TX	29.89	37.27b	37.95a	39.15	40.28c	41.25b	<0.01
	SEM	1.72	1.67	1.70	2.00	1.20	1.57	
Round	M1	23.10	32.36a	30.43ab	34.35a	32.75	34.48a	<0.01
	M2	22.75	26.32b	30.01ab	31.52ab	32.27	34.32a	<0.01
	M3	24.56	29.59ab	32.99b	31.48ab	33.09	39.34b	<0.01
	M4	21.98	26.00b	28.24a	28.49b	30.20	33.95ac	<0.01
	TX	22.88	27.22b	27.49a	27.41b	37.64	30.99c	0.03
	SEM	0.92	1.43	1.28	1.49	3.03	1.15	
Rib	M1	37.84	51.50a	50.60	59.34a	57.58a	58.36ab	<0.01
	M2	34.18	42.97b	49.39	54.23a	54.74ac	55.13a	<0.01
	M3	36.53	49.81ac	53.49	54.86a	56.04a	61.25b	<0.01
	M4	30.56	44.74bc	55.15	48.82b	51.25bc	54.53a	<0.01
	TX	36.02	44.74bc	45.19	47.16b	50.93bc	49.06c	<0.01
	SEM	2.41	1.93	3.88	1.94	1.51	1.70	
Loin	M1	32.19ab	41.06	44.87a	44.50a	45.66a	46.28ab	<0.01
	M2	30.51a	34.53	40.86ac	41.10ac	43.59ac	44.31b	<0.01
	M3	35.01b	40.20	46.11a	45.84a	46.10a	50.94a	<0.01
	M4	27.82a	33.22	37.52c	37.98c	40.81c	45.97ab	<0.01
	TX	29.58a	35.63	37.53c	36.61c	41.55c	40.98b	<0.01
	SEM	1.57	2.13	1.90	2.00	1.28	1.84	
Short loin	M1	33.00	45.44a	47.72ab	50.60a	53.40a	53.57ab	<0.01
	M2	32.01	37.04b	47.05ab	48.19a	50.88ab	50.32bc	<0.01
	M3	36.14	44.53ac	49.88a	51.06a	50.49ab	57.91a	<0.01
	M4	28.49	40.08ab	44.28b	41.63b	46.53b	51.16b	<0.01
	TX	31.77	39.36bc	40.36c	41.40b	46.50b	45.54c	<0.01
	SEM	2.49	1.98	1.72	2.04	1.73	1.87	
Plate	M1	42.88	58.71ab	58.84	65.87a	65.72ac	65.97a	<0.01
	M2	42.09	54.03a	56.95	63.75ab	64.90ab	65.29a	<0.01
	M3	46.22	60.62b	62.19	62.80ab	66.48a	71.28b	<0.01
	M4	41.39	54.06a	57.30	57.90b	60.20b	64.99a	<0.01
	TX	44.74	55.22a	53.61	57.82b	61.15bc	60.49c	<0.01
	SEM	2.71	1.74	2.03	2.15	1.71	1.49	

Brisket	M1	53.72	62.06	61.86	66.17a	67.46a	66.17ac	<0.01
	M2	49.96	57.13	57.88	62.74ac	63.66ab	69.26ab	<0.01
	M3	53.90	64.06	63.45	62.64ab	64.26ac	72.04b	<0.01
	M4	48.40	61.70	60.61	57.74b	60.85bc	65.08ac	<0.01
	TX	50.09	57.64	57.24	59.73bc	60.24b	61.30c	0.02
	SEM	2.58	2.66	2.25	1.72	1.32	1.84	
Flank	M1	55.01	64.55	65.23	68.00	69.21	68.74a	<0.01
	M2	53.31	60.93	64.66	66.62	68.22	69.53a	<0.01
	M3	58.75	65.38	66.71	66.92	69.76	73.65b	<0.01
	M4	48.81	60.59	61.44	63.99	65.75	69.18a	<0.01
	TX	51.31	61.58	62.54	63.14	65.98	65.64a	<0.01
	SEM	2.52	1.80	1.97	1.68	1.60	1.39	
Shank	M1	30.11	36.48	35.37	36.23	38.05	36.22a	0.01
	M2	29.63	30.70	33.87	42.41	36.16	37.45ab	0.12
	M3	30.04	33.62	36.10	35.90	44.01	41.47b	0.11
	M4	39.02	31.73	33.39	32.64	31.67	35.86a	0.8
	TX	26.14	33.35	31.26	32.16	32.65	33.51a	0.13
	SEM	4.84	1.89	1.86	3.84	3.84	1.70	

CT[y] M1- composites based on Angus (early maturing), M2- composites based on Hereford (early maturing), M3- composites of small breeds (early maturing) M4-composites based on Gelbvieh, Limousin (late maturing), TX-composites based Charolais dams (late maturing).

[z] *P* value refers to differences in harvest age within composite type and primal cut.

a,b least square means within column and primal cuts with different letters differ ($P < 0.05$). Letters are only shown when means are different ($P < 0.05$).

*Harvest age is the average age of composites serially slaughtered at six time points.

The highest fat energy proportion changes in all the cuts were observed for M1 and M2 (early maturing) CTs and the lowest change was in the late maturing CTs (Table 3.8). The proportion changes were lower for the small composite type (M3) since they were energetically fat even on the first day of the study. The change of fat energy proportion appeared to be high for M4 since the fat energy proportion was low for M4 on the first day of the study.

Composite types significantly ($P < 0.05$) influenced the energy distribution among muscle and fat tissues in the primal cuts and the distribution pattern changed with the time (Table 3.7 and Table 3.8). Different composites types reached or exceeded that 50% of fat energy equilibrium in primal cuts at different harvest days (Table 3.8). The fat energy proportion in the round did not exceed the 50% level until 456 d and the maximum fat energy proportion in the round at the end of trial period was 34%, 34%, 39%, 34%, and 31% for M3, M1, M2, M4, and TX respectively. The round was the leanest cut as more of the energy was deposited as muscle and less energy deposited as fat.

Higher muscle energy proportion was deposited (Table 3.7) in the chuck during 182 d period for all the CTs except M3 and M3 deposited 52% of total energy as fat at the 456 d (Table 3.8). The fat energy proportion in rib exceeded 50% at an earlier age compared to other major cuts and M1 and M3 exceeded that 50% equilibrium at 347 d, M2 and M4 at 372 d and TX at 427 d. In the loin, the fat energy proportion reached 50% of the total energy between 427 d and 456 d for M3, after 456 d for M1, M2 and M4 whereas TX had a higher proportion of muscle energy at the end of study period compared to all other CTs. In the short loin of M3 fat energy proportion reached 50% at the 372 d, M1 at 399 d, M2 at 427 d, M4 at 456 d whereas TX used more than 50% energy to deposit muscle at the 456 d. In the plate, fat energy proportion for all the CTs exceeded 50% around at 347 d and M3 reached to 50% at slightly earlier age compared to other CTs. Both the brisket and flank are fatty primal cuts and more energy was deposited as fat compared to muscle at an early age in all CTs. The fat energy proportions of these cuts reached or exceeded 50% even on the first day of the study (274 d). However in the shank, most of the energy was deposited as M for all the CTs during the period. The energy percentage changes in major cuts with harvest age of M1 (represents early maturing) and TX (represents late maturing) are shown in the figures in Appendix 1. As shown in these figures, the proportion of fat energy in early maturing CTs exceeded the 50 % equilibrium point relative to total energy in the cuts at early ages compared to late maturing CTs.

The harvest ages at which the whole carcass and five major cuts reach the equilibrium point where M energy = F energy is shown in Table 3.9. The short loin shows a closer relationship to the equilibrium points in whole carcass of each composite type. The harvest ages at the equilibrium point in the chuck, round and loin deviated from whole carcass equilibrium point and the rib and short loin has shown a closer relationship. However, the short loin best represents the whole carcass equilibrium points and suggested harvest ages as in chapter 2.

Table 3.9. Harvest age at which the whole animal and five major primal cuts reach the equilibrium point at which 50% of energy is diverted to muscle and fat production

CT	Whole carcass	Major primal cuts				
		Chuck	Round	Rib	Loin	Short loin
M1	399 d (31.57)	> 456 d (29.80)	> 456 d (19.79)	347 d (31.27)	> 456 d (29.38)	399 d (32.73)
M2	456 d (31.33)	> 456 d (28.49)	> 456 d (19.63)	372 - 399 d (29.61-34.06)	> 456 d (27.56)	427 d (32.38)
M3	427 d (30.97)	456 d (34.27)	> 456 d (23.13)	347 d (29.97)	456 d (33.31)	399 d (33.32)
M4	456 d (31.10)	> 456 d (28.08)	> 456 d (19.57)	372 d (35.68)	> 456 d (29.19)	456 d (33.31)
TX	> 456 d (27.30)	> 456 d (25.56)	> 456 d (17.45)	427 d (31.01)	> 456 d (25.16)	> 456 d (28.87)

The proportions of fat (%) in the carcass or primal cut are shown within the brackets.

Composition of different dissected fat tissues in primal cuts

The changes of fat tissue composition in primal cuts at different harvest ages of CTs are shown in Table 3.10. Energy used in all fat tissues in the primal cuts increased with the age of the animal or harvest age. However, the proportion of the fat tissues changed in different ways in the primal cuts. The differences between CTs were less pronounced and they had similar ($P > 0.05$) fat tissue proportions (BC, SC and IM) at each harvest point in most of the cuts. The chuck had the higher IM fat energy percentage (73%) followed by SC (23%) and BC (4%). Both the IM and BC fat energy proportions in the chuck decreased by 4% and 9% with the age of an animal while the proportion of SC fat energy increased by 18%. In the round the average SC, IM and BC fat energy proportions during study period were 52%, 44% and 4% respectively. Even though it was not significant, the proportion of IM fat energy decreased by 13% while the proportion of SC fat energy increased by 14% for all the CTs within 182 d period. However, the subcutaneous fat energy in the round (50%) was higher in early maturing CTs even at 274 d whereas the proportion of intermuscular fat energy was higher for late maturing M4 composite (54%).

The average IM, SC and BC fat energy proportions in the rib of all the CTs during 182 d was 51%, 38%, and 11% respectively. The BC fat energy proportion of the rib decreased ($P < 0.05$) by 20% whereas SC fat energy proportion increased by 4% with harvest age. However, in the rib the proportion of IM fat energy increased slightly with increased days in the feedlot.

Table 3.10. Energy proportion (%) in different fat depots relative to total fat energy in primal cut

			Harvest age (days)*						
Primal cut	Fat Tissue	CT^y	274 d	347 d	372 d	399 d	427 d	456 d	*P* value^z
Chuck	BC	M1	2.82a	3.47	5.01	3.04	4.11	4.08	0.04
		M2	5.21b	7.52	4.43	5.82	4.43	2.84	0.51
		M3	4.86bc	3.88	4.24	3.19	4.90	3.74	0.11
		M4	3.86ac	7.46	4.16	3.48	4.23	4.13	0.30
		TX	4.04ab	3.78	4.62	6.87	5.14	4.22	0.48
		SEM	0.37	2.13	0.55	1.39	0.80	0.52	
	SC	M1	21.43	27.01	23.68	24.34	22.73	25.76	0.52
		M2	19.33	23.48	24.93	25.09	23.02	24.19	0.12
		M3	22.43	24.44	23.56	22.31	20.91	26.02	0.43
		M4	19.59	19.33	26.19	21.77	20.69	23.29	0.13
		TX	18.86	21.34	18.96	18.81	21.83	21.02	0.81
		SEM	1.93	2.02	1.99	2.20	1.69	1.64	
	IM	M1	75.75	69.53	71.31	72.61	73.16	70.16	0.40
		M2	75.46	69.00	70.64	69.09	72.56	72.98	0.41
		M3	72.71	71.67	72.20	74.49	74.19	70.24	0.60
		M4	76.55	73.21	69.65	74.75	75.08	72.59	0.02
		TX	77.10	74.88	76.42	74.32	73.03	74.76	0.38
		SEM	1.86	2.11	2.07	2.06	1.48	1.74	
Round	BC	M1	2.74	4.73	4.36	4.60	2.82	3.53	0.01
		M2	3.97	3.77	4.03	3.69	2.67	2.61	0.22
		M3	2.67	3.71	3.94	3.92	4.19	2.88	0.18
		M4	3.90	3.60	4.20	4.62	3.96	2.87	0.49
		TX	4.04	3.51	3.47	4.29	2.93	3.08	0.43
		SEM	0.54	0.54	0.52	0.68	0.46	0.42	
	SC	M1	49.76	50.18	53.74	52.24ab	56.14	53.67	0.33
		M2	49.36	49.97	53.97	50.70a	57.37	58.29	<0.01
		M3	50.72	51.15	52.90	56.29b	51.84	54.70	0.24
		M4	42.46	51.92	53.96	51.52a	53.47	55.83	0.08
		TX	48.66	50.42	50.50	48.30a	50.06	51.18	0.86
		SEM	3.42	1.92	1.85	1.71	2.19	1.92	
	IM	M1	47.50	45.09	41.90	43.15ab	41.04	42.79	0.30
		M2	46.67	46.26	42.00	45.61a	39.95	39.10	<0.01
		M3	46.61	45.14	43.17	39.79b	43.97	42.43	0.19
		M4	53.63	44.48	41.85	43.87ab	42.58	41.30	0.06
		TX	47.30	46.07	46.03	47.41a	47.01	45.74	0.95
		SEM	3.40	1.68	1.69	1.51	2.11	1.66	

Rib	BC	M1	13.67	11.52	10.48	10.50	9.64a	11.72	0.06
		M2	15.53	12.22	10.22	13.04	11.23a	8.53	<0.01
		M3	10.71	13.23	11.46	9.39	14.26b	10.36	<0.01
		M4	10.86	9.30	10.83	11.27	10.80a	9.91	0.73
		TX	12.22	16.58	11.32	11.72	11.05a	10.17	0.19
		SEM	1.43	1.91	0.93	0.90	0.806	0.73	
	SC	M1	37.61	40.79	41.09	37.34	38.40	38.27	0.59
		M2	34.89	37.93	39.28	37.43	38.18	39.52	0.69
		M3	38.98	37.47	36.02	39.79	33.92	38.99	0.17
		M4	36.00	39.82	36.69	38.10	36.92	37.85	0.90
		TX	36.48	33.15	36.78	35.62	36.14	36.55	0.87
		SEM	2.32	2.50	2.26	1.91	1.61	2.10	
	IM	M1	48.72	47.69	48.43	52.15	51.97	50.01	0.25
		M2	49.58	49.85	50.50	49.53	50.59	51.95	0.92
		M3	50.31	49.30	52.52	50.82	51.82	50.65	0.82
		M4	53.13	50.89	52.48	50.63	52.28	52.24	0.98
		TX	51.30	50.26	51.89	52.66	52.81	53.28	0.51
		SEM	2.38	1.48	2.40	1.54	1.36	1.81	
Loin	BC	M1	20.22a	19.88	17.87	12.92	14.55	14.71	0.16
		M2	27.03b	19.36	20.67	15.57	14.78	15.62	<0.01
		M3	19.01a	16.29	16.27	12.99	15.87	14.15	0.10
		M4	23.71ab	16.51	20.28	14.14	13.72	13.89	<0.01
		TX	19.55a	18.50	18.14	16.98	14.89	15.29	0.38
		SEM	1.95	2.58	1.38	1.73	1.53	1.04	
	SC	M1	33.29	34.91	38.60	46.12	38.50	42.28	0.02
		M2	29.03	36.93	42.90	42.77	44.10	46.69	<0.01
		M3	36.19	39.72	39.17	43.16	37.97	44.95	0.06
		M4	31.56	41.05	40.08	39.54	39.96	45.54	0.04
		TX	35.14	37.04	33.90	38.95	39.97	40.62	0.22
		SEM	2.77	2.62	2.56	2.14	1.81	2.60	
	IM	M1	46.49	45.21	43.53ab	40.97	46.95	43.01	0.53
		M2	43.93	43.70	36.42b	41.66	41.12	37.69	0.10
		M3	44.80	43.99	44.56ac	43.86	46.16	40.89	0.59
		M4	44.74	42.44	39.64bc	46.33	46.31	40.57	0.14
		TX	45.31	44.46	47.95a	44.07	45.14	44.09	0.66
		SEM	2.22	1.65	2.51	1.91	2.19	2.23	
Short loin	BC	M1	31.79	19.76	25.37	21.15	23.46	21.17	0.03
		M2	37.30	26.72	26.06	21.13	21.62	22.88	<0.01
		M3	34.61	26.31	26.71	24.00	24.48	19.21	<0.01
		M4	32.87	22.01	25.76	21.43	25.87	19.86	0.01
		TX	29.03	22.84	26.85	23.51	21.98	21.73	0.20
		SEM	2.53	3.50	2.19	1.88	1.65	1.57	

	SC	M1	44.47	57.19	51.05	56.23	52.87	55.42	<0.01
		M2	42.37	51.80	53.31	52.95	52.20	56.32	0.01
		M3	45.74	52.03	52.46	53.33	50.59	57.95	<0.01
		M4	41.25	58.04	54.60	58.45	53.83	57.23	<0.01
		TX	49.53	50.42	49.56	52.80	50.99	56.80	0.23
		SEM	2.79	2.77	2.63	2.16	2.01	2.18	
	IM	M1	23.74	23.05	23.58	22.62	23.66	23.40	0.99
		M2	20.33	21.49	20.63	25.93	26.18	20.81	0.47
		M3	19.65	21.67	20.83	22.67	24.93	22.84	0.69
		M4	25.88	19.95	19.64	20.12	20.30	22.91	0.69
		TX	21.44	26.74	23.59	23.69	27.02	21.48	0.61
		SEM	3.76	3.73	2.34	2.03	2.20	2.16	
Plate	BC	M1	24.75	22.22	24.49	24.69	22.16	23.31	0.86
		M2	26.45	25.94	24.49	24.50	22.86	21.16	0.42
		M3	23.69	27.06	22.55	26.23	25.41	24.03	0.24
		M4	25.74	25.62	24.22	24.16	23.91	24.90	0.97
		TX	24.24	27.15	25.61	23.46	26.86	25.10	0.47
		SEM	2.28	1.68	1.66	1.64	1.56	1.67	
	SC	M1	10.69	15.48	13.59	11.75	14.85	13.16	0.59
		M2	13.45	11.41	13.04	14.66	13.08	12.93	0.80
		M3	13.11	13.19	13.53	9.20	13.50	14.94	0.35
		M4	12.18	13.87	12.65	13.08	11.84	13.96	0.80
		TX	10.90	11.35	11.28	11.89	10.31	11.22	0.95
		SEM	1.29	1.75	2.04	1.39	1.48	1.52	
	IM	M1	64.56	62.30	61.92	63.56	62.99	63.53	0.84
		M2	60.10	62.65	62.47	60.84	64.06	65.91	0.38
		M3	63.20	59.76	63.93	64.57	61.09	61.03	0.21
		M4	62.08	60.51	63.13	62.76	64.24	61.14	0.59
		TX	64.86	61.50	63.12	64.65	62.83	63.67	0.86
		SEM	2.15	1.66	1.65	1.90	1.59	1.56	
Brisket	BC	M1	6.14	6.58	5.13	5.39	5.02	4.91	0.68
		M2	5.76	9.96	6.13	6.93	5.31	4.93	0.02
		M3	7.02	5.84	5.96	6.56	6.50	5.39	0.69
		M4	4.60	7.72	5.69	6.26	6.58	3.74	0.16
		TX	6.44	6.18	11.85	6.41	7.96	4.88	0.36
		SEM	1.14	1.26	2.49	0.85	0.82	0.84	
	SC	M1	35.33	36.07	47.97	39.27	36.96	39.27a	0.44
		M2	34.13	34.34	38.04	39.53	42.44	41.85a	0.22
		M3	33.50	39.85	36.19	35.45	36.40	50.02b	<0.01
		M4	33.80	34.07	40.23	36.14	40.81	39.07a	0.28
		TX	32.91	39.94	28.70	37.72	34.88	40.34a	0.14
		SEM	3.45	3.20	5.01	2.08	2.08	2.70	

IM	M1	58.53	57.35	46.91	55.34	58.01	55.82a	0.49
	M2	60.10	55.70	55.83	53.54	52.24	53.22a	0.38
	M3	59.48	54.32	57.84	57.99	57.11	44.59b	<0.01
	M4	61.60	58.21	54.08	57.60	52.62	57.18a	0.45
	TX	60.65	53.87	59.46	55.87	57.16	54.78a	0.29
	SEM	3.35	3.23	4.41	2.02	2.34	2.62	

CT[y] M1- composites based on Angus (early maturing), M2- composites based on Hereford (early maturing), M3- composites of small breeds (early maturing) M4-composites based on Gelbvieh, Limousin (late maturing), TX-composites based Charolais dams (late maturing).

[z] *P* value refers to differences in harvest age within composite type and primal cut.

a,b least square means within column and primal cuts with different letters differ ($P < 0.05$). Letters are only shown when means are different ($P < 0.05$).

*Harvest age is the average age of composites serially slaughtered at six time points.

In the loin, the average proportion of IM fat energy was higher (44%), followed by SC (39%) and BC (17%) fat. Both IM and BC fat energy proportions in the loin decreased by 8% and 33%, respectively, whereas the proportion of SC fat energy increased by 33% during the 182 d period of study. In the short loin the average SC, BC and IM fat energy proportions in all the CTs was 52%, 25% and 23%, respectively. The average SC fat energy proportion in the short loin was 45% at the day 1 in feedlot and increased up to 57% during the 182 d period. The proportion of SC fat energy increased ($P < 0.05$) in the short loin while the BC fat energy proportion decreased by 37% and the IM percentage was similar during the study period for all the CTs except TX. In summary, in the chuck most energy was partitioned in the IM, in the round approximately 55% was partitioned in the SC, in the rib and loin ≥ 50% was partitioned in IM, but in the short loin approximately 55% of energy was partitioned in the SC.

The fluctuations of fat percentages in the plate were observed with advancing harvest age in the different CTs. The average IM, BC and SC fat energy proportions in the plate over 182 d period of all CTs was 63%, 25% and 12%, respectively. The proportion of BC fat energy was higher in the plate than the SC. However, the proportion of IM fat energy remained similar ($P > 0.05$) while the proportion of SC fat energy in the plate increased by 10% and the proportion of BC fat energy decreased by 5% within 182 d period. The average proportion of IM, SC and BC fat energy in the brisket during the 182 d study was 56%, 38% and 6%, respectively (Table 3.10). The SC fat energy proportion in the brisket of small composites increased ($P < 0.01$) by 49% while the IM fat energy proportion decreased by 25% from 274 d to 456 d. The IM and BC fat energy proportion in the brisket of all the other CTs decreased by 8% and 19%, respectively, while the proportion of SC fat increased by 18% during the period. Both the flank and shank cuts did not contain SC and BC fat.

The ratios of energy deposited in SC: IM plus BC are shown in Appendix 2. The highest average ratio was observed for the short loin (1.14) and lowest ratio was observed for the plate (0.14). The average SC: IM plus BC ratio of CTs during the 182 d period was 1.11, 0.66, 0.66, 0.61, 0.29, and 0.14 for the round, loin, brisket, rib, chuck, and plate respectively. Even though the differences of CTs for SC: IM plus BC ratio was not different ($P > 0.05$), early maturing CTs had higher ratio at all the harvest points compared to late maturing CTs.

The SC: IM plus BC ratios of the short loin and loin increased ($P < 0.05$) for early maturing CTs compared to late maturing CTs with increased age. Even though it was not significant, the ratio increased for most cuts with increasing age at harvest. Hence, the proportion of subcutaneous fat energy increased with increasing age. The largest difference in SC: IM plus BC ratio from 274 d to 456 d was observed for short loin (0.51) followed by the loin (0.32), round (0.28), brisket (0.22), chuck (0.06), rib (0.03) and plate (0.01).

3.4 Discussion

The total energy value in each primal cut increased with the days in the feedlot (Table 3.1). At the beginning of this study, cattle of different CTs were leaner and total energy deposited in the cuts was low. However, the proportion of fat tissue in all the cuts increased with days in the feedlot and the energy values increased as the caloric value of fat is high (Brethour, 2000). In energetic terms, 2.6 times more ME energy is required to produce fat than muscle in cattle (Thonney, 2012). Therefore, the proportion of metabolizable energy used for the fat deposition in all the primal cuts increased and energetic efficiency of muscle production decreased with increasing harvest age. Thus, cattle can be harvested at an optimum harvest age to reduce the energy usage for the deposition of unwanted fat.

The energy deposited as muscle (Table 3.2) and fat (Table 3.3) increased with harvest age of different composites as body tissues increased with the growth of cattle. The fat energy more than doubled in all the cuts during the 182 d period and muscle energy increased at a lower rate compared to fat energy in all the cuts. A higher change in fat energy is the result of rapid fat growth of cattle over the fattening period. The loin and rib are the expensive and most preferred cuts followed by the short loin, round and chuck, and higher lean percentage in these cuts would have economic benefits (Koch et al., 1982). Even though many believe that the proportion of the expensive cuts increases as cattle fatten, rapid growth and increased fat proportion are usually experienced in the primal cuts with lower value (Hedrick, 1983). The current study has also shown that the ratio of total energy in the major (expensive) cuts (round+ rib+ loin+ short loin) to total energy in other cuts (Table 3.1) and ratio of muscle energy of the expensive cuts to muscle energy in other cuts (Table 3.2) decreased with harvest age in all the composites. The change in the ratio was lower for small composites (M3) as they had lower muscle energy content even at the beginning of study period. Advancing harvest weight has been shown to increase carcass fatness while decreasing the muscle and bone proportions thereby reducing the proportion of muscle in the expensive cuts of bulls and heifers (Steen and Kilpatrick, 1995). Bures and Barton (2012) also found similar results in that older Simmental and Charolais cross bred cattle (18 months) had a lower proportion of high priced muscle cuts, a higher proportion of separable fat as well as thicker layers of SC fat compared to younger cattle (14 months) fed with the same concentrate diet. There is a fat growth gradient pattern in the animal across the distil limbs to the abdominal area (Kempster, 1980). The fat growth coefficient which indicates the allometric growth coefficient for fat weight in the cuts relative to total fat weight in carcass was low in the distal limb joints and the coefficient increases to the center of the limb and further increases towards the rib and loin (Kempster, 1980).

The tissue (muscle and fat) composition of primal cuts are known to change with increasing harvest age of the cattle (Table 3.5 and Table 3.6) and Koch et al. (1982) found that the relative proportions of fat, muscle and bone differed in all the cuts inconsistently with increasing age of the animal. In the present study, we observed that the proportion of muscle energy deposition decreased (Table 3.7) and fat energy deposition (Table 3.8) increased in all the primal cuts with increasing harvest age of composites. Patterson et al. (1985) also observed a similar pattern where the proportion of fat in the primal cuts increased while the proportion of muscle decreased as the animal fattened. Mukhoty and Berg (1973) also found that the tissue proportions of the primal (wholesale cuts) changed as animals become fatter and breeds that produced fatty carcasses at early ages had a higher proportion of fat deposited excessively in the primal cuts. The results of our study point out differences in the proportions of energy needed to deposit M and F in primal cuts of CTs and this complements the above studies in terms of energy needed. The M and F energy deposition pattern follows the weight distribution in the primal cuts as shown by Goonewardene et al. (2012) in earlier studies.

The proportion of muscle energy was higher and decreased at a lower rate in cuts such as the chuck, round, and shank (Table 3.7) which are involved with locomotion and these cuts are known to have higher amounts of connective tissues or tendons to facilitate the movement (Berg and Butterfield, 1968; Swatland, 1984). Such cuts have a higher proportion of muscle and produce tougher meat (Swatland, 1984). Higher fat energy change during 182 d in the feedlot was observed for the cuts which are located around the middle of the body (Table 3.8) such as the short loin (60%), rib (60%), plate (51%), and loin (48%). The proportional change of fat energy in both the round and chuck was 50%. The fat energy change was lower for brisket (30%) and flank (30%) since they contained a higher proportion of fat even on the first day in feedlot, and the brisket and flank are considered fatty primals (Zgur and Cepon, 2007). Johnson et al. (1972) stated that larger muscles having smaller surface area relative to weight can be seen in the proximal part of the pelvic limb (round) in animals whereas the muscles in abdominal area have larger surface area relative to weight and are loosely arranged. Hence, the pressure in abdominal area is low compared to the round and it contained higher amounts of fat which facilitated more fat energy deposition around the abdominal area (Berg and Butterfield, 1968; Johnson et al., 1972; Mukhoty and Berg, 1973). In addition, the proportion of fat is reported to be higher in the cuts that do not involve locomotion (Kempster, 1980). The proportion of fat change in the shank increased by 21% and was not significant for all the CTs since it contained less fat and more connective tissues and bones compared to the other cuts.

The proportion of fat energy began to exceed 50% of total energy (30% total fat percentage) in the rib and plate at around 347 d, short loin at around 399 d, loin at around 456 d, chuck at around 456 d in the early maturing composites (M1 and M3) whereas the late maturing composites reached to the threshold level at a later age (Table 3.8). However, the proportions of fat and muscle energy in the round and shank were similar for all the composites and these two primal cuts had more than 50% of muscle energy proportion at the end of the study period. We could not find any literature values for the harvest ages in which primal cuts exceed 50% of fat energy and this might be the first study done on this particular subject. Jones et al. (1980) stated that brisket and chuck contained the highest weight of dissected fat in the fore quarter of animal whereas flank had the highest fat content in hind quarter which can be related to the energy values in these cuts in our study. The higher growth rate of total fat was seen in the mid back region (Jones et al., 1980). Therefore, fat energy exceeded 50% in the cuts which are rib, plate, short loin, loin, and flank in mid back region at an early age in composites. Breed differences were observed for the proportions of fat and muscle energy in primal cuts and early maturing cattle produced fatty primal cuts at early ages compared to the late maturing composites (Appendix 1). DuPlessis and Hoffman (2007) also found that small framed animals finished and gained more fat at an early age than medium and large framed cattle. Therefore, they concluded that different breeds have different optimum ages for harvest.

The round was the leanest primal cut (70% muscle energy) (Table 3.7) and Jones et al. (1980) found that the round area had the lowest rate of growth for total fat and therefore the proportion of muscle decreased by a lower percentage compared to the other cuts. The round consists of relatively larger muscles (Swatland, 1984) and they are tightly bound by their attachments. Therefore, fat growth and IM fat deposition has been restricted in the round (Berg and Butterfield, 1968). However, Keane et al. (1989) found that the muscle proportion of hind limb area (round) decreased over a long finishing period due to the accumulation of SC fat over the cuts. Composite type differences were observed for the proportion of muscle energy in round and early maturing cattle had a lower proportion of muscle energy in the round compared to late maturing composites. Priyanto and Johnson (2011) also reported that the breed type influences the muscle content in the proximal hind limb region and that *Indicus* steers (larger breeds) had higher proportion of muscle compared to British breeds and that double muscled types had superior muscle deposition in proximal hind limb area. Hedrick (1983) reported that the proportion of carcass muscle was associated with muscling in the round, bone proportion of the carcass was associated with the shank and the proportion of fat in the flank was highly correlated with the whole carcass fatness.

Even though it was not significant, slight differences of fat deposition in all the depots were observed for CTs during our study (Table 3.10). However, the proportion of BC and IM fat is relatively constant at all harvest ages and most variable is SC fat. The highest proportion of fat energy deposited as SC fat was in the round and short loin. The proportion of SC fat energy increased drastically in the round, short loin, loin, rib, plate, and chuck with the increasing harvest weight and Koch et al. (1982) found the similar pattern with respect to distribution and weight. Kempster (1980) stated that the fat distribution patterns of different breeds were similar and Koch et al. (1982) found that the proportion of different fat depots had relatively small differences among the breeds. In addition, Block et al. (2001) found that there were no differences in the proportion of BC fat between Angus, Charolais, and Hereford at a similar back fat thickness.

Therefore, these studies agree with results in our study which looked at energetics of M and F growth. The SC fat grows under the hide in less resistant areas of an animal body where there is less pressure when walking and does not involve locomotion (Kempster, 1980). Some fluctuations in the proportions of fat energy were observed since the weights from different animals were used for the calculation at each time point. In this study, data of different animal carcasses were used for the comparisons since it was impossible to repeat the measurement on the same animal over time.

The higher proportion of fat energy was deposited in the IM fat depots in the chuck (Table 3.10) and Thonney et al. (1984) found that the IM fat in the chuck was higher and it was lower in the round of grain fed cattle. The forequarter of the animal body contains small muscles whereas hind limb area has large muscles (Swatland, 1984). Hence, the IM fat proportion was higher for the cuts in fore quarter. Kempster (1980) stated that the IM fat growth in forequarter was higher than in the hindquarter as the pressure created by muscles and body shape in hindquarter resisted IM fat growth. Hanson (1999) stated that there was a non-uniform tissue distribution across primal cuts and he found that the chuck had lowest SC fat and higher IM fat whereas the round had the lowest IM and higher SC fat compared to the other major cuts such as the loin and rib. The current study also found the similar fat energy distribution patterns.

The short loin and loin had a higher SC: IM plus BC energy ratio and the early maturing CTs had a higher ratio compared to late maturing CTs (Table 3.10 and Appendix 2). The proportion of SC fat in the loin is reported to be breed dependent (Loveday and Dikeman, 1980). A higher proportion of energy in the loin was observed from the breeds that produced more trim fat (SC) since fat deposition centripetally increased to the rib and loin (Wheeler et al., 1997). Kempster et al. (1976) found that the ratio of SC: IM fat was higher for Hereford and Limousin than Charolais and Simmental. Thonney et al. (1984) also stated that the SC fat content in the chuck, loin, rib, and round increased with age in Angus (early maturing) compared to Holstein (late maturing). Large breeds deposited IM fat in the chuck and rib cuts whereas Angus and Hereford (early maturing) deposited more subcutaneously (Kempster, 1980; Koch et al., 1982). Hence, Angus and Hereford had less total retail product as well as more trim fat than other larger composites (Koch et al., 1982). In the current study the SC: IM fat ratio of the cuts was higher for early maturing cattle than late maturing cattle. The SC fat can easily be trimmed off at retail (Goonewardene et al., 2012) but it is difficult to trim excess IM fat without damaging the muscle in the cuts (Kempster, 1980).

Even though the proportion of intramuscular fat (marbling) was not analyzed in this study, it is very important and is a determinant of grade and price in the beef industry. Pethick et al. (2006) stated that a minimum of 3-4% of intramuscular fat on fresh uncooked basis is needed to have acceptable consumer satisfaction for grilling red meat cuts. In addition, they stated that 5-10% of total fat in the live animal represents the intramuscular fat and percentage is influenced by both breed and age. According to their studies based on intramuscular fat growth curve, intermuscular fat percentage increases linearly from 200 kg to 450 kg carcass weight and reaches maximum at around 500 kg carcass weight and carcass weight is breed dependent. There is a slight relationship between marbling and tenderness. However, only 12 - 15% of the carcass ends up as grilling steaks (Goonewardene et al., 2012) whereas tenderness is achieved in the other cuts during the cooking process.

3.5 Conclusions

In summary, total energy in the primal cuts increased with the increasing harvest age and the proportion of muscle energy decreased while the proportion of fat energy increased in all the primal cuts. The E-muscle: E-fat ratios of primal cuts decreased with increasing the harvest age. The changes were higher for the major primal cuts compared to other primal cuts. The muscle energy of the major cuts to muscle energy in other cuts ratios decreased during 182 d as a result of higher fat accumulation in these cuts with increasing harvest age. The primal cuts show different maturity (fattening) patterns. The proportion of energy deposited as fat increased with the time and exceeded 50% of the total energy in the primal cuts except round and shank whereas the muscle energy proportion decreased to less than 50%. At 274 d (1 d in feedlot) highest proportion of fat energy (more than or equal 50% of total energy in cut) was observed in both the flank and brisket for all the CTs and the proportion of fat energy exceeded 50% of total energy (30% total fat percentage) in the rib and plate at around 347 d, short loin at around 399 d, loin at around 456 d, chuck at around 456 d in early maturing composites whereas late maturing composites reached this equilibrium point at a later age. However, fat and muscle energy proportions in the round and shank were similar for all the composites and these cuts had more than 50% of muscle proportion of energy at the end of study period. The short loin best represented the whole carcass equilibrium points of all the composites compared to other major primal cuts. There was a clear composite type effect on tissue distribution of primal cuts: small breeds and M1, M2 (early maturing CTs) exceeded the fat energy proportion more than 50% of total energy in most of all primal cuts at an earlier age compared to M4 and TX which are late maturing composites. The energy deposition in subcutaneous (SC) fat depots was higher in the hind quarter cuts whereas energy deposition in intermuscular (IM) fat depots was higher in fore quarter cuts. The short loin and loin had higher SC: IM plus BC energy ratio and the early maturing CTs had slightly a higher ratio compared to late maturing CTs. Early maturing CTs can be harvested at early ages compared to late maturing CTs to get low caloric lean primal cuts while reducing feed costs, feed wastage and reduce labour requirements during the fabrication of primal cuts.

3.6 Literature cited

Ahmed, P. O., M. F. Miller, S. D. Shackelford, L. P. Johnson, S. E. Williams, M. A. McCann, and J. O. Reagan. 1992. Effect of hot-fat trimming on factors associated with the sub primal yield of beef carcasses. J. Anim. Sci. 70:439–443.

Apple, J. K., J. C. Davis, J. Stephenson, J. E. Hankins, J. R. Davis, and S. L. Beaty. 1999. Influence of body condition score on carcass characteristics and sub primal yield from cull beef cows. J. Anim. Sci. 77:2660-2669.

Association of Official Analytical Chemists. 1980. Official methods of analysis. 13th ed. AOAC, Washington, DC.

Basarab, J. A., M. A. Price, J. L. Aalhus, E. K. Okine, W. M. Snelling, and K. L. Lyle. 2003. Residual feed intake and body composition in young growing cattle. Can. J. Anim. Sci. 83:189-204.

Beef and pork whole animal buying guide. 2009. University of Nebraska. http://food.unl.edu/c/document_library/get_file?uuid=e195a5b1-57f1-42f5-97a8-b4e62ddefe59&groupId=4089462&.pdf. Accessed August 15, 2012.

Berg, R. T. and R. M. Butterfield. 1968. Growth patterns of bovine muscle, fat and bone. J. Anim. Sci. 27:611-619.

Block, H. C., J. J. McKinnon, A. F. Mustafa, and D. A. Christensen. 2001. Manipulation of cattle growth to target carcass quality. J. Anim. Sci. 79:133–140.

Brethour, J. R. 2000. Using serial ultrasound measures to generate models of marbling and back fat thickness changes in feedlot cattle. J. Anim. Sci. 78:2055–2061.

Brethour, J. R. 2004. The relationship of average back fat thickness of feedlot steers to performance and relative efficiency of fat and protein retention. J. Anim. Sci. 82:3366–3372.

Bures, D. and L. Barton. 2012. Growth performance, carcass traits and meat quality of bulls and heifers harvested at different ages. Czech J. Anim. Sci. 57(1):34-43.

Canadian Council on Animal Care. 1993. Guide to the care and use of experimental animals. In E. D. Olfert, B. M. Cross, and A. A. McWilliams, eds. Vol. 1. CCAC, Ottawa, ON.

DuPlessis, I. and L. C. Hoffman. 2007. Effect of harvest age and breed on the carcass traits and meat quality of beef steers finished on natural pastures in the arid subtropics of South Africa. S. Afr. J. Anim. Sci. 37:143–153.

Goonewardene, L. A., J. A. Basarab, Z. Wang, M. A. Price, P. Ramsey, T. Marx, J. Aalhus, R. W. Seneviratne, W. G. N. P. Yalingasinghe, and E. K. Okine. 2012. Tissue distribution in primal cuts of Canadian beef composites and opportunities for harvesting younger and leaner cattle. Int. J. Anim. Veter. Adv. 4(1):1-15.

Hanson, D., C. Calkins, B. Gwartney, J. Forrest and, R. Lemenager. 1999. The relationship of beef primal cut composition to overall carcass composition. University of Nebraska Cooperative Extension MP 71, Beef cattle report 1999.

Hedrick, H. B. 1983. Methods of estimating live animal and carcass composition. J. Anim. Sci. 57:1316–1327.

Johnson, E. R., R. M. Butterfield, and W. J. Pryor. l972. Studies of fat distribution in the bovine carcass. 1. The partition of fatty tissues between depots. Aust. J. Agric. Res. 23:381-388.

Jones, S. D. M., M. A. Price, and R. T. Berg. 1980. Fattening patterns in cattle. 2. Fat distribution among the wholesale cuts. Can. J. Anim. Sci. 60: 851-856.

Jones, S. D. M., T. D. Burgess, J. W. Wilton, and C. H. Watson. 1984. Feedlot performance, carcass composition and efficiency of muscle gain in bulls and steers of different mature size harvested at similar levels of fatness. Can. J. Anim. Sci. 64:621–630.

Keane, M. G., G. J. More, O. Ferrall, and J. Connolly. 1989. Growth and carcass composition of Friesian, Limousin x Friesian and Blonded Aquitaine x Friesian steers. Anim. Prod. 48:353-365.

Kempster, A. J., A. Cuthbertson, and G. Harringlon. 1976. Fat distribution in steers carcasses of different breeds and crosses. I. Distribution between depots. Anim. Prod. 23:25-34.

Kempster, A. J. 1980. Fat partition and distribution in the carcasses of cattle, sheep and pigs: A review. Meat Sci. 5:83–98.

Koch, R. M., M. E. Dikeman, and J. D. Crouse. 1982. Characterization of biological types of cattle (cycle III). III. Carcass composition, quality, and palatability. J. Anim. Sci. 54:35-45.

Kress, D. D., K. C. Davis, and M. W. Tess. 1996. Adjusting scrotal circumference of yearling beef bulls in five composites. Can. J. Anim. Sci. 76:189–191.

Loveday, H. D. and M. E. Dikeman. 1980. Diet energy and steer type effects on adipose composition, lipogenesis and carcass composition. J. Anim. Sci. 51:78-88.

Miller, M. F., C. B. Ramsey, S. W. Claborn, and C. K. Wu. 1995. Effects of breed type and accelerated fat removal on sub primal yields and carcass values. J. Anim. Sci. 73:1055-1063.

Morris, C. A., N. G. Cullen, and D. G. McCall. 1999. Genetic and phenotypic relationship among carcass measurements in beef cattle. New Zealand J. Agric. Res. 42:415-421.

Mukhoty, H. and R. T. Berg. 1973. Influence of breed and sex on muscle weight distribution of cattle. J. Agric. Sci. Camb. 81:317-326.

Navajas, E. A., R. I. Richardson, A. V. Fisher, J. J. Hyslop, D. W. Ross, N. Prieto, G. Simm, and R. Roehe. 2010. Predicting beef carcass composition using tissue weights of a primal cut assessed by computed tomography. Animal. 4: 1810-1817. http://journals.cambridge.org/abstract_S1751731110001096.

Pabiou, T., W. F. Fikse, A. R. Cromie, M. G. Keane, A. Nasholm, and D. P. Berry. 2011. Use of digital images to predict carcass cut yields in cattle. Livest. Sci. 137: 130–140.

Patterson, D. L., M. A. Price, and R. T. Berg. 1985. Patterns of muscle, bone and fat accretion in three biological types of feedlot bulls fed three dietary energy levels. Can. J. Anim. Sci. 65:351-361.

Pethick, D. W., G. S. Harper, J. F. Hocquette, and Y. H. Wang. 2006. Marbling biology-what do we know about getting fat into muscle?. Pages 103-110. Australian Beef-the Leader Conference. Australia.

Priyanto, R. and E. Johnson. 2011. Muscle growth and distribution in fattening steer of different breeds. Med. Pet. J. Anim. Sci. Tech. 34 (1):19-22.

http://microbiology.journal.ipb.ac.id/index.php/mediapeternakan/article/view/3163/2107. Accessed December 07, 2011.

Robertson, J. A. and P. J. Van Soest. 1981. The detergent system of analysis and its application to human foods. Page 123 in W. P. T. James and O. Theander, eds. The analysis of dietary fiber in food. Marcell Dekker, Inc., New York, NY.

Savell, J. W., R. H. Knapp, M. F. Miller, H. A. Recio, and H. R. Cross. 1989. Removing excess SC and internal fat from beef carcasses before chilling. J. Anim. Sci. 67:881-886.

Steen, R. W. J. and D. J. Kilpatrick. 1995. Effects of plane of nutrition on harvest weight on the carcass composition of serially harvested bulls, steers and heifers of three breed crosses. Livest. Prod.Sci. 43:205–213.

Swatland, H. J. 1984. Structure and development of meat animals. Prentice-Hall Publications Inc. Englewood Cliffs, New Jersey, USA.

Thonney, M. L., A. Y. M. Nour, J. R. Stouffer, and W. R. C. White. 1984. Changes in primal cuts with increasing carcass weight in large and small cattle. Can. J. Anim. Sci. 64:29-38.

Thonney, M. L. 2012. A mature size model of growth and efficiency. Cornell University.

http://www.ansci.cornell.edu/courses/as360/lecture/growth/growth.html.

Accessed on October 2012.

Wheeler, T. L., L. V. Cundiff, R. M. Koch, M. E. Dikeman, and J. D. Crouse. 1997. Characterization of different biological types of steers (Cycle IV): Wholesale, sub primal, and retail product yields. J. Anim. Sci. 75:2389−2403.

Žgur, S. and M. Čepon. 2007. Fat tissue distribution between subcutaneous and intermuscular fat tissue in Simmental and Brown bulls. Poljoprivreda. 13:120-123.

Chapter 4. General Discussion

4.1 Significance of the study

Harvesting of leaner beef at a younger age which is nutritionally healthier can contribute to a reduction in the consumption of saturated fats in human diets and thereby reduce heart disease which is the leading cause of death in Canada (Li et al., 2005; Health Canada, 2008). In addition, harvesting younger cattle can reduce the possibilities of prion diseases such as bovine spongiform encephalopathy from entering the food chain (Smith and Bradley, 2003) and increase the efficiency of beef production fulfilling the consumer's preferences for lean and tender beef.

When the rate of fat deposition exceeds that of muscle, the efficiency of muscling declines and feed is primarily utilized to produce fat, which requires a higher energy input (McDonald et al., 1988). Production of fat in beef is costly and wasteful. In addition, it is difficult to compete with other protein sources such as poultry and pork since the consumers prefer leaner products with low caloric value (Dikeman, 1984). Brethour (2004) stated that optimal harvest date of an animal is the date when incremental production cost (feed cost) equals the incremental increase in animal value (carcass weight and carcass value). Harvesting animals at the optimum time, decreases the feeding period thereby decreasing the waste fat production as well as amount of grain used per unit of meat production. Cost of production in the beef industry is shown to increase at a faster rate than cattle prices (Dikeman, 1984). Harvesting steers at around 12-13 months of age will lower the production costs while increasing the profit per steer (Girard et al., 2011). The price and health concerns of humans are the major reasons for the demand for leaner beef by the consumers and the beef grading system needs to be modified towards leanness to improve the efficiency of the beef industry while providing leaner beef products to consumers (Dikeman, 1984). In addition, increasing cost of production, health and food safety concerns, beef price fluctuation, effect on climate change have negatively affected on the per capita consumption of beef (López-Campos et al., 2012).

Harvesting cattle at younger age will decrease the influence of collagen cross-linking to the toughness of cooked beef since the complexity of collagen cross linkages increase with advancing harvest age (Palokangas et al., 1992). Further, age related toughening of beef occurs through increasing muscle fibre cross sectional area which is related to animal age (Møller, 1980). Hence, the influence of both connective tissue and muscle fibre on toughness may be less for beef from a steer that is 12 - 13 months old than the beef from a steer that is 18-20 months (Girard et al., 2011).

About one percent of Canada's total greenhouse gases are attributed to the livestock industry and the beef cattle industry are responsible for 91% of it (AAFRD, 2000). Methane is emitted by the animal during the digestion process and nitrous oxide and small amount of methane are emitted from manure storage, handling and spreading. Both of these gasses are potent greenhouse gases as their 100 years global warming potentials are 23 (CH_4) and 298 (N_2O) times more potent than carbon dioxide (Basarab et al., 2012). Steers consuming 10 kg of dry matter day^{-1} of a 90% concentrate diet, release about 140 g CH_4 day^{-1} and 4% of GEI is lost each day thru eructation, respiration and flatulence (Basarab et al., 2005). Therefore, harvesting cattle at an earlier age can help to reduce the emission of these greenhouse gasses into the environment.

4.2 Summary of the present study

The amount of energy used for the fat deposition increased with the age of animal. The value of the carcass is decreased with increasing fat deposition in all depots and fatty carcasses are discounted. This depends on price signals given by our present grading system which rewards marbling and under discounts excess fat. Hence, feeding cattle after they reach an optimum fat level is a waste of feed and money. The marbling fat to other fat ratio is pegged at 1:10 (Goonewardene et al., 2012). Every 1 kg of marbling results in 10 kg of other fat (BC, SC and IM) which is finally trimmed off and has very low cash value.

In chapter 2, the ideal harvest age to obtain lean meat of different composite types was investigated energetically using carcasses of steers from five BeefBooster® lines. The total energy and proportion of fat energy increased while the proportion of muscle energy decreased for all the composite types with increasing harvest age. Each composite type had an optimum harvest age so as to obtain a leaner carcass with optimum fat for juiciness and flavour. Beyond that point, proportion of fat energy in the carcass increased by more than 50% and early maturing cattle achieved that point at an early age than late maturing composite types. The efficiency of conversion of metabolizable energy to retained energy decreased with increasing harvest age and more metabolizable energy was used for fat deposition as composites got older. A higher proportion of fat energy was deposited in the IM fat depots followed by the SC and BC. However, with the increase in harvest age, energy deposition in both the IM and BC fat depots decreased while energy deposition in the SC depots increased. We suggest that composites of cattle be harvested at different harvest ages and according to the current study it can be suggested that M1 be harvested at around 399 d, M2 at around 399 d or 427 d, M3 at around 372 d or 399 d, M4 at around 456 d and TX can be fed more than 456 days to obtain leaner beef in a more energetically efficient way.

In chapter 3, the energy distribution pattern among the primal cuts in the carcass was determined. The proportion of muscle energy was highest in the round and the proportion of fat energy was highest in the flank. The energy distribution in the primal cuts changed with increasing harvest age and some primal cuts deposited more than 50% of total energy as fat energy at an early age compared to other cuts. The short loin has shown a close relationship to the whole carcass equilibrium points. In addition, composite type differences were observed for the energy distribution patterns and early maturing composites deposited fat in most of the cuts at a higher proportion compared to the late maturing composite types. The proportion of both BC and IM fat was relatively constant in all the composites at all harvest ages and energy deposition in the SC fat depots increased with increasing harvest age and early maturing composites had more SC fat percentages at early ages compared to the late maturing composites within the primal cuts.

4.3 Limitations

In this study a classical serial harvest approach was used to determine tissue weights, proportions and to calculate the energy values of M and F. However, there was a large variation among harvest groups of each composite type and that led to a fluctuation of energy values from a normal pattern. As an example, the body weights of some animals of the same composite type which were harvested at 99 days were higher than the animals which were harvested at 127 days. Although cattle were to be selected randomly at each harvest end point, heavier cattle have been selected at earlier harvest times leaving lighter yet, older cattle to be harvested at later ages. In addition, the body composition of animals which were harvested on the first day in the feedlot was used as initial or reference values. This created a problem in finding out the weight gain differences. Sometimes weight differences (between start and end weights) were negative. Hence, regression analysis was used in part to solve these problems and to remove some outliers. As different animals were harvested at each end point repeated measurements on the same experimental unit was not possible. It is suggested that in the future design of such studies, the number of experimental units be increased by 25% as our study clearly showed that at 456 d, there were no animals to select from. The M2 composite type has shown some similarities to M4 during the study. Although the foundation breed of M2 was Hereford, the Simmental breed was used as an infused breed. This might be a reason why M2 and the late maturing breeds were similar.

4.4 Future work

The current grading system is dependent on the fat content (back fat thickness and marbling) and muscling (ribeye area) of the carcass. There appears to be an over emphasis on marbling which is only important in 12- 14% of the steaks from proximal cuts whereas 50% of the cuts in the carcass is sold as ground beef where marbling is not important (Goonewardene et al., 2012). Different composite types have particular optimum harvest ages and early maturing cattle can be harvested at early ages compared to the late maturing cattle to obtain lean beef. However, breed differences are not reflected in the current grading system. Hence, there is a need to have another parallel grading system, especially based on leanness and muscling relevant to composite types or modification of current grading system that rewards lean meat yield while discounting excess fat, since the trend among consumers defects concerns about the saturated fats and caloric value of red meat. Very few studies have been conducted based on the energetic values of producing muscle and fat in a beef carcass and primal cuts. Even though this research has suggested different harvest ages for different composite types by looking at energetic values in muscle and fat in the carcass, further analyze and research need to be conducted to validate optimum harvest ages for other crossbred beef cattle. Furthermore, the cost of production which is an issue in beef production can be decreased while fulfilling consumer acceptance and requirements for lean beef.

It is estimated that about 45% of slaughter cattle in Alberta are weaned, fed a high concentrate diet (> 90%) and then harvested at 13-16 months of age (Basarab et al., 2009; López-Campos et al., 2012). The present study applies to composite cattle fed a high concentrate diet in the feedlot and harvested. However, the tissue distribution and energy partitioning over time may be different for grass fed or grass/grain (blend) fed cattle (yearling-fed cattle harvested at 18-22 months of age). It is well established that grass fed cattle are less fat and have a more beneficial fatty acid profile relative to human dietary recommendations. Energy partitioning and efficiencies under a grass fed beef slaughter system can be quite different to these results. Future research can be directed to this area which appears to be gaining momentum.

4.5 Literature Cited

Alberta Agriculture, Food and Rural Development (AAFRD). 2000. Greenhouse Gas Emissions and Alberta's Livestock industry. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/cl9706. Accessed March, 2011.

Basarab, J. A., E. K. Okine, V. S. Baron, T. Marx, P. Ramsey, K. Ziegler, and K. Lyle. 2005. Methane emission from enteric fermentation in Alberta's beef cattle population. Can. J. Anim. Sci. 85: 501-512.

Basarab, J. A., V. S. Baron, and E. K. Okine. 2009. Discovering nutrition related opportunities in the carbon credit system for beef cattle. Pages 241-260. Proc. 30th Western Nutrition Conf., Sept. 23-24, 2009. Winnipeg, MB, Canada.

Brethour, J. R. 2004. The relationship of average back fat thickness of feedlot steers to performance and relative efficiency of fat and protein retention. J. Anim. Sci. 82:3366-3372.

Dikeman, M. E. 1984. Cattle production systems to meet future consumer demands. J. Anim. Sci. 59:1631-1643.

Girard, I., J. L. Aalhus, J. A. Basarab, I. L. Larsen, and H. L. Bruce. 2011. Modification of muscle inherent properties through age at harvest, growth promotants, and breed crosses. Can. J. Anim. Sci. 91:635-648.

Goonewardene, L. A., J. A. Basarab, Z. Wang, M. A. Price, P. Ramsey, T. Marx, J. Aalhus, R. W. Seneviratne, W. G. N. P. Yalingasinghe, and E. K. Okine. 2012. Tissue distribution in primal cuts of Canadian beef composites and opportunities for harvesting younger and leaner cattle. Int. J. Anim. Vet. Adv. 4(1):1-15.

Health Canada. 2008. Heart and Stroke. http://www.hc-sc.gc.ca/hc-ps/dc-ma/heart-coeur-eng.php. Accessed September, 2012.

Li, D., S. Siriamornpun, M. L. Wahlqvist, N. J. Mann, and A. J. Sinclair. 2005. Lean meat and heart health. Asia. Pac. J. Clin. Nutr. 14(2):113-119.

López-Campos, Ó., J. L. Aalhus, E. K. Okine, V. S. Baron, J. A. Basarab. 2012. Effects of calf production systems and growth promotants on production and Profitability. Final Report. Alberta Livestock and Meat Agency Ltd., Edmonton, AB, Canada.

McDonald, P., R. A. Edwards, and J. F. D. Greenhalgh. 1988. Animal nutrition. 4th Ed. Longman Scientific and Technical, NY, USA.

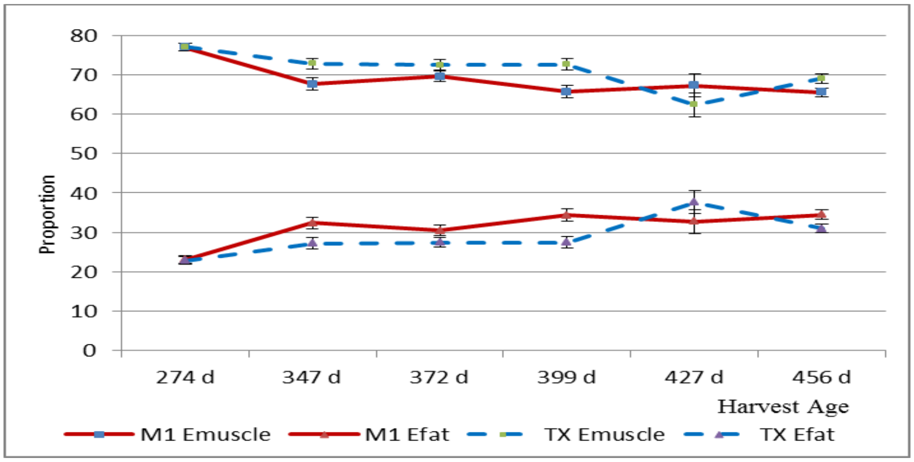
Møller, A. J. 1980. Analysis of Warner-Bratzler shear pattern with regard to myofibrillar and connective tissue components of tenderness. Meat Sci. 5:247-260.

NRC. 2000. Nutrient requirements of beef cattle. 7th rev. ed. Update 2000. Natl. Acad. Press, Washington, DC.

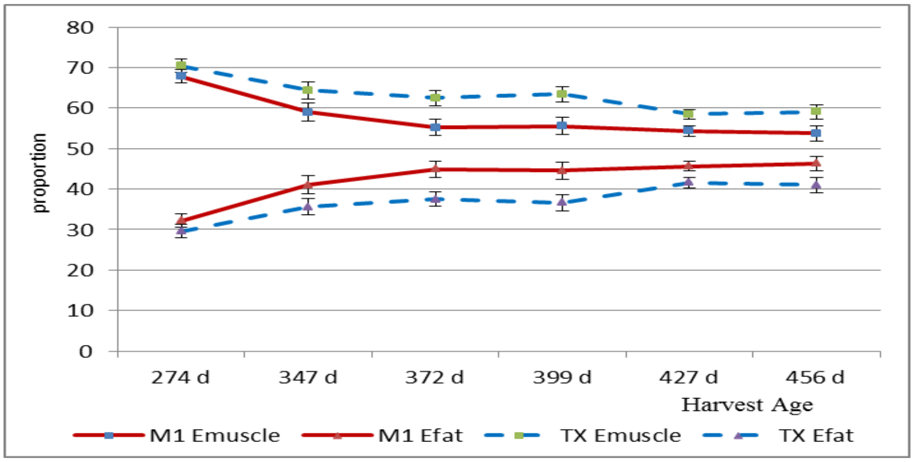
Palokangas, H., V. Kovanen, A. Duncan, and S. Robins. 1992. Age-related changes in the concentration of hydroxypyridinium crosslinks in functionally different skeletal muscles. Matrix. 12:291-296.

Smith, P. G. and R. Bradley. 2003. Bovine spongiform encephalopathy (BSE) and its epidemiology. Br. Med. Bull. 66:185-198.

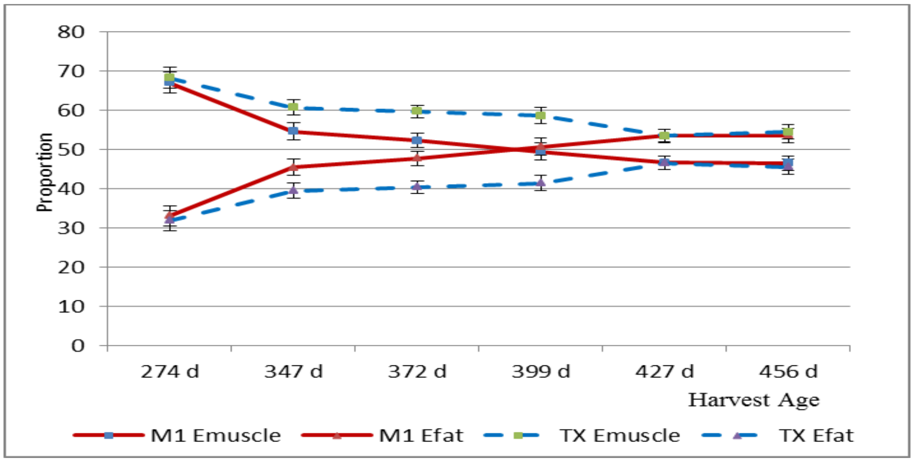
Appendix 1



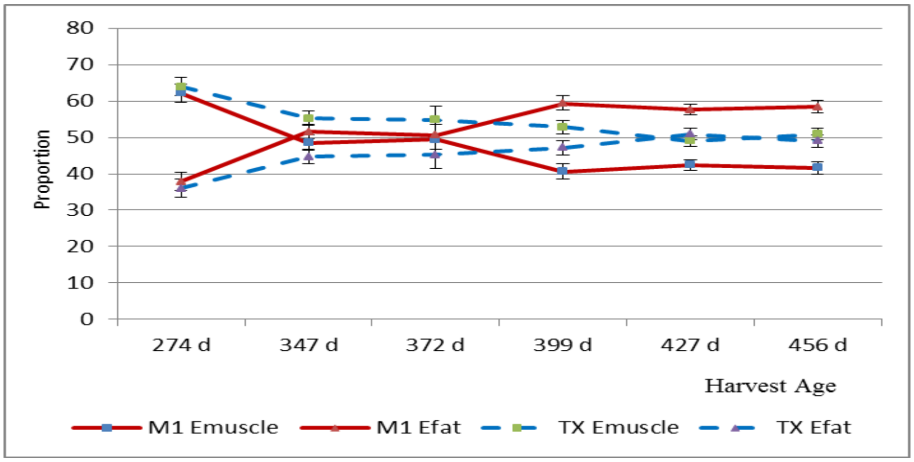
Appendix 1.1 Proportion of energy used for fat and muscle deposition in the round by early and late maturing composite types at different harvest ages



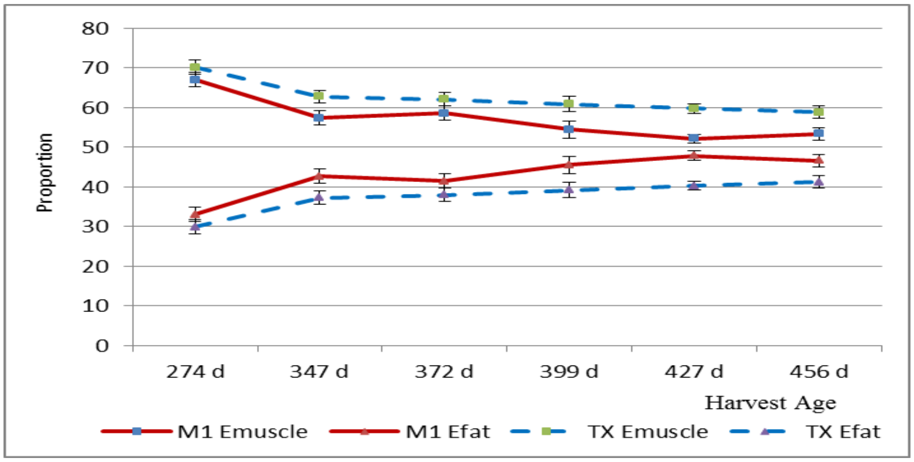
Appendix 1.2 Proportion of energy used for fat and muscle deposition in the loin by early and late maturing composite types at different harvest ages



Appendix 1.3 Proportion of energy used for fat and muscle deposition in the short loin by early and late maturing composite types at different harvest ages



Appendix 1.4 Proportion of energy used for fat and muscle deposition in the rib by early and late maturing composite types at different harvest ages



Appendix 1.5 Proportion of energy used for fat and muscle deposition in the chuck by early and late maturing composite types at different harvest ages

Appendix 2. Energy ratio of subcutaneous fat to intermuscular plus body cavity fat (energy SC : energy BC + energy IM)

		Harvest age (days)*						*P* value
Primal cut	CT^{y}	274 d	347 d	372 d	399 d	427 d	456 d	
Chuck	M1	0.28	0.37	0.32	0.32	0.30	0.35	0.55
	M2	0.24	0.31	0.33	0.34	0.30	0.32	0.13
	M3	0.29	0.33	0.31	0.29	0.26	0.36	0.44
	M4	0.25	0.25	0.36	0.28	0.26	0.31	0.09
	TX	0.23	0.27	0.24	0.24	0.29	0.27	0.84
	SEM	0.03	0.03	0.03	0.03	0.03	0.03	
Round	M1	0.99	1.01	1.19	1.10ab	1.37	1.18	0.38
	M2	0.98	1.01	1.18	1.04a	1.36	1.42	<0.01
	M3	1.04	1.06	1.14	1.3b	1.09	1.23	0.20
	M4	0.82	1.11	1.18	1.07a	1.18	1.29	0.06
	TX	0.96	1.03	1.03	0.96a	1.01	1.06	0.92
	SEM	0.09	0.08	0.08	0.07	0.13	0.09	
Rib	M1	0.62	0.69	0.70	0.60	0.63	0.63	0.62
	M2	0.54	0.62	0.66	0.61	0.62	0.67	0.59
	M3	0.65	0.60	0.57	0.67	0.52	0.65	0.18
	M4	0.58	0.67	0.60	0.63	0.59	0.61	0.93
	TX	0.58	0.52	0.58	0.56	0.57	0.58	0.94
	SEM	0.06	0.05	0.05	0.05	0.04	0.05	
Loin	M1	0.51	0.56	0.64	0.86	0.63	0.74	0.01
	M2	0.41	0.59	0.79	0.76	0.79	0.90	<0.01
	M3	0.58	0.66	0.66	0.77	0.62	0.84	0.04
	M4	0.49	0.71	0.67	0.66	0.68	0.88	0.06
	TX	0.55	0.60	0.52	0.66	0.67	0.69	0.24
	SEM	0.06	0.06	0.07	0.06	0.05	0.09	
Short loin	M1	0.82	1.37	1.06	1.30	1.15	1.25	0.02
	M2	0.74	1.11	1.21	1.15	1.11	1.32	0.04
	M3	0.85	1.10	1.13	1.15	1.03	1.44	<0.01
	M4	0.76	1.41	1.24	1.47	1.21	1.37	0.02
	TX	0.98	1.08	1.00	1.14	1.05	1.34	0.12
	SEM	0.08	0.12	0.11	0.11	0.10	0.13	
Plate	M1	0.12	0.20	0.16	0.13	0.18	0.15	0.60
	M2	0.16	0.13	0.15	0.17	0.15	0.15	0.79
	M3	0.15	0.15	0.17	0.10	0.16	0.18	0.45
	M4	0.14	0.16	0.15	0.15	0.13	0.16	0.81
	TX	0.12	0.13	0.13	0.14	0.12	0.13	0.96
	SEM	0.02	0.03	0.03	0.02	0.02	0.02	

Brisket	M1	0.57	0.59	1.87	0.66	0.59	0.66a	0.38
	M2	0.54	0.54	0.62	0.67	0.74	0.75a	0.20
	M3	0.51	0.67	0.59	0.55	0.58	1.06b	<0.01
	M4	0.54	0.54	0.68	0.57	0.70	0.65a	0.39
	TX	0.53	0.68	0.43	0.61	0.55	0.68a	0.19
	SEM	0.09	0.08	0.50	0.05	0.05	0.09	

CT [y]M1- composites based on Angus (early maturing), M2- composites based on Hereford (early maturing), M3- composites of small breeds (early maturing) M4-composites based on Gelbvieh, Limousin (late maturing), TX-composites based Charolais dams (late maturing).

[x]P value refers to differences in harvest age within composite type and primal cut.

a,b least square means within column and primal cuts with different letters differ ($P < 0.05$). Letters are only shown when means are different ($P < 0.05$).

* Harvest age is the average age of composites serially slaughtered at six time points.