Effect of Castration on Feedlot Performance, Carcass Characteristics and Meat Quality Of Western Sudan Baggara Bulls

BY

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SEPTEMBER, 1993

A thesis submitted in partial fulfillment for the requirement of the degree of M. Sc. in Animal Production

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May, 2006
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DEDICATION

TO MY DEAR MOTHER AND TO MY DEAR FATHER,
WITH LOVE AND RESPECT
TO MY SISTERS, BROTHERS AND THEIR CHILDREN
TO
ACKNOWLEDGEMENT

Primarily, my praise and thanks should be to Allah, the almighty, most gracious and most merciful, who grant me means to conduct this work and other uncountable good things in my life.

Deep gratitude and indebtedness to my supervisor Dr. Abdalla Sidahmed Babiker for his keen interest, valuable advice, helpful and patient guidance during the course of this study.

Special thanks and appreciations to my co-supervisor Prof. Omer Abdelrahim Elkhidir for his invaluable advice and assistance.

I am grateful to the Animal Production Research Center (A.P.R.C) represented in Livestock Fattening Research Department, for making all facilities available and for the opportunity they provided me.
My thanks are also extended to the staff, workers and technicians of the Large Ruminant Fattening Research Unit for helping.

Thanks are extended to the staff of meat laboratory, Faculty of Animal Production, University of Khartoum.

Thanks and appreciations to Dr. Abdelrahman Magzoub and Dr. Babiker Awadelseed for their valuable help in collection of some of the literature provided in this study.

Special thanks are also due to Dr. Isameldin Elnazir and Dr. Mortada Abdelaziez for their valuable help in taking some of the attached photographs.

Warm thanks and appreciations to my family for their continuous support and encouragement.

ABSTRACT

Twenty-four Western Sudan Baggara bulls ranging in live body weight from 175-185kg and age from 2.0-2.5 years were used to study the effect of castration on feedlot performance, carcass characteristics and meat quality. The animals were divided by stratified random sampling into two groups and the groups were randomly assigned to either castrated or entire treatment. The groups were fed *ad libitum* molasses based ration (11.09 MJ/kgDM, ME) and sorghum stover as 1.43kgDM/head/day. Green fodder ‘*Medicago sativa*’ was given as a supplementary source of vitamin A (2kg/head/2week). The bulls were slaughtered at an average target live weight of 258 kg (250-265 kg).

A significant superiority of the intact bulls over the castrated ones was proved in the following studied parameters: they took shorter feeding period
(P<0.05), scored higher for the measurements width of shoulder, hump base length (P<0.05), heart girth around the hump (P<0.001) and height at tip of hump (P<0.01). They also had heavier heads (P<0.05) and total genitalia (excluding fat) (P<0.001). Their carcasses recorded heavier neck and chuck and blade joints (P<0.05), heavier sirloin’s muscular tissue (P<0.05), higher muscle to fat (P<0.001) and bone to fat (P<0.001) ratios.

The meat of the intact bulls was also proved to have higher moisture and protein percentages (P<0.05), ash, sarcoplasmic and myofibrillar protein percentages (P<0.001) and significantly higher pH (P<0.01).

A non-significant superiority of the intact bulls over the castrated ones was proved in growth rate (0.89 vs. 0.82kg/day), feed conversion efficiency (8.85 vs. 9.44 kg DM/kg live wt. Gain) and the rib eye area (49.65 vs. 48.57 cm²).

A significant superiority of the castrated bulls over the intact ones was detected in the following studied parameters: they scored higher for the measurements length from patella to posterior midline and depth of patella from tail junction (P<0.05). Higher percentage of genital fat (P<0.001), kidneys and pelvic fats (P<0.01), omental (P<0.001) and mesenteric fat (P<0.05). They were also found to have significantly thicker subcutaneous fat layer (P<0.001), higher chilled dressing percentage on empty body weight basis (P<0.05) and lower chiller shrinkage percentage (P<0.001).

The meat of the castrated group had higher Hunter lightness value (P<0.001), superior water holding capacity (P<0.001), lower cooking loss percentage (P<0.001) and pH level (P<0.01). It was also of higher ether extract percentage (P<0.001), juicier (P<0.05) and had a better overall acceptability of the cooked meat (P<0.05).
A non-significant superiority of the castrated bulls over the intact ones was shown in the carcass measurement leg circumference (95.33±5.61 vs. 92.92±4.25cm) and cold carcass weight (135.08±3.54 vs. 132.91±5.36kg).
اليدوية: تدوينات الإحصائية

8.85 vs. 9.44 kg

المقارنة

السيرة الدورية

96.33 إلى بعضاً أكبر

السودان التالية (قدر).

القياس أخذت طول الدولتين ببلغت / ويوماً 

ال낀ية

الذكور

الدراسة

الذكور 265-250) 2 بر لحومية لازم بعض

الأيوان

الأمراض السارية

الغيرة

الصحة

العدد

الذريحة

اللاطيحة

الجسم

الجسم

الأنثى

الأمراض الدورية

الثروة المركزية

الصحة

الذكور

النسبة كمجمعة

الأكتاف المخصصة

الصحة

الثروة

النسبة كمجمعة

ال责任制 الأعصاب

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Buttock muscle weight showed an increase in the studied area compared to the reference. The height was increased and the buttocks were observed to have a higher weight. The skin thickness was also increased in the section where the muscle was located. The reduction in fat content was notable in both the studied and reference areas. The observed changes are significant and warrant further investigation.

Figure 1 and Plate 5.3: Figures showing the differences in muscle weight and skin thickness between the studied and reference areas. The changes are significant and require further analysis.
CHAPTER ONE
INTRODUCTION

Sudan is a tropical vast wide country (2.5 million km$^2$), lying between latitude 3 and 23° N. Therefore, it acquires opportunities for climatic diversity and presence of various natural resources. One of the most important natural resources in the country is the wide range of natural pasture on which the majority of the large population of cattle (39.8 million heads) (M.A.R.F, 2004) is raised by nomadic tribes. Western Sudan Baggara cattle are the most dominant and highly efficient meat producer in Sudan. They provide the majority of meat consumed locally and contribute considerably to the export trade, hence to the national economy of the country (Guma, 1996).

The accelerating advances in living standards and human nutrition have brought about some changes in Sudanese eating habits. These circumstances formulate the need for informed management strategies in developing both the qualitative and quantitative traits of meat produced in the country. Yet, the problem of beef production might be regarded from two different points of view: that of producing (economically) the kind of beef that could meet the progressing local and international market demands for good quality products, and that of trying to maximize the energy efficiency of daily gain.

The relation between breeds and tenderness has long been an issue of debate. Zebu type ($Bos indicus$) and their crosses are less tender beef producers compared to the temperate ones ($Bos taurus$). This was evident by numerous investigations (Purchas, 1972; Crouse et al., 1987; Wheeler et al., 1996). It is noticeable in the literature that differences in tenderness exist between breeds whenever Brahman or crosses involving Brahman were
studied and compared with other breeds. The meat obtained from Brahman or its crosses ranks less tender than British breeds on basis of shear force or sensory pannel observations. Recent agreement was realised in the study involving Western Sudan Baggara cattle and Friesian crosses (Eltahir, 1994). The values reported for shear force were 4.05 vs. 3.04 kg/cm² for the two breeds, respectively.

On the other hand, the consumer demand for lean, yet tender meat, and excess fat from steers and heifers compared to bull carcasses have attracted attention to the effects of male castration on meat quality and quantity.

Castration of male cattle intended for beef production is a common managerial practice in many developed countries. It improves the colour, texture, tenderness, juiciness and flavour of meat, through its incremental effect on intramuscular fat (Purchas et al., 2002). This added more for the priority of meat from castrated animals in most Western countries. But still, the cost of production favours intact males (Martinez-peraza et al., 1999) since they have a greater live weight growth potential than steers or females (Morris, 2003). However, castrating bulls with the consideration of optimum chronological and/or physiological age and weight could manage to overcome the advantageous feature of entire bulls over the castrates represented in the leanness and higher gain potentiality of the former. Hence, delayed castration (post-puberty) and slaughtering at a shorter interval could provide the possibility to capture some of the live weight advantages of bulls while still getting the carcass and meat characteristics of steers (ZoBell et al., 1993; Knight et al., 1999a,b and Heaton et al., 2004).

In Sudan, cattle castration is an old technique, but it is rarely practiced even in modern beef production system. However, in the traditional animal husbandry on natural pasture, castration is intended
mainly to decrease some of the managerial problems such as aggressiveness, sexual behavior and control of bulls not intended for breeding rather than for beef quality raising purposes. In the past, in addition to the banding, nomads used to use a very inhumane, primitive and painful method for castration, which involves crushing the spermatic cord by hammering, using a suitable weight. Instead, other modern instruments such as burdizzo are being of a wide use.

Although castration of males for meat production has long been and still is universally practiced, very limited experimental evidence is available on comparative effects of castration of male cattle at the same age, and at different ages, on growth and development of body proportion in farm animals. Nevertheless, in Sudan, information pertaining to cattle castration in the field of beef production is rare as compared to the immense literature on this subject for the international breeds.

This investigation was performed to study the effect of castration of Western Sudan Baggara bulls, fed on molasses based diet, on their:

1. Feedlot performance.
2. Carcass characteristics.
CHAPTER TWO
LITERATURE REVIEW

2.1. Sudanese cattle population:

Sudan occupies the first rank for the total Arab and African ruminant livestock population (FAO, 2002).

Cattle in Sudan possess a remarkable position among Sudanese livestock. They comprise about 29.5% of the total ruminant livestock population (M.A.R.F, 2004) (Table 1). They were classified mainly into three breed types; Southern Nilotic, Nuba Mountains and Northern Sudan Zebu cattle (Arab type) (Bennett et al., 1954).

2.1.1. Nilotic type:

Found in Southern Sudan where it is raised by Nilotic tribes (Payne, 1970) as Dinka, Neur and Anuak in Bahar Algazal and Upper Nile (Mason and Maule, 1960). It is considered as beef type and is characterised by white colour, small body size, long and large horns, small cervicothoracic hump.

2.1.2. Nuba Mountain type:

Found in Southern Kordofan in the area of Nuba Mountains. Characterised by different coat colours, small body size, short broad head, short horns with variable forms, thoracic hump with variable sizes and well-developed dewlap. The type is considered as a beef type (Mason and Maule, 1960).

2.1.3. Arab type:
Herded by the nomadic and semi-nomadic tribes in northern and central Sudan. They include: Kenana, Butana and Western Sudan Baggara as well as the White Nile and Northern Province cattle (Payne, 1970).

### Table 1. Estimate of Animal Population (X1000 head) 2000 – 2004

<table>
<thead>
<tr>
<th>Year</th>
<th>Cattle No.</th>
<th>Sheep No.</th>
<th>Goats No.</th>
<th>Camels No.</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>37093</td>
<td>46095</td>
<td>38548</td>
<td>3108</td>
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Source: M.A.R.F – Statistic and Information
Kenana type is common in the area between latitudes 10° and 14° north, including the Blue Nile, White Nile and Gezira States. They are characterised by their whitish grey coat colour with graduation from nearly white to nearly black on head, neck, hump, hindquarter and legs with sometimes black points in muzzle, tail tip and hooves (Payne, 1970). Also they have cervicothoracic hump which tends to slope from front to rear. It is considered as a dual-purpose breed.

Butana type is found in Butana plains and restricted by Atbara river as northern boundary, Blue Nile as southern boundary on latitude 14° N. Raised by Alshukria and Albatahin tribes. The breed is considered as a milk producer and is characterised by dark to light red colour, short horns and neck, which is well attached to the body (Williamson and Payne, 1978).

White Nile type is found in central Sudan in the White Nile valley in Kosti district. It originated from Kenana and Butana types. It is characterised by a variety of coat colours, white, red, black and admixture of these colours (Mason and Maule, 1960).

Baggara type is found in the Baggara belt between latitudes 10° and 12 ½° N. They are raised by Baggara tribes in southern Kordufan, Darfur and the western part of the White Nile region (Khalil, 1961). They are characterised by large cervicothoracic hump, large dewlap, relatively short horns that seldom exceed 31-35 cm (Wilson and Clarke, 1975). The coat colour and body size are variable ranging from the whitish for the large size Nyalawi (herded by Habania, Beni Helpa and Falata in Darfur region) to the reddish, black and admixture colours of medium and small sizes (herded by Messiriya, Hawazma and Rizigat in Kordufan region) (Elkhalifa et al., 1985).
Most of Baggara cattle travel on hooves for vast distances beginning with the rainy season to the local livestock markets and export terminals. The journey takes 35 to 70 days covering a distance of 350 to 700 km (Ahmed et al., 1980). Although the journey is very stressful, the cattle are still capable of maintaining their high quality beef when rested and allowed access to feedlots (Appendix 1).

2.2. Male gonads and sex hormones:

Testicles are the male animal gonads representing the main source of androgens, the principal among which is the testosterone hormone. It is secreted by groups of modified epithelial cells lying between seminiferous tubules and transported via blood plasma to the target organs (Wood, 1974). Sex hormones are the ultimate determinants of any somatic characteristic by which the male differs from the female (Short, 1980). This is obvious, as intact male have relatively greater muscle in the forequarter, especially those in the neck and crest region than females or castrates (Judge et al., 1989 and Brandstetter et al., 2000). Moreover, they are important factors in breeding rhythmicity through their determination and maintenance of sexual activity and behavior (Wood, 1974).

2.2.1. Functions and activities of testosterone:

- Testosterone is a more potent growth stimulant than the ovarian steroids (Davis et al., 1984). It is important in stimulating growth at puberty as it stimulates the anabolic agents for increasing the efficiency of nitrogen utilization from the diet, an action that is accompanied by decreased fat deposition (Judge et al., 1989 and Lawrence and Fowler, 1997).
- Increases body retention of calcium and phosphorus, which bring about more bone or skeletal growth.
- Stimulates generation of sperms and promote growth, development and activities of sexual accessory organs as cowpers and prostate glands, vas deference, penis and scrotum.

2.3. Castration:

Castration of a male animal means the functioning of the testicles is stopped by preventing production of male hormones so that the animal is unable to reproduce. This is achieved either by the removal of the testicles or by stopping the development of the testicles without removing, by cutting off the blood supply to them. It is universally long-standing practice intended for meat production (Turton, 1962).

2.3.1. Importance of castration:

The importance of castration is reflected in three aspects each of them is more important through their effect on farm production. The first; castration was believed to modify and improve carcass characteristics and meat quality. It accelerates the finishing process. The practice is also intended to remove male odour and this is particularly important in boars and mature male goats. The second aspect; is the facilitation of farm management; generally steers are easier to handle and more docile than bulls. They are also not as rough on equipment as intact bulls, such that, sexual drive, fighting, mounting and aggressiveness are reduced through castration. The third aspect; is to discriminate inbreeding and to prevent pregnancy of immature cows.

2.3.2. Castration techniques:

There are two main recommended methods for castration, the bloodless castration and surgical removal of the testicles. The choice of each will be
determined by the preference of the operator, age and weight of calf and the time of year the procedure is being performed (MattClaeys, 1996). Very recently, immunocastration and chemical castration techniques were also developed.

**2.3.2.1. Bloodless methods:**

**2.3.2.1.1. Burdizzo method:**

In this method the burdizzo instrument ‘of a suitable size’ is used by which spermatic cord and the blood vessels leading to the testicles are cut, causing their re-absorption, while the skin of the scrotum remains intact.

After the animal is flanked and securely tied, one spermatic cord is pushed towards the scrotum wall while the bull is standing or lying down. Then the jaws of the burdizzo are applied, with free hand checking to see that the cord is held in one place by the cord-stops. The handles are firmly closed and left in place for a few seconds. This procedure should be repeated below the first crush on the same cord (Plate 1). Then the procedure is repeated on the other cord. It is important to clip the 2 cords at different levels; the crush marks on each side do not join to form a continuous line across the scrotum, for the scrotal sack to receive enough blood. Otherwise it will become gangrenous (Anderson, 1993). The testicles tend to swell for a while, stop functioning and degenerate (Appendix 4 and 5). By then, animals that are properly castrated will have small, soft, or oddy shaped testicles when compared to uncastrated animals of the same age (McNITT, 1983).

Local application of anesthesia may contribute to inflammatory reaction resulting in prolonged scrotal swelling. However, correct use of the burdizzo should cause afferent nerves from the testicles to be destroyed
(Robertson et al., 1994), thus minimizing any pain involvement. This method has to be properly applied; otherwise, some animals may escape castration or become as stags. Its advantageous feature is that it is bloodless; therefore, infection and maggot infestation seldom occur.

2.3.2.1.2. Elastrator method:

This method also stops the blood supply to the testicles and causes the scrotum to falloff within 10 to 14 days (MattClaeys, 1996). In this method, the descending of the testes in the scrotum has to be checked before application of the ring. Then the animal is restrained, the elastrator band or ring is stretched and both testicles are placed through the ring, then the ring is released from the elastrator and around the scrotum neck (Fell et al., 1986; Chase et al., 1995; MattClaeys, 1996) (Plate 2.a and 2.b). It is the best method used for castration of lambs (Harold, 2000) and at an early age in cattle between birth and about 10 days of age so as to prevent tetanus or general infection in the case of late ages. In addition, old animals will feel more pain over along period of time, which further will impede growth.

The disadvantage of the method is the prolonged feeling of pain. Sometimes a testicle can be missed and be retained in the belly cavity, resulting in a stag animal. In addition, the slow healing of wound may expose the animal to infection by Clostridial tetani (MattClaeys, 1996). However, it is bloodless, calves handled easily and little labour is involved.

2.3.2.1.3. Short scrotum method:

In this technique rubber rings are used to hold the testicles in the body cavity after they have been pushed up ‘cryptorchid’. Yet, the testicles continue to produce hormones but not live sperms. Care has to be taken to
push the testicles well up into the body cavity before putting on the rings; otherwise, some live sperms may be produced (Harold, 2000). Calves will grow into sterile bulls with better growth and feed conversion rates than steers, but may have behavioral problems (aggressiveness).

2.3.2.2. Surgical method:

It is the most certain method of castration. The testicles are removed surgically (Jennings, 1984; Faulkner et al., 1992; Anderson, 1993; Chase et al., 1995; Fisher et al., 1996; MattClaeys, 1996). Before the operation, the person doing the operation must wash his hands well. The instruments must be boiled and kept in antiseptic solution and the scrotum disinfected thoroughly with iodine or another suitable disinfectant. Then, the calf should be restrained; both the rear legs and at least one of the front legs have to be tied securely.

The method is performed as one testicle is pulled down at a time and is held firmly towards the outside so that the skin of the scrotum is pulled tight over the testicle. A sharp knife is used to slit the outside lower third of the scrotum adjacent to the leg. The incision must extend around the bottom third of the scrotum to ensure adequate drainage (Plate 3.a and 3.b). The testicle will pop out after its removal from the supporting membrane of the opened portion of the scrotum ‘by ones fingers’ and turned several times to twist the cord. Then the cutting should be as high up the cord as possible to avoid leaving tissues that could produce testosterone and result in stag (MattClaeys, 1996). In very young calves, the testicles can be pulled from the body, with
tension breaking the spermatic cord. In older calves, an emasculator is applied to cause a crushing action, which arrests hemorrhage, and a cutting action, which allows the testicle to be removed. After the removal of the testicles, apply an antiseptic that is effective, yet, not irritating, and/or antibiotic powder to prevent infection and a fly repellent.

The risk of infection in surgical castration is present in all ages. However, the risk of bleeding increases in older bulls (Anderson, 1993). Also the method is likely to cause more prolonged distress than other methods, thus experienced person is recommended (Harold, 2000).

2.3.2.3. Immunocastration technique:

During the last decade, investigators developed the immunocastration technique to achieve castration by inducing immunoneutralization of hypothalamic-pituitary-testicular axis hormones (Adams and Adams, 1992; Finnerty et al., 1994). This is thought to have minimal stress effects.

2.3.2.4. Chemical castration:

This is most recently developed castration technique. Chemical castration is performed by injecting a chemical directly into each testicle of bull calf. The appropriate amount of the chemical injected into the testicle causes degeneration of the testicle tissue (Dave et al., 2002).

2.3.3. Effect of castration on blood cortisol level:

Generally, cortisol is regarded as a catabolic hormone. Its higher concentration in the plasma decreases the feed intake and weight gain (Fisher et al., 1996). Castration, regardless of its method, increases the level of blood cortisol concentration. However, higher peak cortisol concentration following surgical and banding castration was observed (Earley and Crowe, 2002). King
et al. (1991) reported no difference in plasma cortisol concentration for surgical compared with burdizzo castration of cattle during 3 hours post-treatment, but higher concentrations for surgically castrated calves at 6 hours was observed. This was substantiated by the result of Kehlet (1991) and Fisher et al. (1996) who reported that pain and inflammation due to trauma are major inducers of more prolonged cortisol secretion following surgery. Earley and Crowe (2002) concluded that surgical castration induced a significant elevation in cortisol secretion; however this can be reduced to the level of intact calves by administration of anti-inflammatory ketoprofen but not local anesthesia.

2.4. Effect of castration on feedlot performance:

Performance of fattening animals refers to three contemporary and very much correlated parameters namely growth rate or body gain, amount of feed consumed and the feed conversion ratio. Armsby and Fries (1911) observed that type of an animal affected the ability of that animal to convert feed to weight.

2.4.1. Growth rate:

Growth is an important biological phenomenon that forms the basis of production especially in meat animals. It is defined as an increase in tissue mass by hyperplasia early in life and hypertrophy later in life, although hyperplasia of adipose tissues continues throughout the life (Owens et al., 1993). Others defined growth as gain of live weight per unit time and body measurements (Pomeroy, 1955) which occurs when a healthy young animal is given adequate feed, water and shelter.
Sex of the animal, plane of nutrition, age of the animal, hormonal implants and to some extent the method applied for castration, together, manipulate growth rate of an animal.

**Sex.** With few exceptions, there seems to be a general agreement between researchers that castration tends to decrease growth rates of cattle, sheep and goats. Williams *et al.* (1965) studied differences due to sex, between bulls, steers and heifers and reported that average daily gain was significantly higher in bulls than steers and heifers. Similarly, Purchas *et al.* (2002) showed the higher growth rates and leaner carcasses of bulls compared to steers. Knight *et al.* (1999b) found that bulls grew 14-19% faster than steers and had 6.8-7.9% higher fasted live weight at slaughter. These were supported by Klosterman *et al.* (1954); Berg and Butterfield (1976); Newman *et al.* (1989) and Grings *et al.* (2001).

**Nutrition.** Adequate nutrients and energy intake are the most important factors affecting beef and other animals to express their potential growth rate (Anderson and Sexhus, 1996). Nevertheless, an optimal level of nutrition is also reflected on the normal development of sexual differences in farm animals. Wylie *et al.* (1997) studied the effect of sex on growth rate of lambs, when kept on grass with their dams until weaned at 20 weeks. They found that the growth rates of ram, wether and ewe lambs were 293, 253 and 224 g/day, respectively and the difference was significant. This is concurrent with the results of many researchers (Palsson and Verges, 1952; Cobic, 1968 and Silva *et al.*, 1980). However, Almallah *et al.* (1979) studied the effect of breed and castration on performance of Iraqi lambs. Awassi and Kurdi lambs averaging 5 months of age were used. Approximately half the lambs of each breed were castrated. All lambs were fed according to a 2-phase feeding
programme. Castration had no significant effect on weight gain in either phase.

**Age.** Age of the animal at castration has also been observed to affect body weight gain and growth rate. ZoBell *et al.* (1993) and Heaton *et al.* (2004) reported that delayed castration of beef calves has been suggested as a mean to improve live animal performance and the rib-eye area. Cosgrove *et al.* (1996) reported that post-pubertal castration of bulls could produce meat with steer characteristics if the interval from castration to slaughter was long enough, but it may be difficult to retain the growth rate and live weight advantage of bulls after castration. Similarly, Gazzola *et al.* (2002) reported that although delayed castration resulted in no behavioral or management problems, it did not produce a commercially useful increase in growth rate. At both 7 and 16 months of age surgical castration of bulls caused no animal welfare problems, however, body weight gain was affected by genotype with *Bos taurus* types having a lower body weight gain than *Bos indicus* and F1-cross cattle. Field *et al.* (1966) and Cobic (1968) showed that during the whole period of growth from birth to slaughter bulls achieved higher daily live weight gain than steers. These were in line with the finding of other investigators (Reyneke, 1976; Knight *et al.*, 1999b and Schoonmaker *et al.*, 2002a,b). However, Elshafie (1965) studied weight gain of Butana calves castrated at 9 months of age and reported no difference in average daily gain (2 lbs/day) between the castrated and intact males. Similarly, Rahama (1996) studied the effect of sex on weight gain and reported that bull calves had higher weight gain and withers height than heifers of Friesian cattle, however, significant results were not obtained.

On the other hand, the effect of age at castration on growth rate of sheep and goats was similar to that in cattle (Field, 1971; Seideman *et al.*, 1982; Mohamed,
1994 and Eldow, 2001). However, some workers suggested that early castration improves growth rate to statistically significant level. Earlier, Machenzie (1967) stated that the daily gain in Toggenbarg kids castrated in the first week after birth was higher than the daily gain of entire males and females. Owen and Matenga (1980) reported that from weaning to 24.5 kg male Saanen kids grew faster than castrates (222 vs. 183 g/day), but from 24.5 to 36.5 kg the performance was reversed and castrates had a higher growth rate than intact males (234 vs. 185 g/day, respectively).

**Castration method.** The method of castration also affects growth rate few days to weeks following castration. The stress response as measured by plasma cortisol, average daily gain and average daily feed intake would be greater following surgical than burdizzo castration. ZoBell et al. (1993) showed that both surgical and banded castration had severe reduction on average daily gains when castrates are compared to intact bulls. However, banded bulls performance was higher than surgically castrated bulls. Fisher et al. (1996) found the average daily gain of calves castrated using burdizzo was not different from that of intact ones from day 0 to day 7 but was lower from day 15 to day 21, however, reduction in average daily gain was observed from day 0 to day 7 for calves castrated surgically. They also concluded that, both surgical and burdizzo castration caused increases in plasma cortisol concentrations and decreases in feed intake and weight gain. However, cortisol rise was greater and more prolonged for surgical castrates and immunocastration technique resulted in minimal stress effects (Adams and Adams, 1992; Finnerty et al., 1994). Maminove et al. (1976) studied 3 groups of ram lambs of equal age (3-4 months) and number of heads (100). The first and second groups were castrated using surgical and closed method, respectively while the third group was left intact as control. Body weight averaged 15.7, 15.8 and 15.2 kg at the time of castration; 10.4, 18.5 and 19.8 kg one month later and 34.7, 35.1 and 37.4 kg eleven months later. It was found that surgical method reduced weight gain compared to the other methods. Rodriguez and Castell (1991) found that the
average daily gains for intact lambs, short scrotum lambs and burdizzo-castrated lambs were 169, 147 and 142 g, respectively and the differences between groups were significant. Mahgoub et al. (1998) reported that intact and cryptorchid Omani sheep had significantly higher average daily gain than castrates (155 g/day, 150 g/day and 109 g/day, respectively). However, King et al. (1991) reported no difference in monthly average daily gain in either surgical or burdizzo castrates compared with controls.

**Hormonal implants.** Hormonal implants are devices containing synthetic growth-promoting substances designed for slow release, placed beneath the skin on the back of an animals’ ear. They apparently exert a positive effect on growth and feed efficiency through their enhancement on growth hormones secretion via pituitary gland, resulting in increased formation of muscle and decreased formation of fat tissue (Judge et al., 1989 and Davis, 2002). However, adequacy of the finishing diet and the health of the animal are of important consideration for the response of implants application (James et al., 1997).

Newman et al. (1990) reported that growth-promoting implants increased growth rate and feed conversion ratio of steer, but implantation of intact bull produced variable results. Similarly, Baker et al. (2000) concluded that combining castration and implanting allows producers to maximize weaning weight of calves. Lemieux et al. (1990) reported that implanting steers increased daily body protein gain during growing and finishing phases. Moloney et al. (1990) found that implantation increased carcass weight and decreased weight of the hide and internal organs, thereby, increasing dressing percentage.

However, the hormonal control of muscle growth has not been elucidated and the biological mechanisms responsible for the anabolic effects of implants are also unknown (Hayden et al., 1992; Trenkle, 1997; Johnson et al., 1998).

**2.4.2. Feed intake:**
The voluntary feed intake of a healthy animal is affected by the capacity of the animal to metabolize nutrients, which further depends on the age, weight, stage of growth and the sex of the animal (Ørskov, 1998).

Abundant investigations on cattle, sheep and goats revealed that, total average daily feed intake of entire and castrated animals of the same live weight is often not very different to statistically significant levels. Elshafie (1965) showed that average daily feed intake was about the same for castrated (11.9 lbs) and non-castrated (11.5 lbs) Butana calves. Similar findings were reported by Grings et al. (2001) that dry matter intake did not differ between bulls and steers. Supporting to these, Eldow (2001) found that the daily dry matter intake was similar between the two sex groups; the values were 1.26 and 1.27 kgs for entire and castrated Sudan Desert lambs, respectively. Similarly, Cooper et al. (1989) reported that, the mean daily feed intake for Saanen kids was similar between the two partners in concern; the values were 710g vs. 750g, respectively. Babiker et al. (1985) reported equal feed intake of 359 g/day for entire kids and 349 g/day for early castrated kids. However, some investigators found evidence for the tendency of entire male animals to consume rather more feed than castrates (Klosterman et al., 1954 and Mohamed, 1994).

The reduction in feed intake persisted beyond the duration of cortisol elevation, indicating that such performance measurements are useful additional measurements to stress related hormone concentrations in revealing the stress response of cattle during few hours to weeks following this procedure (Fisher et al., 1996). Faulkner et al. (1992) indicated the tendency for castration to reduce feed intake took over 27 days. Other studies suggested that, reductions in feed intake and growth for castrates were only present up to 10 days post-castration (Fisher et al., 1996, 1997) and alteration in white blood cells numbers was also observed (Chase et al., 1995).
2.4.3. Feed conversion efficiency:

Efficiency of feed is expressed as specific amount of feed required for production of a unit of weight gained. It has a marked influence in meat production system and the economy of fattening (Lister et al., 1976). The live weight, breed and sex of the animal affect its feed conversion efficiency.

**Live weight.** Feed conversion efficiency is affected by the live weight of the animal through its effect on maintenance requirements and production needs. The heavier the animal the greater are its maintenance requirements and the lower is its feed conversion ratio (Elshafie and McLeroy, 1964; Romita et al., 1980; Morris, 2003 and Mohammed, 2004).

**Breed.** The effect of breed on feed conversion efficiency was also obvious. *Bos indicus* breeds have almost lower feed efficiency than *Bos taurus*, while cross bred cattle were intermediate. Eltahir (1994) reported that, 50% Friesian crosses were more efficient feed converters (5.58) than Western Sudan Baggara bulls (6.50) fed on molasses based diet. Similarly, the average respective values of feed conversion ratio of Boran, Herford and Abergeen Angus were 16.6, 8.1 and 8.4 kg dry matter per kg weight gain (Ledger et al., 1970). These were in accord with Stanton (2004) who suggested that breeds and individual animals maturing at heavier weights require more energy for maintenance compared to breeds of light mature body weights (*Bos indicus*).

**Sex.** Numerous investigations in cattle provided evidence for the poor feed conversion efficiency in castrates and females (Turton, 1962; Cobic, 1968; Hedrick et al., 1969; Field, 1971; Preston and Willis, 1974; Seideman et al., 1982; Anderson et al., 1988 and Grings et al., 2001). Morgan et al. (1993) implicated that the increased growth rate and efficiency of bulls
compared to steers is due partially to increased protein muscle accretion resulting from reduced muscle protein degradation. Newman et al. (1990) reported that castration reduced feed conversion efficiency by 13%. Lean intact male produced higher carcass yield, but were generally of low quality grade. On the other hand, steers compared to intact bulls tended to accumulate more external fat, that was accompanied by a decrease in weight gain and an increase in feed conversion ratio (Schanbacher et al., 1983).

The reduction in feed conversion ratio as a result of castration was also observed in sheep (Puccia and Combellas, 1984; Mahgoub et al., 1998; Eldow, 2001) and goats (Babiker et al., 1985; Cooper et al., 1989; Mohamed, 1994).

2.4.4. Slaughter weight:

There is abundant experimental evidence that confirms the superiority of intact bulls over steers in growth to market weight (Klosterman et al., 1954 and Turton, 1962). Similarly, Prescott and Lamming (1964) reported that, bulls reared intensively had higher slaughter weight than steers. Grings et al. (2001) implicated that steers required 12 more days to reach 386 kg live body weight compared to bulls.

The same findings are probably true for goats (Sye, 1983; Babiker et al., 1985; Mohamed, 1994) and sheep (Rodriguez and Castell, 1991; Wylie et al., 1997; Mahgoub et al., 1998; Eldow, 2001). Other investigators reported discrepant views that no difference existed between rams, cryptorchids and castrates (Abdullah et al., 1994). This was supported by the findings of Kumar et al. (1981) who noted difference in live weight at slaughter between groups of goat kids castrated at different ages and intact males.

2.5. Effect of castration on carcass characteristics:
The carcass is that portion of the animal remaining after the removal of head, skin, feet, tail and internal organs except the kidneys and its surrounding fat (Yeates, 1965). Its economical value depends upon its yield of salable meat as well as the cutting and processing quality.

2.5.1. Dressing out percentage and carcass weight:

Dressing out percentage is described as the dressed carcass weight expressed as percentage of slaughter weight or empty body weight. Economically, the dressing percentage is considered as the most important parameter for the producer and consumer to look after, as it determines the profitable cutability and the saleable parts of the slaughtered animal.

The hot dressing percentage of Western Sudan Baggara cattle on live body weight and empty body weight basis varies between 49.69% (56.38%) (Mohamed, 1999) and 51.97% (56.92%) (Eltahir, 1994) and it may reach up to 57.8% (62.9%) (Guma, 1996). However, this parameter is affected by different factors including live weight, age, nutrition, breed and sex of the animal.

Live weight and age. With increasing age and fattening of the animal the dressing percentage increases until it reaches a point where it tends to cease. This pattern of increase was described by Palsson and Verges (1952) to be mainly due to the high growth rate of carcass tissues relative to organs and offals. There is a linear relationship between carcass weight and the live weight of an animal (Preston and Willis, 1974). This has been substantiated by Harris et al. (1997) in their implication that slaughter end point seems to be more important determinant of carcass traits. Recently, Mohammed (2004) studied the effect of slaughter weight on meat production potential and reported that, dressing percentages of Western
Sudan Baggara bulls followed the values of 49.40, 50.56, 54.03 and 54.39% for 200, 250, 300 and 350 kg slaughter weights, respectively. However, he found the dressing percentages on empty body weight basis to be 57.12, 57.71, 61.45 and 61.70% for the four weight groups, respectively. Gaili and Nour (1980) reported dressing percentages ranging between 55 and 66% on empty body weight basis for Sudan Kenana bulls for the weight range from 100 to 400 kgs.

**Nutrition.** Nutritional history of the animal is an important determinant of its future dressing out percentage. Many investigations in the field of beef production have discouraged forage finishing of meat animals. This is attributable to the resultant lower dressing percentage, higher cooler shrinkage and lower quality grade (Schroeder *et al.*, 1980 and Smith, 1990). Mohamed (1999) found that, the dressing percentage of hot and cold carcass on both slaughter and empty body weight basis were significantly greater for Western Sudan Baggara bulls fed higher dietary energy than those fed low energy diet. Bennett *et al.* (1995) reported a significant difference between dressing percentage of steers fed concentrate diet and those fed forages. Carcass gain as a fraction of live weight gain was almost twice as great during the feedlot phase as that during the growth phase. In the Coleman *et al.* (1995) study, the dressing percentage increased from approximately 57% to 64% during the 105 days finishing period. Gaili (1976) found that the dressing out percentage of unfattened desert goat ranged from 40.36 to 43.01 while with fattening it increased to a value, which ranged from 49.01 to 54.08 for young yearling and mature goats, respectively.

**Breed.** Breed on the other hand, had been shown to exert a major effect on dressing percentage. Eltahir *et al.* (2000) showed that, mean hot
carcass dressing percentages, on empty body weight basis, were 56.91 and 58.30% for Western Sudan Baggara cattle and 50% Friesian crosses fed on molasses based diet, respectively. The corresponding values of the cold carcass dressing percentage were 55.19% and 56.81% for Sudan Baggara and half-cross Friesian bulls, respectively.

**Sex.** Castration, generally, influences the dressing percentage in meat animals. Field (1971) found that bulls dressed significantly higher (P<0.01) than castrates. Purchas *et al.* (2002) reported that weight adjusted dressing percentages were slightly higher for bulls than steers. This substantiated previous studies (Purchas and Grant, 1995). However, Elshafie (1965) studied the effect of castration on yearling Sudan Butana calves and showed that warm dressing percentages ranged from 47.7 to 53.9 with a mean of 51.6 for the castrated group and 46.5 to 51.7 with a mean of 50.9 for the non-castrated group. The result showed no significant difference between the two groups. Similar findings have been reported for sheep and goats (Babiker *et al.*, 1985; Mohamed, 1994; Mahgoub *et al.*, 1998 and Eldow, 2001). Similarly, Lee *et al.* (1990) found that the dressing percentage increased with increasing live weight over the entire range of weights studied. However, in intact and castrated male goat kids it varied with live body weight. At an average body weight of 20kg intact male had lower (44.4) dressing percentage than castrates (48.4). However, at 26kg intact male goat kids had similar dressing percentages as castrates (45.1 versus 45.1). Entire lambs had lower dressing percentage than ewe lambs. However, Babiker *et al.* (1985) found that the dressing out percentage (expressed on live weight basis) at 7.5 months of age was slightly lower (45.82%) for intact than castrated (47.56%) male kids of Sudan Desert goats. However, when the ratio was expressed on empty body
weight, no significant difference was found between castrated and entire male goat kids. Mohamed (1994) reported that hot and cold dressing-out percentages, on slaughter body weight basis, were not significantly different between the two treatment groups. However, on cold carcass weight basis, castrated goat kids dressed slightly higher than the entire goat kids. Elbayoumi and Elshiekh (1989) reported that, castration has no significant effect on dressing out percent irrespective of time of castration.

Castration affects carcass weight as well. Entire bulls had heavier hot carcass weight than immunocastrates, late castrates and steers (Jago et al., 1996). Mandell et al. (1999) reported that breed differences in hot carcass weight of bulls were much larger than breed differences of steers. This is concurrent with the result of Mohamed (1994) who found the significantly heavier hot carcass of entire than castrated Sudan Desert goat kids. However, the difference between the two groups in cold carcass weight was lower due to increased chiller shrinkage of entire kid carcasses. Similar finding was revealed in the field of sheep castration (Eldow, 2001).

2.5.2. Carcass composition:

The composition of the carcass i.e. the proportions of major tissues bone, muscle and fat, largely determines its value. Bone growth precedes muscle growth. Fattening occurs later in life. However, the percentage of each of the three tissues in the carcass either decreases (bone), increases to a limited extent (muscle) or accelerates (fat) with age or slaughter weight of the animal. This is supported by the finding of Jenkins et al. (1991) that protein gain slowly decreases as an animal grows, and fat gain increases slowly at first then, more quickly after a certain point at which fattening is thought to commence. Recently, Mohammed (2004) studied carcass composition of Western Sudan Baggara bulls and reported values of 19.44, 17.41, 15.90 and
15.69 % for bone, 64.09, 64.34, 65.97 and 65.00 % for muscle and 16.10, 17.79, 18.19 and 19.39 % for fat in four weight groups at 200, 250, 300 and 350 kg, respectively.

Castration alters growth rate and carcass composition in cattle due to the change in hormonal status (Lee et al., 1990 and Hunt et al., 1991). This is supported by the finding of Devendra and McIeroy (1983) that endocrine system (represented in sex hormones) helps to regulate the growth of different animal tissues. However, other factors such as mature body size and nutritional history of the animal have a major role in manipulating carcass composition.

Early castration affects mature body size of the animal, which in turn influences carcass composition. This is supported by the earlier findings of Hammond (1932) and Palsson and Verges (1952) that sex has great influence on age changes in the body proportions of sheep. Similarly, steers have relatively small body size compared to entire animals. In young female animals, initially growth rate may be stimulated, but eventually oestrogens accelerate ephiphyseal plate closure and the overall effect on muscle growth is less pronounced than that of androgens (Judge et al., 1989 and Lawrence and Fowler, 1997). This work has elucidated the fact that females are earlier maturing than males i.e. the former attaining more advanced stage of development in early life than the latter. For example, when comparing ewes and wethers at 9 weeks of age and equal dressed carcass weight of 30lbs. Palsson and Verges (1952) found that the ewes had 4.7% higher dressing percentage and had all joints of the carcass, except head and feet, proportionally better developed than the wethers. At this age the earlier maturing tissues, bone and muscles were lighter in the ewes than the wethers,
while the latest maturing tissues, the fat was much better developed in the ewes.

2.5.2.1. Carcass Fat:

Percentage of fat in a carcass is proposed as an index of acceptability, which further depends on the local customs and consumer demands.

The effect of castration on animal fat was similar in all types of livestock. The relatively greater proportion of fat in castrates agrees with the observation that castrates have greater ability to deposit fat. Entire males have less fat and more muscle than castrates and females (Prescott and Lamming, 1964). Steers were significantly fatter than bulls at the same carcass weight for all measurements of fatness (Purchas et al., 2002). Similarly, Gaili (1978) found that females had more intermuscular fat than males in all sites examined. Hedrick et al. (1969) reported that bull carcasses had significantly less fat percent than steers and heifers. This fact is confirmed by the general principle of Hammond (1932), that muscle and fat are late maturing tissues relative to bone.

Castration is also known to enhance the rate of fat deposition in sheep (Abdullah et al., 1994; Mahgoub et al., 1998; Eldow, 2001) and goats (Owen et al., 1978; Giiney et al., 1984; Mohamed, 1994).

The subcutaneous and intermuscular fat have a large visual impact and improve consumer acceptance of carcasses and cuts and facilitates the storage and consequently the marketing of the product. Early studies have indicated that subcutaneous fat thickness is the single most important trait in the prediction of carcass composition (Crouse et al., 1975; Miller et al., 1988).
Castration had an incremental effect on the amount and thickness of back fat cover of meat animals. Grings et al. (2001) found bulls tended to deposit less back fat than steers as measured by ultra-sonography. Cosgrove et al. (1996) reported that castrates were intermediate between bulls and steers in fat depth; however, breed differences in carcass composition between bulls may not be the same as in steers. Similarly, Knight et al. (1999a) found fat cover score and fat depth were lower for bulls than steers. Eldow (2001) reported significantly higher subcutaneous fat measurements for castrated than entire Sudan Desert lambs; the values were 3.37 vs. 2.10 mm, respectively. These were explained by Palsson and Verges (1952) findings that in the late maturing subcutaneous fat depot, the difference between the sexes was still greater than in the earlier maturing intermuscular fat.

2.5.2.2. Carcass lean:

Many studies have reported that, bulls gain more rapidly and are more efficient in producing leaner carcasses than steers. These correspond closely with the results of Jacobs et al. (1977a) who found that bulls yielded 16% more edible meat than did steers, and also with those of Landon et al. (1978) that bullocks yielded a greater percentage of retail cuts, primarily due to differences in fat trim among sex groups. Supporting to this, Morris (2003) reported that composition of live weight gain of bulls contained more protein and less fat than of steers and similar difference existed between steers and heifers. Morgan et al. (1993) concluded that the increased growth rate and efficiency of bulls compared with steers is due partially to increased protein muscle accretion resulting from reduced muscle protein degradation. They reported that, the direct mechanism by which castration alters protein turnover remains unclear. These findings were supported by Santidrian et al. (1982)
and Lobley et al. (1987) who reported that treatment of rats and lambs with testosterone increased muscle growth by suppressing muscle protein degradation.

On the other hand, lean lambs production might also be increased by rearing entire ram lambs or by delaying castration. Similarly, Arnold and Meyer (1988) found that delaying castration and pasture grazing reduced fatness.

The finding that intact males produce lean carcass has been reported for sheep (Ahmed and Davis, 1986 Eldow, 2001) and goats (Elbayoumi and Elsheikh, 1989; Mohamed, 1994).

**Longissimus dorsi muscle** (*Longissimus thoracis et lumborum*) is a long muscle lying ventrally to the transverse processes of the vertebrae and forms the large round eye of meat in rib and loin steaks or chops (rib eye area).

Castration had a reduction effect on the *Longissimus dorsi* muscle area. Knight et al. (1999a) and Purchas et al. (2002) reported that steers had significantly smaller *Longissimus* muscle area than bulls. Grings et al. (2001) found that bulls had larger *Longissimus* muscle area (89.5 cm²) than steers (84.1 cm²). Similarly, Reiling et al. (1992) reported that bulls had significantly less subcutaneous fat and greater *Longissimus* muscle area than did either steers or heifers. This was supported by the early study of Hedrick et al. (1969) that *Longissimus* muscle area was significantly greater for bulls than for steers or heifers, however, the difference between steers and heifers was not significant. Jacobs et al. (1977a) compared Hereford bulls and steers from the same herd and nutritional background, for eye muscle area and found that bulls had greater rib-eye areas (83.9 cm²) than steers (73.5 cm²).
Meaker and Liebenberg (1982) reported that bulls had significantly larger eye muscle area than steers castrated either at 24 hours of birth (52.9 cm²), three months of age (54.7 cm²) or at 6 months (58.9 cm²). Similarly, Cosgrove et al. (1996) found that during finishing, castrates retained the high eye muscle area, but lost the pronounced development of the neck musculature of bulls.

2.5.2.3. Carcass bones:

Bone is the earliest developing tissue in the carcass and muscle growth is dependant on it. Osman et al. (1970) in their study on carcass composition of fattened rams and wethers of Sudan Desert sheep showed that rams had a higher percent of bone in their carcasses than wethers and the values at 25 kg live weight were 23.4 and 21.3% for rams and wethers, respectively. Mahgoub et al. (1998) reported that entire lambs had a significantly higher weight of bone than castrate and ewe lambs. Wynn and Thwaites (1981) reported that rams yielded significantly more bone and less fat than did wethers. Castrated animals will have bones that are smaller in diameter than those of the intact animals but the length may actually be increased if the animal is retained until mature (Lawrence and Fowler, 1997).

Mohamed (1994) and Eldow (2001) showed that bone percentages were not significantly different between the late castrated and entire males; however, it was slightly higher in the entire animals of both species. Nevertheless, Elbayoumi and Elsheikh (1989) studied the effect of castration on bone percentage and showed a non-significance difference between the intact and castrated goat kids. Similarly, Abd Elmoula (1996) reported that although there was no significant difference between the total carcass bone percentage in males and females of Sudan Desert goats, still the bone tissue of males was 9.28% greater than that of females.
2.6. Effect of castration on non-carcass components:

Non-carcass components include external offals (the head, skin and feet) and internal offals (tongue, lungs and trachea, heart, liver kidneys, spleen, gastrointestinal tract and blood).

Sex class and castration largely affect the development of non-carcass components. Purchas et al. (2002) reported that hearts were heavier for bulls than steers. Lirette et al. (1984) found that non-castrated lambs had significantly heavier digestive tract and heavier small intestines than castrated lambs. For the visceral fat, Grings et al. (2001) reported that kidney, pelvic and heart fat of bulls averaged about 71% of that of steers. This was substantiated by the data of Landon et al. (1978) who stated that steers would tend to possess greater kidney, pelvic and heart fat than bulls. Similarly, Elshafie (1965) reported that the mesenteric and kidney fat depots ranged from 6 to 25 lbs. with an average of 13.4 lbs. for the castrated; and from 5 to 12 lbs. with an average of 9.1 lbs. for the non-castrated Butana calves.

Castration seems to have little or no effect on most non-carcass components in other species as well. Pulenets et al. (1987); Mohamed (1994) and Eldow (2001) reported non-significant differences between entire and castrated male animals in the percentage made by the head, skin and feet from the empty body weight. However, the finding that castration increases the percentage of body fat and decreases the percentage of the reproductive organs have also been reported for sheep (Pulenets et al., 1987; Eldow, 2001; Mahgoub and Lodge, 1994) and goats (Mohamed (1994).

2.7. Effect of castration on muscle composition:
The chemical composition of meat has a significant impact on quality attributes (Moloney, 1999). It contains about 75% water, 19% protein, 2.5% lipid and 3.5% soluble non-protein substances (Lawrie, 1991).

There is a general agreement between researchers that castration affects the chemical composition of meat for some extent. Eldow (2001) reported a significant difference between castrated and intact male lambs in the percentages of moisture and crude protein, which were higher in entire lambs than castrates. Fat percentage was significantly higher in castrated (3.93%) than entire (1.45%) lambs; however, ash percentage was not significantly different between the two sexes. Similarly, Mohamed (1994) reported a significant difference between castrated and entire goat kids in the percentage of moisture (74.51 vs. 73.61%) and crude protein (20.14 vs. 19.09%) where entire goat kids had higher values. Ash percentage was not significantly different in the two sexes. Fat percentage was significantly different between the two groups, whereas entire males scored 3.2% and the castrated ones scored 4.92%. Similarly, Schanbacher et al. (1980) stated that the carcasses of intact rams contained more water and protein but less fat and gross energy than wethers.

Morgan et al. (1993) reported that bulls showed more myofibrillar protein accretion than steers. Lower myofibrillar fragmentation index (MFI%) values were reported in studies showing lower proteolytic enzyme activity in muscle from bulls (Morgan et al., 1993; Thompson et al., 1996). Similarly, non-protein nitrogen was significantly higher for entire than castrated group. This agrees with the findings of Mohamed (1994) and Eldow (2001) that sarcoplasmic, myofibrillar protein and non-protein nitrogen percentages were significantly different between the two sex groups, where entire animals had higher values than castrates.
2.8. Effect of castration on meat quality attributes:

Meat quality is another most important parameter in meat production aspects. It is a very subjective term in meat industry. It is likely to be defined differently by exporters, retailers, or purchasers and consumers. The processor may perceive beef quality as a reflection of carcass weight, fatness grade, lean meat yield and the timeliness of carcass supply in relation to market requirements. On the other hand, cut size, meat colour, fat colour, marbling, texture appearance and the healthiness and/or safety aspects of the meat influence the retailer and/or purchaser conception (Moloney, 1999).

From a perspective view muscle colour is the most important factor in the selection of meat and meat products (Hedrick et al., 1994). It is related to the level of pigmentation (myoglobin) present in the muscle. Myoglobin is a water-soluble protein that stores oxygen for aerobic metabolism in the muscle (Boles and Pegg, 2002). Initially muscles are purplish in colour and jelly-like in appearance. When beef is cut the myoglobin (purplish) is oxygenated, giving rise to a bright red colour (oxymyoglobin), a process known as blooming. Exposure of beef to low oxygen pressure changes its colour slowly to brown due to conversion of myoglobin to metmyoglobin. Redness (myoglobin concentration) increases as an animal matures and with exercise. Moloney (1999) reported that a high level of pre-slaughter stress could lead to a rise in pH, which can result in dark coloured beef. Also muscles that are used for greater physical activity often have more myoglobin.

2.8.1. Muscle colour and pH:

Many researchers had investigated the effect of castration on meat colour and pH. Mohamed (1994) showed that Hunter lightness (L) values were significantly higher for meat from castrated goat kids than that from
entire ones. Similarly, redness (a) values were significantly higher in the meat of entire goat kids. Yellowness (b) values were not significantly different in the meat of the two sexes, but castrates meat tended to have slightly higher yellowness values than entire goat kids. These were in line with the findings of Eldow (2001), however; he reported the non-significant difference between the two sex groups for the yellowness. These results are substantiated by the earlier studies of Hammond (1932) that castration decreases the intensity of the red colour of meat and also bulls had darker meat than females due to the effect of sex hormones. Wilson (1981) reported that bulls had darker meat than steers and females. Knight et al. (1999a) found that bulls had a darker Longissimus dorsi than steers; the redness and yellowness values were lower for bulls than steers.

The nature of relationships between pH and quality characteristics was consistent with those reported previously (Purchas et al., 1999), in that higher pH values were associated with darker meat. This is in line with the results of Knight et al. (1999a) and Purchas et al. (2002) that ultimate pH values were higher for bulls than steers or castrates. Similarly, Purchas and Grant (1995) found mean pH values of 5.64 and 6.07 for Friesian-cross steers and bulls, respectively. Page et al. (2001) suggested that bullock carcasses had higher muscle pH values and lower lightness (L) and redness (a) values than steers or heifers. Although there is an anomaly of high pH beef also being tender, such beef is dark in colour and will have poorer keeping qualities (Moloney, 1999).

2.8.2. Tenderness:

The tenderness of beef is a quality characteristic that is closely related to the overall acceptability of beef (Chambers and Bowers, 1993). The tenderness of a piece of beef at the time of consumption is a complex
characteristic that is determined by a range of intrinsic determinants within the muscle, many of which can be influenced not only by the genetic makeup and age of the animal, but also by many external factors. These may act during animal growth, pre-slaughter period, postmortem period, both before and after rigor mortis, and during cooking (Harper, 1999; Ferguson et al., 2001). Supporting to this, an early investigation by Lawrie (1991) showed that tenderness is affected by different factors such as age, sex and nutrition.

Physiological maturity of the carcass and tenderness are inversely related (Boleman et al., 1996). Connective tissue was found to increase with age (Damergi et al., 1998). Hunsley et al. (1971) reported that age and sex are of equal importance in affecting tenderness. Clear reduction in beef tenderness has been reported when wide ranges in age have been considered for increase in collagen cross-linking with age (Goll et al., 1964; Nishimura et al., 1999). Increases in age of 8 to 10 months may be associated with less tender beef for cattle finished on pasture, and beef from bulls is likely to be less tender than that from steers (Purchas et al., 2002). Supporting to this, Field et al. (1966) showed that beef was tougher for bull aged 600 to 699 days relative to those aged 300 to 399 days, but was tenderer for steers and heifers of similar ages.

Objective measures of tenderness also showed that beef from bulls requires higher force for the Warner Bratzler device (more toughness) than that from steers and that is due to collagen differences in beef from bulls and steers (Dikeman et al., 1986; Bosselmann et al., 1995). Similarly, Jacobs et al. (1977b) found that shear force measures indicated that bulls were slightly less tender than steers. The range in shear force in bulls was very high (6 - 14 kg/cm²) as compared to steers (6-10 kg/cm²). The overall mean of Warner-Bratzler shear force was 6.57 and 6.34 kg/cm² for bulls and steers,
respectively. However, Purchas et al. (2002) reported that the more tender beef from steers was associated with a slightly lower ultimate pH, higher myofibril fragmentation indexes and more intramuscular fat. Similar results were obtained in goats (Mohamed, 1994 and Abd Elmoula, 1996).

An increase in the level of nutrition and energy supply during the finishing period generally has a positive effect on tenderness, juiciness and flavour, which is most likely due to an increase in intramuscular fat deposition and a decrease in the heat stability of the muscle connective tissue (Moloney, 1999). Aalhus et al. (1992) have shown decreased shear force values with increasing time on feed. Mohamed (1999) indicated that shear force and connective tissues strength were significantly lower in Western Sudan Baggara bulls fed high dietary energy level compared with the bulls on low energy level and that was attributed to carcass fat level, which is known to dilute connective tissue content (Lawrie, 1991). This increase in tenderness follows the finding of Aberle et al. (1981) who showed that 70 days of intensive pre-slaughter feeding resulted in an increased percentage of soluble collagen.

An earlier investigation by Smith et al. (1976) suggested that increased quantities of subcutaneous fat or intramuscular fat increased tenderness via changes in postmortem chilling rate which further induced a potential decrease in cold shortening. Increased fat decreases the rate of temperature decline (insulation effect), enhances the activity of autolytic enzymes and thereby increases the ultimate tenderness. Following this logic Tatum (1981) questioned whether tenderness was nutritionally controlled. He reviewed the reports of several workers and concluded that although there is some indication that nutrition directly influences various intrinsic properties of postmortem muscle, the bulk of existing data suggest that intensive feeding
improves tenderness by increasing carcass weight and fatness, thereby reducing the susceptibility to rapid postmortem chilling and cold-induced toughening.

2.8.3. Juiciness:

Juiciness was included in the sensory analysis because it has been shown to be an integral component of the sensory perception of meat texture and palatability (Mathoniere et al., 2000). It has two major components. The first is the impression of wetness produced by the release of fluids from the meat during the first few chews. The second is the more sustained juiciness that apparently results from the stimulating effect of fat on the production of saliva and the coating of fat that builds up on the tongue, teeth and other parts of the mouth. It tends to be associated with marbling, hence fatter animals produce juicier beef, and it seems to decline as animal ages. However, the meat of young animals gives an initial impression of juiciness; but this is associated with a dry sensation in the mouth, because of the relative absence of fat (Moloney, 1999).

Bull beef was assessed as being less juicy and is attributed to the low level of intramuscular fat (only 30% of that of steers) compared to steers (Purchas et al., 2002). Mohamed (1994) and Eldow (2001) reported that though there was no significant difference between the cooked Longissimus dorsi muscle of entire and castrated animals, still tenderness and juiciness scores were slightly lower in the former.

2.8.4. Flavour:

The flavour of meat can be associated with either the water in the meat or the fat components of the tissue. It is influenced by the deposition of compounds from the feed in the fat of the animal (Moloney, 1999).
Cross et al. (1979) reported higher marbling scores significantly contributed to higher sensory flavour intensity. Similarly, Moloney (1999) in his report noted that as the fat content of meat increases so does flavour. Thus beef from older and castrated animals is more intense in flavour than meat from younger and intact ones. Eldow (2001) found that meat from castrated Sudan Desert lambs was rated higher for odour than that from entire ones though the difference was not significant. In case of goats, many studies were conducted to detect the presence of an abnormal odour and flavour in intact animals (taint). In most cases castration reduced these taints (Louca et al., 1977). Mohamed (1994) reported non-significant difference between castrated and entire goat kids, but the meat from castrates had less male taint than that from entire males.

However, other substances (steroids) deposited in the tissues of some mature pigs (boars) extremely affect their meat flavour (Cross, 1987). Patterson (1968) and Judge et al. (1989) reported that metabolites such as ‘5α Androst-16-en-3 one’ produced from the degeneration of testosterone hormone in mature boars are responsible for the offensive urine-like odour in their meat.

2.8.5. Water holding capacity and cooking losses:

Water holding capacity is the ability of meat to retain its own or added water during the application of an external forces such as cutting, heating, grinding or pressing (Hamm, 1960).

The low water holding capacity of a bull beef may partially explain the lower levels of tenderness for beef from bulls relative to that from steers (Purchas et al., 2002). Mohamed (1994) reported that water-holding capacity of the muscle from castrated and entire kids was not significantly different,
but castrates showed slightly lower values than entire goat kids. The same trend was observed in the percentages of cooking loss where there was no significant difference between entire and castrated kids, but it tends to increase slightly for castrated group (40 vs. 36%). Eldow (2001) found that cooking loss was not significantly different between the two sex groups but castrated lambs had slightly higher cooking loss than entire ones. A similar finding was observed in water holding capacity but the ratio was inferior in castrated lambs (1.9) compared with entire ones (1.7).
CHAPTER THREE
MATERIALS AND METHODS

3.1. The experimental animals:

Thirty entire Western Sudan Baggage bulls were selected from the commercial herd at Animal Production Research Center (A.P.R.C)-Khartoum North, for uniformity of age (2.0-2.5 years) and live body weight (175-185 kg). The commercial stock was purchased from Omdurman livestock market (Elmoalih) on the 7th of April 2003 and moved on hoof to A.P.R.C, a stressful distance of about 30 km, where the study was conducted.

The experimental study covered two periods, the adaptation period and the experimental period.

3.1.1. The adaptation period:

Following their arrival, the animals were rested, identified with ear tags and vaccinated against Anthrax, Black Quarter, Hemorrhagic Septicemia and Contagious Bovine Pleuropneumonia diseases. The animals were also sprayed and treated against external and internal parasites by Gammatox and Ivomec, respectively. Then underwent an adaptation period of three weeks to enable the animals to compensate for any previous feed restriction and to permit gut micro flora to adapt to the experimental diet as the latter was given gradually to the animals. Then it was offered as ad libitum from the mid throughout the rest of the adaptation and the experimental period.

3.2. The experimental procedures:

Following the termination of the adaptation period, the experiment was conducted between the 1st of May and 15th of August 2003 when the last animal was slaughtered. Bulls were individually weighed at the end of the adaptation period and only 24 heads were used in the experiment. The bulls were divided by stratified random sampling into two groups (12 individuals each). The groups were assigned randomly to either castrated or entire treatment. The mean live weight of the castrated group was 180.42±3.34kg and that of entire bulls was 180.83± 2.89kg. Each group was separately
penned (5.0 X 10.2 m/pen). The pens were shaded with bamboo held at 3.0m above the ground and the sides were made of iron pipes 2 inches in diameter. Pens were equipped with feeding troughs (constructed outside the pens) and watering facilities.

### 3.2.1. Castration:

A day before the start of the experiment, one of the two contemporary groups was castrated and designated as castrates, whereas the other was left intact (control).

Bloodless castration using burdizzo device of 8cm jaw size (Plate 4.1) was applied. This method was adopted to avoid wound contamination that is frequently noted with some other castration methods and because the experiment was conducted during the wet season. The instrument was used ‘under local anesthesia’ to crush and destroy the spermatic cord and blood vessels carrying blood to the testicles while the skin of the scrotum remained intact. The bull was restrained and made to lay on the ground and the tail held (Plate 4.2). One of the spermatic cords was pushed towards the scrotum wall (Plate 4.3) and the burdizzo jaws were then applied, making sure that the cord was held in one place by the cord-stops, and the handles were firmly closed at approximately 2 inches above the testicle (Plate 4.4) and left in place for 20 seconds (Plate 4.5). The procedure was repeated using a gap below the first crush (Plate 4.6) to prevent the scrotum from falling off and for the operation to be more effective, leading to the nonfunctioning and atrophy of the testicle. The same procedure was repeated on the other cord of the opposite side (Plate 1).

### 3.2.2. The experimental feed:

The experimental diet was composed of roughage and concentrate components given separately to the animals. The ingredients of the concentrate ration were weighed and mixed at the Molasses Block Factory of the A.P.R.C. The proportions made by the ingredients in the ration are listed in Table 2. Chemical composition of both concentrate feed and roughages is also shown in Table 3. All chemical analyses were performed at the Central Nutrition Research Laboratory under the auspices of A.P.R.C, according to A.O.A.C (1980) methods. Metabolizable energy (ME) content of the diet was calculated according to equation described by Ministry of Agriculture, Fisheries and Food (M.A.F.F, 1975):

\[
ME = 0.012 \; CP + 0.031 \; EE + 0.005 \; CF + 0.014 \; NFE
\]
Where, CP and the other components of the equation were expressed as g/kg DM.

3.3. The feedlot data collection:

3.3.1. Feeding and feed intake:

The animals were group-fed during the experiment. They were offered the concentrate ration once a day ‘at 8 AM’ at a level permitting free choice of feed intake ‘ad libitum’. Then sorghum stover was offered at mid-day at the rate of 1.5kg/head throughout the experimental period. Green fodder ‘Medicago sativa’ was given at a rate of 2kg/head/2weeks as a supplementary source of β-carotene (vitamin A). Daily records of total feed consumption by each group were maintained. Daily intake was calculated as the difference between the amount of feed offered and feed refused, which was collected next morning. Fresh water was freely available for the animals throughout the experimental period.

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Kg/Ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat bran</td>
<td>390</td>
</tr>
<tr>
<td>Molasses</td>
<td>520</td>
</tr>
<tr>
<td>Groundnut cake</td>
<td>50</td>
</tr>
<tr>
<td>Urea</td>
<td>30</td>
</tr>
<tr>
<td>Common salt</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1000</strong></td>
</tr>
</tbody>
</table>
Table 3. Chemical composition of the experimental diet (% of DM)

<table>
<thead>
<tr>
<th>Components</th>
<th>Molasses concentrate</th>
<th>Sorghum stover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>11.60</td>
<td>04.37</td>
</tr>
<tr>
<td>Ash</td>
<td>06.20</td>
<td>07.88</td>
</tr>
<tr>
<td>Crude protein (CP)</td>
<td>19.60</td>
<td>05.81</td>
</tr>
<tr>
<td>Crude fiber (CF)</td>
<td>04.26</td>
<td>39.00</td>
</tr>
<tr>
<td>Ether extract (EE)</td>
<td>02.12</td>
<td>02.15</td>
</tr>
<tr>
<td>Nitrogen free extract (NFE)</td>
<td>56.22</td>
<td>40.79</td>
</tr>
<tr>
<td>Metabolizable energy (Mj/Kg DM)</td>
<td>11.09</td>
<td>06.69</td>
</tr>
</tbody>
</table>

*Mj: Mega joule  
Kg: Kilogram  
DM: Dry matter

3.3.2. Live weight measurements:

3.3.2.1. Live weight gain:

During the course of the experiment, the animals were individually weighed on weekly basis using a weighbridge of 1500 kg maximum capacity load and of 5 kg division. The weighing was done in the morning before feeding.

3.3.2.2. External live animal measurements:

Linear live body measurements were recorded at the endpoint for each animal. They were taken according to the procedure modified by Green et al. (1970) and Lawrence and Fowler (1997). In this procedure, flexible steel tape and a measuring stick constructed with two sliding arms ‘caliper’ and graduated in centimeters were used for circumference and linear measurements. All measurements were taken using the tape (Plate 5.1) except height at wither, height at tip of hump, height at hips (Plate 5.2) and width of shoulder where the measuring caliper-stick was used.
Measurements were taken while the movement of the animal was restricted and its legs set squarely and the head in normal position. In addition, the surface under the animal was hard and leveled. During the procedure, the tape was pulled snugly about the animal, tightened enough to keep the hair down. The measurements that were recorded included:

- **Heart girth**: measured around the animal at the point of the smallest circumference, just behind the forelegs and posterior to the shoulder at about the 4th or 5th rib (Plate 5.1).
- **Heart girth around the hump**: the same procedure for measuring the heart girth was applied, but with the inclusion of the hump at its highest point.
- **Width of shoulders**: determined by measuring the widest horizontal width across the shoulder region using the caliper.
- **Height at withers**: measured from the highest point over the scapulae at medial plane over the spinal process of the second thoracic vertebra vertically to the ground using a measuring stick.
- **Height at tip of hump**: measured from the ground vertically to the highest point of the hump.
- **Hump base length**: measured by placing the tape from the anterior base of the hump longitudinally passing over the hump tip to the posterior base on the broadest part of the hump.
- **Height at hips**: measured from the ground vertically to the dorsal midline at the level of the two-tuber coxa (hook bones) where the arm attaches (Plate 5.2).
- **Depth of hook**: measured from the dorsal midline to the ventral tip of the tuber coxae using the flexible tape.
- **Length from patella to posterior midline**: measured from the anterior point of the patella to the posterior junction of the buttocks using the tape (Plate 5.3).
• Depth of patella from tail junction: measured from the junction of tail with the dorsal midline to the anterior point of the patella using the flexible tape (Plate 5.3).
• Body length: measured from the point of shoulder (front point of humorous) laterally to the pin bone, using the measuring flexible tape.

3.4. The slaughter procedure and slaughter data:

All the 24 experimental animals were slaughtered at a target live weight in the range of 250-265kg. Feed but not water, was withheld for 15 hours prior to slaughter to minimize gut fill so as to obtain enable a good estimate of the dressing-out percentage and to reduce the chance of carcass contamination. Local Muslims slaughtering procedure was practiced, i.e. the animal was bled ‘without stunning’ by serving the jugular veins and the carotid arteries on both sides as well as the esophagus and trachea, with a very sharp knife held by a skilful person.

3.4.1. Non-carcass components data:

When complete bleeding was achieved, the head was separated at the articulation with the atlas vertebra and weighed. Then blood was collected and weighed. The hide was cut along the limbs and down the abdomen and removed manually and weighed. The front and hind feet were removed with a knife at the proximal end of the metacarpal and metatarsal joints, respectively, and each was weighed with its hide cover. The tail was separated at the first intercoccygeal articulation and weighed as well.

Following carcass dressing, the carcass was opened by cutting through the sternum and abdomen. Then all visceral, thoracic and the genital organs were removed and weighed separately. The components of the alimentary tract were weighed with or without their contents. In addition, the mesenteric, omental, and the genital fat depots were removed and weighed. The gut fill was computed by the difference in weight of the full and empty alimentary tract. The sum of the weights of gut fill and blood was then subtracted from the slaughter weight to determine the empty body weight (E.B.W).

3.4.2. Carcass data:
Carcass assessment was carried out by different techniques including quantitative measurements, chemical analysis and subjective evaluation of cooked meat.

### 3.4.2.1. Quantitative measurements:

#### 3.4.2.1.1. Carcass weight:

The hot carcass weight was determined with the kidneys, kidney channel and pelvic fat depots in the carcass. The carcass was then split along the vertebral column into right and left sides (Plate 6.1 and 6.2), using a sharp steel saw. The carcass was stored in a chilling room at 4°C for 24 hours. The chilled or cold carcass weight was then obtained. The left side was first weighed and then prepared for fabrication by stripping off and weighing kidney and pelvic cavity fat depots. Subsequently, linear measurements were recorded and subcutaneous fat thickness measured.

#### 3.4.2.1.2. Linear carcass measurements:

Linear measurements were recorded in centimeters, on the cold left side of the carcass as it was hanged by the hind limb with the aid of a gambrel. Here the steel tape was the only measurement tool used.

- **Body length**: measured from the caudal edge of the cut pelvic bone to the midpoint of the cranial edge of the first rib (between the 7th cervical and the 1st thoracic vertebra).
- **Hind leg length**: measured from the distal end of the tarsal bone along the inside of the leg to the symphysis of the pelvis.
- **Hind leg circumference**: measured by encircling the tape around the leg at the point of the largest circumference.
- **Abdominal depth**: measured from the spinous process of the 4th abdominal vertebral to the most prominent edge of the flank joint.

#### 3.4.2.1.3. Carcass cutting:

The left side was then split between the 10th and 11th ribs to expose the *Longissimus* muscle and to yield the fore and hindquarter as well (Plate 7.2 and 7.3). The cross sectional area of the *Longissimus dorsi* muscle (rib eye) at a transverse cut on the 10th rib interface (forequarter) was traced on a...
transparent paper, and the area subsequently measured using a digital plain-meter. Then the reading was converted into square centimeters. The fat thickness over this muscle at the same site (between 10th and 11th ribs) was measured using a steel caliper at a point two-thirds of the lateral length of the rib eye muscle from the split chine bone.

Then the fore and hindquarter were subjected to further subdivisions into 8 and 6 wholesale cuts, respectively. This was applied according to the procedure of Meat and Livestock Commission for beef carcasses (M.L.C, 1974) as demonstrated in Plate 7.1 as follows:

**3.4.2.1.3.1. Forequarter wholesale cuts:**

Included: Shin, Clod, Neck, Brisket, Thin ribs, Thick ribs, Chuck and blade and the Extended roasting ribs joints. Their separation procedures were as follows:

- **Shin:** was removed from the natural joint of elbow, following the contour of the shinbone, passing through the joint, cutting across the muscle.

- **Clod and Neck:** were separated by cutting along from the posterior edge of the humorous bone to the scapular joint. The cutting was extended in a straight line separating the neck at the 6th vertebra and passing along to the dorsal edge of the forequarter. Then the two cuts were removed from each other by the natural anatomical seaming.

- **Brisket:** separated by cutting along a straight line extending from a point on the 10th rib; about 3 inches from the joint of the ribs and cartilage to the anterior removal point which was defined during the removal of the clod and neck.

- **Thick ribs (4 bones) and Extended thin ribs (6 bones):** the two cuts were separated by marking the point on the posterior edge of the 10th rib at a distance measured from the ventral tip of eye muscle and equal to the length of the eye muscle. The two cuts were removed from the carcass by a straight
cut from the already marked point to a point on the first rib measured 2 inches from the vertebral edge of the vertebral body. The thick rib cut was then separated from the extended thin ribs by a straight cut along the posterior edge of the 4\textsuperscript{th} rib.

\textit{Chuck and blade (4 bones) and Extended roasting ribs}: these were separated from each other by cutting vertically along the posterior edge of the 4\textsuperscript{th} rib, while the separation anteriorly was already achieved by removal of the neck and clod joints (Plate 7.4).

3.4.2.1.3.2. Hindquarter wholesale cuts:

Included: Hindquarter flank, Sirloin, Rump, Topside and silver, Thick flank and the Leg (Plate 7.2 and 7.3). Their separation as follows:

\textit{Hindquarter flank}: was removed by cutting along a straight line extending from a point on the 10\textsuperscript{th} rib located at a distance from the base of the rib eye muscle equal to the eye muscle length to the ventral tip of the rump muscle. It consisted of 3 ribs.

\textit{Rump}: separated by cutting along a straight line extended from a point just near of the anterior edge of the hip bone and posteriorly from a point 2 inches anterior to the aitch bone.

\textit{Sirloin}: its posterior and ventral separation was already achieved by the removal of the rump and the hindquarter flank. It included 3 ribs with the whole lumbar vertebrae.

\textit{Leg}: separated by cutting along a line passing through the stifle joint between the tibia and the femur bones.

\textit{Thick flank and Topside and silver}: these two joints existed in the femur (aitch) zone. The thick flank was removed by cutting along the ventral edge touching the femur bone, following the contour from the patella to the ventral edge of the muscle, thereby, the separation of topside and silver (Plate 7.2 and 7.3) was also achieved.
3.4.2.1.4. Joint dissection:

Each cut was weighed. The Sirloin cut was placed on a dissecting bench and dissected into lean, bones, fat and connective tissues ‘trim’ following the procedure described by Hankins and Howe (1946). Each of the four major tissues was weighed immediately after its separation using a balance of 10kg maximum capacity load to the nearest 25g and calculated as percentage of Sirloin weight.

Then the weight of each cut as a percentage of the cold half carcass weight was calculated.

Samples were taken from the *Longissimus dorsi* muscle part included in the dissected sirloin cut for chemical analysis and quality assessment.

3.4.2.2. Chemical measurements:

3.4.2.2.1. Chemical analysis:

Total moisture, protein, ether extractable fat and ash contents were determined according to (A.O.A.C, 1980) method.

3.4.2.2.2. Protein fractionation:

The fractionation procedures were carried at 4°C following the procedures described by Babiker and Lawrie (1983).

3.4.2.3. Qualitative attributes:

3.4.2.3.1. Colour determination:

Hunter Lab Tristimulus colourimeter was used for measuring the color of the *Longissimus dorsi* samples. Each sample was left to oxygenate for half an hour at 4°C before colour determination. Hunter color components L ‘lightness’, a ‘redness’ and b ‘yellowness’ were measured and recorded. Two readings were taken for every sample and then averaged.

3.4.2.3.2. Water-holding capacity (W.H.C):

Samples (1g) from the minced muscle were used. Each sample was placed on a humidified filter paper (Whatman No. 1), kept in a dessicator over saturated KCl solution and pressed between two plexiglass plates for 3 minutes at 25 kg load. The meat film area was traced with a ball pen and the filter paper was allowed to dry. Meat and loose moisture areas were measured
with a compensating plain-meter. The resulting areas covered by the meat and moisture were used to give a ratio called water-holding capacity (W.H.C) of meat. A large ratio indicates a decrease in W.H.C.

\[
W.H.C = \frac{\text{Meat and loose water area}}{\text{Meat film area}}
\]

3.4.2.3.3. pH determination:

For pH determination, a sample of 1g of lean was homogenized in 20 ml distilled water for one minute then the pH was read on a laboratory pH meter (adjusted with buffer, pH 7.0) at room temperature.

3.4.2.3.4. Cooking loss determination

Samples of Longissimus dorsi muscle were thawed at 5°C for 24 hours and weighed. Samples were cooked in plastic bags in a water bath at 80°C for 90 minutes, cooled in running tap water for 20 minutes, dried from fluids and reweighed. Cooking loss was determined as the loss in weight during cooking and expressed as a percent of pre-cooking weight:

\[
\text{Cooking loss} = \frac{(\text{Weight before cooking} - \text{Weight after cooking})}{\text{Weight before cooking}} \times 100
\]

3.4.2.3.5. Subjective quality evaluation:

The sensory evaluation was conducted in A.P.R.C at the Meat Technology Research Unit. Frozen Longissimus dorsi muscle samples representing 9 animals from each group (18 samples) were thawed at 4°C (overnight) and wrapped in aluminum foil, roasted in electric oven at 180°C for 1 hour (Griffin et al., 1985). The samples were presented to semi-trained panelists (N=10), each of whom evaluated 9 animal samples from each of the two groups over 3 respective days with 6 samples being evaluated by each panelist in each session. Scoring was made on a
hedonic scale of 4-5 points (Appendix 9). Tap water at room temperature was available to remove the remaining flavour of the previous samples. The scores were averaged for each character and the average gave the quality attribute of the particular parameter mentioned.

3.5. Statistical procedures:

The data were examined by the Student t-test for independent samples to reveal the significance of the differences between the two treatments. All analyses followed the procedures described by a commercial statistical package (Statistica, 1995).
CHAPTER FOUR
RESULTS

4.1 Feedlot performance:

Data related to the performance of intact and castrated Western Sudan Baggara bulls in feedlot are shown in Table 4.

On similar level of feeding intact bulls took significantly (P<0.05) shorter duration to attain the target slaughter weight than castrated bulls. However, the daily rate of gain was not significantly different between the two groups but entire bulls had slightly higher growth rate than the castrated ones.

In spite of the longer feeding period for castrates, still there were no statistical differences between the two groups in all the parameters of feed intake. However, total roughage intake was significantly (P<0.05) different between the two groups; castrated bulls consumed more roughage than their counterpart.

The feed conversion ratio, though not significantly different between the intact and castrated bulls, was slightly lower in the intact animals (Table 4).

4.2. External live body measurements:

The effect of castration on external live body measurements of Western Sudan Baggara bulls is shown in Table 5. There were no significant differences between the intact and castrated bulls in heart girth, height at withers, height at hips, depth of hook and body length, however, significant differences (P<0.05) were detected in the measurements width of shoulder
and hump base length, where intact bulls had higher values than the castrated ones. On the other hand, significant differences (P<0.05) were also proved for

Table 4. Feedlot performance of the intact (entire) and castrated Western Sudan Baggara bulls

<table>
<thead>
<tr>
<th>Item</th>
<th>Mean ± S.D.</th>
<th>L.S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Entire</td>
<td>Castrated</td>
</tr>
<tr>
<td>Number of animals</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Initial live weight (kg)</td>
<td>180.83 ± 02.89</td>
<td>180.42 ± 3.34</td>
</tr>
<tr>
<td>Slaughter weight (kg)</td>
<td>258.33 ± 03.89</td>
<td>258.33 ± 3.26</td>
</tr>
<tr>
<td>Experimental period (days)</td>
<td>089.00 ± 11.24</td>
<td>096.33 ± 9.44</td>
</tr>
<tr>
<td>Total gain (kg/head)</td>
<td>077.50 ± 02.61</td>
<td>077.92 ± 2.57</td>
</tr>
<tr>
<td>Rate of gain (kg/head/day)</td>
<td>000.89 ± 00.13</td>
<td>000.82 ± 0.08</td>
</tr>
<tr>
<td>DM intake:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daily concentrate intake (kg/head)</td>
<td>006.24 ± 00.34</td>
<td>006.20 ± 00.26</td>
</tr>
<tr>
<td>Daily roughage intake (kg/head)</td>
<td>001.43 ± 00.00</td>
<td>001.43 ± 00.00</td>
</tr>
<tr>
<td>Total concentrate intake (kg/head)</td>
<td>556.79 ± 83.53</td>
<td>597.50 ± 62.91</td>
</tr>
<tr>
<td>Total roughage intake (kg/head)</td>
<td>127.67 ± 16.12</td>
<td>138.19 ± 13.54</td>
</tr>
<tr>
<td>Total DM intake (kg/head)</td>
<td>684.46 ± 99.06</td>
<td>735.69 ± 75.46</td>
</tr>
<tr>
<td>Daily DM intake (kg/head)</td>
<td>007.67 ± 00.34</td>
<td>007.64 ± 00.26</td>
</tr>
<tr>
<td>Total DM intake as % of slaughter weight</td>
<td>002.97 ± 00.16</td>
<td>002.96 ± 00.11</td>
</tr>
<tr>
<td>Feed conversion ratio (kg DM feed/kg live wt. gain)</td>
<td>008.85 ± 01.41</td>
<td>009.44 ± 00.97</td>
</tr>
</tbody>
</table>

In this and subsequent tables,
L.S = level of significance          * = Significant at P<0.05
N.S = Not significant.               ** = Significant at P<0.01
S.D = Standard deviation            *** = Significant at P<0.001
Table 5. External live body measurements (cm) of the intact and castrated Western Sudan Baggara bulls

<table>
<thead>
<tr>
<th>Trait</th>
<th>Mean ± S.D. Entire</th>
<th>Mean ± S.D. Castrated</th>
<th>L.S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of animals</td>
<td>12</td>
<td>12</td>
<td>-</td>
</tr>
<tr>
<td>Slaughter weight (kg)</td>
<td>258.33 ± 3.89</td>
<td>258.33 ± 3.26</td>
<td>N.S</td>
</tr>
<tr>
<td>Heart girth</td>
<td>147.75 ± 1.56</td>
<td>147.33 ± 1.56</td>
<td>N.S</td>
</tr>
<tr>
<td>Heart girth around the hump</td>
<td>163.58 ± 1.02</td>
<td>160.67 ± 1.61</td>
<td>***</td>
</tr>
<tr>
<td>Width of shoulders</td>
<td>030.13 ± 2.28</td>
<td>028.75 ± 1.14</td>
<td>*</td>
</tr>
<tr>
<td>Height at withers</td>
<td>116.44 ± 4.05</td>
<td>115.17 ± 2.71</td>
<td>N.S</td>
</tr>
<tr>
<td>Height at tip of hump</td>
<td>122.54 ± 2.57</td>
<td>119.63 ± 3.08</td>
<td>**</td>
</tr>
<tr>
<td>Hump base length</td>
<td>027.83 ± 5.17</td>
<td>023.79 ± 2.75</td>
<td>*</td>
</tr>
<tr>
<td>Height at hips</td>
<td>120.25 ± 2.44</td>
<td>120.00 ± 3.52</td>
<td>N.S</td>
</tr>
<tr>
<td>Depth of hook</td>
<td>014.13 ± 1.05</td>
<td>014.67 ± 0.81</td>
<td>N.S</td>
</tr>
<tr>
<td>Length from patella to posterior midline</td>
<td>039.71 ± 2.01</td>
<td>041.42 ± 2.40</td>
<td>*</td>
</tr>
<tr>
<td>Depth of patella from tail junction</td>
<td>058.13 ± 2.15</td>
<td>060.50 ± 3.91</td>
<td>*</td>
</tr>
<tr>
<td>Body length</td>
<td>119.21 ± 5.66</td>
<td>121.04 ± 3.59</td>
<td>N.S</td>
</tr>
</tbody>
</table>
the measurements length from patella to posterior midline (Figure. 1) and depth of patella from tail junction, where intact bulls scored lower values for these measurements than the castrated bulls. Intact bulls had significantly higher values than the castrated group for heart girth around the hump (P<0.001) and height at tip of hump (P<0.01).

4.3. Non-carcass components:

Table 6 shows the non-carcass components of the two groups. As a proportion of the empty body weight (E.B.W), the total weight of the reproductive organs (including genital fat) was not significantly different between the intact and castrated bulls. However, testicles and penis were significantly heavier (P<0.001) in entire than the castrated bulls. There was also a significant difference (P<0.001) between the two groups in the weight of the genital fat that was heavier in the castrated than the intact bulls.

Mesenteric fat (P<0.01) and omental fat (P<0.001) as well as kidney and pelvic fat (P<0.01) depots were significantly heavier in the castrated than entire bulls. On the other hand, the weight of blood, four feet, tail and the other visceral organs (Table 6) were not significantly different between the two groups. However, the head was significantly (P<0.05) heavier in the intact than castrated bulls. The hide; though it was not significantly different between the experimental groups, it was slightly heavier in the entire group than in the castrated group.

4.4 Carcass characteristics:

4.4.1 Carcass measurements:

As seen in Table 7 all linear measures studied here with the exception of subcutaneous fat thickness showed non-significant differences between the
Figure (1) External Live Boy Measurements (cm)

Length from Patella to Posterior Midline (L.P.M) & The Hump Base Length (H. B)

- **Intact Bulls**
  - Mean+SD = 27.83+5.17
  - Mean-SD = 27.83-5.17
  - Mean = 27.83

- **Castrated Bulls**
  - Mean+SD = 39.71+2.01
  - Mean-SD = 39.71-2.01
  - Mean = 39.71

- **Intact Bulls**
  - Mean+SD = 23.79+2.75
  - Mean-SD = 23.79-2.75
  - Mean = 23.79

- **Castrated Bulls**
  - Mean+SD = 41.42+2.40
  - Mean-SD = 41.42-2.40
  - Mean = 41.42
Table 6. Non-carcass components of the intact and castrated Western Sudan Bagbara bulls (as percentage of empty body weight)

<table>
<thead>
<tr>
<th>Components</th>
<th>Mean ± S.D. Entire</th>
<th>Mean ± S.D. Castrated</th>
<th>L.S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of animals</td>
<td>12</td>
<td>12</td>
<td>-</td>
</tr>
<tr>
<td>Blood</td>
<td>04.84 ± 0.43</td>
<td>04.90 ± 0.40</td>
<td>N.S</td>
</tr>
<tr>
<td>Head</td>
<td>06.92 ± 0.45</td>
<td>06.56 ± 0.38</td>
<td>*</td>
</tr>
<tr>
<td>Hide</td>
<td>08.57 ± 0.52</td>
<td>08.36 ± 0.86</td>
<td>N.S</td>
</tr>
<tr>
<td>Four feet</td>
<td>02.83 ± 0.27</td>
<td>02.73 ± 0.19</td>
<td>N.S</td>
</tr>
<tr>
<td>Stomach weight (full)</td>
<td>16.91 ± 1.51</td>
<td>18.06 ± 1.95</td>
<td>N.S</td>
</tr>
<tr>
<td>Intestine weight (full)</td>
<td>05.20 ± 0.78</td>
<td>04.87 ± 0.73</td>
<td>N.S</td>
</tr>
<tr>
<td>Stomach weight (empty)</td>
<td>04.03 ± 0.36</td>
<td>04.20 ± 0.38</td>
<td>N.S</td>
</tr>
<tr>
<td>Intestine weight (empty)</td>
<td>02.84 ± 0.24</td>
<td>02.74 ± 0.28</td>
<td>N.S</td>
</tr>
<tr>
<td>Reproductive organs</td>
<td>00.90 ± 0.19</td>
<td>00.85 ± 0.04</td>
<td>N.S</td>
</tr>
<tr>
<td>Testicles</td>
<td>00.16 ± 0.06</td>
<td>00.03 ± 0.01</td>
<td>***</td>
</tr>
<tr>
<td>Penis</td>
<td>00.25 ± 0.03</td>
<td>00.16 ± 0.02</td>
<td>***</td>
</tr>
<tr>
<td>Genital fat</td>
<td>00.50 ± 0.12</td>
<td>00.67 ± 0.05</td>
<td>***</td>
</tr>
<tr>
<td>Mesenteric fat</td>
<td>00.42 ± 0.12</td>
<td>00.55 ± 0.15</td>
<td>**</td>
</tr>
<tr>
<td>Omental fat</td>
<td>00.96 ± 0.25</td>
<td>01.44 ± 0.37</td>
<td>***</td>
</tr>
<tr>
<td>Kidney weight</td>
<td>00.57 ± 0.17</td>
<td>00.54 ± 0.08</td>
<td>N.S</td>
</tr>
<tr>
<td>Kidney fat</td>
<td>01.26 ± 0.37</td>
<td>01.86 ± 0.51</td>
<td>**</td>
</tr>
<tr>
<td>Pelvic fat</td>
<td>00.27 ± 0.09</td>
<td>00.37 ± 0.08</td>
<td>**</td>
</tr>
<tr>
<td>Liver</td>
<td>01.59 ± 0.41</td>
<td>01.77 ± 0.18</td>
<td>N.S</td>
</tr>
<tr>
<td>Heart</td>
<td>00.47 ± 0.06</td>
<td>00.47 ± 0.06</td>
<td>N.S</td>
</tr>
<tr>
<td>Tail</td>
<td>00.42 ± 0.06</td>
<td>00.40 ± 0.03</td>
<td>N.S</td>
</tr>
<tr>
<td>Lungs and trachea</td>
<td>01.72 ± 0.49</td>
<td>01.74 ± 0.24</td>
<td>N.S</td>
</tr>
<tr>
<td>Diaphragm</td>
<td>00.66 ± 0.04</td>
<td>00.65 ± 0.03</td>
<td>N.S</td>
</tr>
<tr>
<td>Spleen</td>
<td>00.42 ± 0.06</td>
<td>00.42 ± 0.07</td>
<td>N.S</td>
</tr>
<tr>
<td>Pancreas</td>
<td>00.17 ± 0.11</td>
<td>00.13 ± 0.02</td>
<td>N.S</td>
</tr>
</tbody>
</table>
Table 7. Linear carcass measurements of the intact and castrated Western Sudan Baggar bulls

<table>
<thead>
<tr>
<th>Item</th>
<th>Mean ± S.D.</th>
<th>L.S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Entire</td>
<td>Castrated</td>
</tr>
<tr>
<td>Number of animals</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Carcass length (cm)</td>
<td>113.88 ± 2.59</td>
<td>113.83 ± 2.63</td>
</tr>
<tr>
<td>Leg length (cm)</td>
<td>072.63 ± 1.40</td>
<td>072.25 ± 1.82</td>
</tr>
<tr>
<td>Leg circumference (cm)</td>
<td>092.92 ± 4.25</td>
<td>095.33 ± 5.61</td>
</tr>
<tr>
<td>Abdominal depth (cm)</td>
<td>078.33 ± 4.12</td>
<td>079.75 ± 4.59</td>
</tr>
<tr>
<td>Rib eye area (cm²)</td>
<td>049.65 ± 6.58</td>
<td>048.57 ± 5.57</td>
</tr>
<tr>
<td>S/C fat thickness (mm)</td>
<td>003.83 ± 0.49</td>
<td>006.04 ± 0.78</td>
</tr>
</tbody>
</table>
entire and castrated bulls. The values for leg circumference and the abdominal depth were slightly lower in the entire than in the castrates. The rib eye area (R.E.A) was not significantly different between the two groups, but was slightly larger in the intact bulls (Figure 2). On the other hand, the difference between the two groups in subcutaneous fat thickness was significant (P<0.001) where castrated bulls had a thicker subcutaneous fat than the entire ones (Plate 6.1, 6.2, 7.2 & 7.3).

4.4.2 Carcass yield:

The data pertaining to empty body weight (E.B.W) and dressing percentages are given in Table 8. With the exception of the chilled dressing percentage (on E.B.W basis), hot and cold carcass weights and all the dressing percentages showed non-significant difference between the entire and castrated bulls. Chilled dressing percentage was significantly higher (P<0.05) for the castrated group. The same trend was observed for E.B.W and the hot dressing percentage on E.B.W basis. However, chiller shrinkage percentage decreased significantly (P<0.001) with castration.

4.4.2.1 Wholesale cuts yield:

Table 9 shows the yield of the wholesale cuts from carcasses of entire and castrated bulls. As a percent of the cold half carcass weight, the weights of the neck and chuck and blade were significantly (P<0.05) heavier in entire than castrated bull carcasses. However, the other wholesale cuts showed no significant difference between the two experimental groups, though the brisket, sirloin, rump and thick rib percentages tend to increase slightly in the castrated group.
4.4.2.2 Carcass composition:

Table 10 shows the composition of the sirloin cut as percentages of its weight. The muscle tissue was significantly (P<0.05) higher in entire bulls,
Table 8. Carcass yield and characteristics of the intact and castrated Western Sudan Baggara bulls

<table>
<thead>
<tr>
<th>Item</th>
<th>Mean ± S.D.</th>
<th>L.S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Entire</td>
<td>Castrated</td>
</tr>
<tr>
<td>Number of animals</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Slaughter weight (kg)</td>
<td>258.33 ± 3.89</td>
<td>258.33 ± 3.26</td>
</tr>
<tr>
<td>Empty body weight (kg)</td>
<td>215.68 ± 4.66</td>
<td>213.74 ± 3.94</td>
</tr>
<tr>
<td>Empty body weight (%)</td>
<td>083.49 ± 1.25</td>
<td>082.74 ± 1.51</td>
</tr>
<tr>
<td>Hot carcass weight (kg)</td>
<td>136.59 ± 5.35</td>
<td>137.58 ± 3.69</td>
</tr>
<tr>
<td>Cold carcass weight (kg)</td>
<td>132.91 ± 5.36</td>
<td>135.08 ± 3.54</td>
</tr>
<tr>
<td>Chiller shrinkage (%)</td>
<td>002.70 ± 0.39</td>
<td>001.82 ± 0.27</td>
</tr>
<tr>
<td>Cold carcass side weight (kg)</td>
<td>067.92 ± 3.05</td>
<td>068.44 ± 1.81</td>
</tr>
<tr>
<td>Hot dressing % (Slaughter wt base)</td>
<td>052.87 ± 1.84</td>
<td>053.27 ± 1.77</td>
</tr>
<tr>
<td>Hot dressing % (Empty body wt base)</td>
<td>063.33 ± 2.14</td>
<td>064.38 ± 1.60</td>
</tr>
<tr>
<td>Chilled dressing % (Slaughter wt base)</td>
<td>051.45 ± 1.86</td>
<td>052.30 ± 1.70</td>
</tr>
<tr>
<td>Chilled dressing % (Empty body wt base)</td>
<td>061.63 ± 2.15</td>
<td>063.20 ± 1.48</td>
</tr>
<tr>
<td>Gut fill %</td>
<td>014.98 ± 1.66</td>
<td>016.00 ± 2.16</td>
</tr>
</tbody>
</table>
Table 9. Carcass components (wholesale cuts) of the intact and castrated Western Sudan Baggara bulls (as percentage of cold side weight)

<table>
<thead>
<tr>
<th>Components</th>
<th>Mean ± S.D.</th>
<th>L.S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Entire</td>
<td>Castrated</td>
</tr>
<tr>
<td>Number of carcasses</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Shin</td>
<td>03.33 ± 0.23</td>
<td>03.22 ± 0.15</td>
</tr>
<tr>
<td>Neck</td>
<td>06.46 ± 0.78</td>
<td>05.89 ± 0.57</td>
</tr>
<tr>
<td>Clod</td>
<td>05.64 ± 0.22</td>
<td>05.75 ± 0.39</td>
</tr>
<tr>
<td>Chuck and blade</td>
<td>11.10 ± 1.02</td>
<td>10.44 ± 0.50</td>
</tr>
<tr>
<td>Extended roasting ribs</td>
<td>06.79 ± 0.66</td>
<td>06.63 ± 0.58</td>
</tr>
<tr>
<td>Thick rib</td>
<td>05.49 ± 0.54</td>
<td>05.72 ± 0.43</td>
</tr>
<tr>
<td>Thin rib</td>
<td>03.23 ± 0.21</td>
<td>03.35 ± 0.19</td>
</tr>
<tr>
<td>Brisket</td>
<td>08.17 ± 0.76</td>
<td>08.60 ± 0.75</td>
</tr>
<tr>
<td>Thin flank</td>
<td>06.25 ± 0.56</td>
<td>06.43 ± 0.52</td>
</tr>
<tr>
<td>Thick flank</td>
<td>05.13 ± 0.45</td>
<td>04.93 ± 0.33</td>
</tr>
<tr>
<td>Leg</td>
<td>05.39 ± 0.46</td>
<td>05.21 ± 0.29</td>
</tr>
<tr>
<td>Sirloin</td>
<td>06.47 ± 0.54</td>
<td>06.80 ± 0.46</td>
</tr>
<tr>
<td>Rump</td>
<td>07.16 ± 0.38</td>
<td>07.37 ± 0.23</td>
</tr>
<tr>
<td>Topside and silver</td>
<td>17.45 ± 0.90</td>
<td>17.36 ± 0.74</td>
</tr>
</tbody>
</table>
Table 10. Composition of high priced wholesale cut (Sirloin) as percentage of its weight (kg)

<table>
<thead>
<tr>
<th>Item</th>
<th>Mean ± S.D.</th>
<th>L.S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Entire</td>
<td>Castrated</td>
</tr>
<tr>
<td>Number of samples</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Muscle</td>
<td>64.87 ± 1.93</td>
<td>62.73 ± 3.38</td>
</tr>
<tr>
<td>Bone</td>
<td>22.94 ± 1.19</td>
<td>22.24 ± 2.67</td>
</tr>
<tr>
<td>Fat</td>
<td>05.36 ± 0.92</td>
<td>08.96 ± 1.34</td>
</tr>
<tr>
<td>C.T</td>
<td>06.09 ± 0.71</td>
<td>05.61 ± 0.85</td>
</tr>
<tr>
<td>Muscle: bone</td>
<td>02.84 ± 0.20</td>
<td>02.87 ± 0.49</td>
</tr>
<tr>
<td>Muscle: fat</td>
<td>12.48 ± 2.51</td>
<td>07.18 ± 1.37</td>
</tr>
<tr>
<td>Muscle: (fat + C.T)</td>
<td>05.75 ± 0.82</td>
<td>04.36 ± 0.64</td>
</tr>
<tr>
<td>Bone: fat</td>
<td>04.39 ± 0.79</td>
<td>02.52 ± 0.37</td>
</tr>
</tbody>
</table>

C.T = Connective Tissue proper
while the fat percent was significantly higher (P<0.001) in castrated than in entire animals (Plate 7.4). The bones as well as the connective tissue (C.T) percentages were not significantly different between the two groups (Figure 3).

Similarly, muscle to bone ratio was not significantly different between the two groups. The muscle to fat, muscle to (fat + C.T) and bone to fat ratios were significantly higher (P<0.001) in the entire than in castrated bull calves.

4.5 Meat chemical composition:

The chemical composition of the Longissimus dorsi muscle of both the entire and castrated bulls is shown in Table 11.

Entire bull muscles had significantly higher moisture and protein (P<0.05), fat and ash (P<0.001) percentages. Sarcoplasmic, myofibrillar and non-protein nitrogen concentrations were also significantly higher (P<0.001) in the intact bulls. The muscle pH was significantly different between the two groups (P<0.01) where it was higher in the entire than the castrated one. However, soluble protein was similar in the intact and castrated bulls.

4.6 Meat quality attributes:

Table 12 shows the meat quality attributes for the two groups. Hunter lightness (L) values were significantly (P<0.001) lower for entire than the castrated group, while redness (a) value was higher (P<0.05) in the entire bulls. However, yellowness (b) was not significantly different between the two experimental groups. Values of water holding capacity (W.H.C) and
cooking loss were significantly higher (P<0.001) in entire bulls than in castrates.

The subjective evaluation of meat quality of the cooked *Longissimus dorsi* muscle obtained from the intact and castrated bulls are also presented in Table 12. Castrates had significantly (P<0.05) higher scores for juiciness and overall acceptability than that obtained from entire bulls. Differences in colour, flavour and tenderness were not significant.
Figure. (3) Sirloin Composition (%)

<table>
<thead>
<tr>
<th>Muscles</th>
<th>Fats</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intacts</td>
<td>5.36</td>
<td>64.87</td>
</tr>
<tr>
<td>Castrates</td>
<td>8.96</td>
<td>62.73</td>
</tr>
</tbody>
</table>
Table 11. Meat chemical composition\(^1\) of the intact and castrated Western Sudan Baggara bulls

<table>
<thead>
<tr>
<th>Item</th>
<th>Mean ± S.D.</th>
<th>L.S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Entire</td>
<td>Castrated</td>
</tr>
<tr>
<td>Number of samples</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>75.24 ± 0.37</td>
<td>74.94 ± 0.21</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>21.07 ± 0.31</td>
<td>20.86 ± 0.21</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>02.54 ± 0.13</td>
<td>02.92 ± 0.10</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>01.05 ± 0.04</td>
<td>00.96 ± 0.06</td>
</tr>
<tr>
<td>Sarcoplasmic protein (%)</td>
<td>05.90 ± 0.12</td>
<td>05.32 ± 0.19</td>
</tr>
<tr>
<td>Myofibrillar protein (%)</td>
<td>12.04 ± 0.13</td>
<td>11.81 ± 0.14</td>
</tr>
<tr>
<td>Non-protein nitrogen (%)</td>
<td>00.46 ± 0.01</td>
<td>00.45 ± 0.01</td>
</tr>
<tr>
<td>Soluble protein (%)</td>
<td>00.51 ± 0.02</td>
<td>00.51 ± 0.01</td>
</tr>
<tr>
<td>Muscle pH</td>
<td>05.88 ± 0.20</td>
<td>05.68 ± 0.17</td>
</tr>
</tbody>
</table>

\(^1\) as percentage of fresh Longissimus dorsi muscle sample weight
Table 12. Meat quality attributes of the intact and castrated animals

<table>
<thead>
<tr>
<th>Item</th>
<th>Mean ± S.D. Entire</th>
<th>Mean ± S.D. Castrated</th>
<th>L.S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of samples</td>
<td>12</td>
<td>12</td>
<td>-</td>
</tr>
<tr>
<td>Colour:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>34.26 ± 0.63</td>
<td>36.39 ± 0.51</td>
<td>***</td>
</tr>
<tr>
<td>a</td>
<td>17.29 ± 0.49</td>
<td>16.95 ± 0.46</td>
<td>*</td>
</tr>
<tr>
<td>b</td>
<td>06.43 ± 0.36</td>
<td>06.49 ± 0.44</td>
<td>N.S</td>
</tr>
<tr>
<td>Water holding capacity (ratio b)</td>
<td>02.88 ± 0.15</td>
<td>02.36 ± 0.16</td>
<td>***</td>
</tr>
<tr>
<td>Cooking loss (%)</td>
<td>36.42 ± 0.54</td>
<td>34.41 ± 0.60</td>
<td>***</td>
</tr>
<tr>
<td>Subjective evaluation c:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colour</td>
<td>03.00 ± 1.05</td>
<td>02.90 ± 1.10</td>
<td>N.S</td>
</tr>
<tr>
<td>Flavour</td>
<td>03.00 ± 0.82</td>
<td>03.30 ± 0.67</td>
<td>N.S</td>
</tr>
<tr>
<td>Juiciness</td>
<td>02.40 ± 0.84</td>
<td>03.30 ± 0.82</td>
<td>*</td>
</tr>
<tr>
<td>Tenderness</td>
<td>03.00 ± 0.82</td>
<td>03.30 ± 0.67</td>
<td>N.S</td>
</tr>
<tr>
<td>Overall acceptability</td>
<td>03.40 ± 1.26</td>
<td>04.30 ± 0.67</td>
<td>*</td>
</tr>
</tbody>
</table>

**Colour:**  

\[ L \] = degree of lightness  
\[ a \] = degree of redness  
\[ b \] = degree of yellowness

\( b \). The greater the ratio the lower is the water holding capacity.

\( c \). Longissimus dorsi muscle samples were used.
CHAPTER FIVE
DISCUSSION

5.1. Growth rate:

As shown in Table 4, entire bulls gained 0.07 kg/day more than the castrated ones, however a significant difference between the two groups was not perceived. This result is in agreement with the findings of Grings et al. (2001) that steers gained 0.09 kg/day less than bulls and that the difference between the two groups was not significant. Berg and Butterfield (1976) reported live weight gain of 1.07, 0.98 and 0.87 kg/day for bulls, steers and heifers, respectively. This low weight gain could probably be ascribed to the effect of age at castration, which was delayed in these studies (post-puberty). This is substantiated by ZoBell et al. (1993) and Heaton et al. (2004) who suggested delayed castration of beef calves as a mean to improve live animal performance and the rib-eye area. Similarly, Knight et al. (1999b) found post-pubertal castrates could capture some of the live weight advantages of bulls while still getting the carcass and meat characteristics of steers. On the other hand, many investigations presented evidence for the significantly faster gain of bulls as compared to steers (Klosterman et al., 1954; Williams et al., 1965; Purchas et al., 2002). This might be due to the fact that castration was performed at earlier ages in these experiments.

The reduction in growth rate of castrates either in the current or the mentioned investigations might be due to the adverse effect of castration on the animal’s hormonal status. The androgen testosterone is an extremely potent growth stimulant. The higher expected level of such hormone
circulating in the blood of intact bulls might have a direct contribution to the increase in growth rate of the intact animals. This is in agreement with the finding of Lee et al. (1990) that bulls had sufficient endogenous anabolic steroids for maximum growth. Supporting to this, Arnold et al. (1997) related the greater muscle growth capacity in intact males to the presence of testicular hormones.

5.2. Feed conversion ratio:

In spite of the non-significant difference, castration had a reduction effect on feed conversion efficiency, where intact males were 3.23% more efficient than castrates (Table 4). This could be attributed to the effect of testosterone hormone that is known to increase the efficiency of nitrogen utilization from diet (Lawrence and Fowler, 1997). This ultimately increases muscle protein accretion in intact bulls and reduces muscle protein degradation in castrated ones. However, the direct mechanism by which castration alters protein turnover remains unclear (Morgan et al., 1993). This is in agreement with the finding in other species that castrated males converted feed into live body weight less efficiently than entire ones (Babiker et al., 1985; Mohamed, 1994; Eldow, 2001). Grings et al. (2001) found that feed efficiency averaged 14g more live weight gain per kg DMI for bulls compared to steers. Similarly, Newman et al. (1990) reported that castration reduced feed conversion efficiency by 13%.

5.3. Experimental period:

Since the experimental animals were slaughtered to the same live weight (258 kg), neither the slaughter weight nor the live weight gains showed significant difference between the intact and castrated bulls (Table 4). However, a pronounced effect of castration on the experimental period was proved. Intact bulls took significantly (P<0.05) shorter duration to attain the
target slaughter weight than the castrated ones. This is probably related to the slightly inferior growth rate and feed conversion efficiency of castrated bulls though no significant differences were obtained for these two parameters between the two animal groups as had been discussed previously.

This result parallels the implication of Grings et al. (2001) that steers required 12 more days to reach 386 kg live body weight than bulls. Klosterman et al. (1954) agreed that bulls had higher slaughter weight than steers. Eldow (2001) showed that slaughter weight among the entire and castrated lambs was significantly different, where entire lambs were heavier (36.87kg) than castrates (34.47kg).

5.4. External live body measurements:

The effect of castration on the external live body measurements in the present study is shown in Table 5. Non-significant differences were detected between the two groups in the measurements heart girth, height at withers, height at hips, depth of hook and body length. This is in line with the findings of Purchas et al. (2002) that wither heights did not differ significantly between treatment groups when values were adjusted to the same live weight. Rahama (1996) reported that weight gain and withers height were higher in males than females, however, significant results were not obtained.

On the other hand, intact bulls exhibited significantly (P<0.05) higher scores for the measurements shoulder width and hump base length and further higher significant differences (P<0.001) for the heart girth around the hump and height at tip of hump (P<0.01) than the castrated bulls. However, castrates had significantly (P<0.05) higher values for the distance from patella to posterior midline (Fig. 1 and Appendix 6) and depth of patella from tail junction than the entire ones.
This result may be due to the effect of castration on hormonal status, which is responsible of phenotypic changes and characteristics, that make the male differs from the female. This is obvious, as intact males have relatively greater muscle in the forequarter, especially those in the neck and crest region (for reproductive purposes) than females or castrates (Judge et al., 1989 and Brandstetter et al., 2000). Similarly, Cosgrove et al. (1996) found that during finishing, castrates retained the high eye muscle area, but lost the pronounced neck musculature of bulls. However, a conclusive explanation for the allometric growth of certain muscles is lacking (Brandstetter et al., 2000).

5.5. Non-carcass components:

Table 6 reveals the characteristics of non-carcass components of the two groups. The total weight of the reproductive organs, including genital fat, was not significantly different between the intact and castrated bulls. This could be due to marked development of genital fat in the castrated animals in order to compensate for the significantly low weight of the testicles and penis, which degenerated as a result of castration (Appendix 5).

There was a significant difference between the two groups in the amount of kidney, pelvic, mesenteric and omental fat depots, which were significantly heavier in, castrated than intact bulls. This is because castration enhanced fat accretion; and resulted in differences in maturity where castrated bulls attain maturity earlier than entire bulls.

The findings of the present study are in accord with the findings of Elshafie (1965) that the mesenteric and kidney fat depots weighed 13.4g for the castrated and 9.1g for the non-castrated Butana calves. In support to this finding, Landon et al. (1978) stated that steers would tend to possess greater kidneys, pelvic and heart fat depots than bulls. Similarly, Grings et al. (2001)
reported that the weight of the latter fat depots in bulls averaged 71% of that of steers.

On the other hand, the weights of blood, four feet, tail and the other visceral organs (Table 6) were not significantly different between the two groups. The hide, though not significantly different, it was slightly heavier in the entire group than in the castrated one. However, The head was significantly (P<0.05) heavier in the intact than in the castrated bulls, which is probably due to the effect of testosterone hormone in increasing muscle tissue of intact bulls. Similar trends were evident for other species. Mahgoub and Lodge (1994) reported that ram lambs had heavier heads, feet, reticulum-rumens and livers but lower non-carcass fat than wether and ewe lambs. Supporting to this, Mohamed (1994) reported that the non-carcass components as percentage of empty body weight showed no significant differences for head, skin, feet, heart, lungs and trachea, liver, spleen, empty rumen, intestine and kidney, but these values tended to be slightly higher in entire Desert goat kids than in castrates.

5.6. Carcass characteristics:
5.6.1. Carcass weight and dressing out percentage:

There was no significant treatment difference in either hot or cold carcass weight (Table 8). This is probably because the animals were slaughtered at the same target weight. A slight increase in cold carcass weight of castrates was observed (2.17 kg). This could be explained by the result of the present study that castration significantly (P<0.001) reduced the percentage of carcass shrinkage (Table 8). This might be due to the insulation effect of the thicker subcutaneous fat of castrated bull carcasses (Plate 6.1 and
7.3) in reducing evaporation (Lawrie, 1991) compared to that of intact ones (Plate 6.2 and 7.2).

There are no significant differences due to castration on hot dressing percent either on slaughter weight or empty body weight basis (Table 8). Similar trends are observed for the cold carcass dressing percent on slaughter weight basis, but not on empty body weight basis where the dressing percentage was significantly (P<0.05) higher in the castrated bulls than the intact ones. This could partially be due to the increase in the weight of the non-carcass components of the intact bulls and to the fact that castrates were fatter than entire bulls, the matter that acquired the former resistance to chilling shrinkage. This was in accord with Elshafie (1965); Mohamed (1994); Elbayoumi and Elsheikh (1989) that dressing out percentage, although not significantly different, was slightly greater in castrates than in entire animals. However, Purchas and Grant (1995) and Purchas et al. (2002) found significantly higher dressing percentages for bulls compared to steers. This difference might be attributed to the effect of age at castration and to the length of finishing period.

5.6.2. Wholesale cuts yield:

There were no significant differences between treatment in the percentages of wholesale cuts probably because carcass weight was similar in intact and castrated bulls. The percentages made by the neck and chuck and blade joints from the carcass were significantly higher (P<0.05) in intact than castrated bulls (Table 9). These differences could be ascribed to the marked development of musculature in intact male because of testosterone secretion. The difference was marked in the neck and crest including the hump (Judge et al., 1989 and Brandstetter et al., 2000). Similarly, Cosgrove et al. (1996)
found that during finishing, castrates lost the pronounced neck musculature of bulls.

5.6.3. Carcass composition:

5.6.3.1. Subcutaneous fat and rib eye area:

Castration had a pronounced effect on the deposition of carcass fat in the present study. Table 7 revealed that castrated bulls deposited significantly (P<0.001) more subcutaneous fat than intact bulls. However, a slight reduction effect of castration on the rib eye area was observed. This is probably related to the suppression effect of castration on testosterone hormone, which enhances muscle growth.

The present result is in agreement with the findings of many investigators that bulls had less subcutaneous fat and greater Longissimus muscle area than steers (Reiling et al., 1992; Grings et al., 2001; Purchas et al., 2002). In the present study, the non-significant reduction of rib eye area of castrates compared to the intact bulls might be due to the fact that the animals were castrated at a late stage of development and to the shorter duration of the experiment. Similarly, Cosgrove et al. (1996) found that during finishing, castrates retained their high eye muscle area.

5.6.3.2. Fat, muscle and bone percentages:

The sirloin cut of castrates in this study yielded more dissected fat (P<0.001) than in intact bulls. Muscle development showed an opposite trend to fat deposition, and percentage made by muscle tissue from the carcass was significantly higher (P<0.05) for intact than castrated bulls. This suggests that differences in propensity to deposit lipids as energy reserves could be influenced by castration (enhancement effect), whereas, muscle and protein
accretion were retarded. This is probably because castration suppressed testosterone release. The present findings are supported by the reports of Santidrian et al. (1982) and Lobley et al. (1987) who concluded that treating rats and lambs with testosterone increased muscle growth by suppressing muscle protein degradation. This is parallel with the findings of the majority of researchers. Purchas et al. (2002) found that steers were significantly fatter than bulls at the same carcass weight for all measurements of fatness. Similar results were found in studies in sheep and goats castration (Ahmed and Davis, 1986; Mohamed, 1994 and Eldow, 2001).

In the present study however, bone percentage was not significantly different between the two treatment groups (Table 10). This is in line with the findings of Mohamed (1994) and Eldow (2001) that bone percentage was non-significantly (P>0.05) lower in bulls castrated late in life and entire bulls. This might possibly be due to the fact that bone is an early maturing tissue (Hammond, 1932) and castration was performed in this study rather late in the life.

Similarly, entire bulls scored significantly (P<0.001) higher muscle to fat, muscle to (fat+C.T) and bone to fat ratios than their contemporaries. This result may be attributed to less leaner carcasses from castrates as compared to the intact bulls as castration increases fat deposition and suppresses lean accretion.

In conclusion, at the same carcass weight, castrates had more carcass fat, and entire bulls more lean tissue but carcass bone percentage was similar in both groups. These differences could be ascribed to the effect of castration as it accelerates achievement of mature body size of an animal, which further affects its carcass composition. This fact is confirmed by the general
principles of Hammond (1932) that muscle and fat are late maturing tissue relative to bone. Owens et al. (1995) reported that protein accretion declines to zero when cattle reach their mature body size, even though, mature animals can continue to accrete fat.

5.7. Meat chemical composition:

The present results on chemical composition revealed that entire bulls had higher water and protein values but lower lipid values than castrates. This was a reflection of the effect of sex hormones on the synthesis and deposition of protein, as androgens are known to improve metabolism and increase nitrogen retention in the body. In castrates, ether extract was more; this is presumably due to the higher intra-muscular fat content of Longissimus dorsi muscle of castrates compared to entire bulls.

In support to the present findings, Morris (2003) reported that the composition of live weight gain of bulls contained more protein and less fat than that of steers; and similar difference existed between steers and heifers. Schanbacher et al. (1980) reported that the carcasses of intact rams contained more water and protein but less fat and gross energy than wethers. Similar finding has been reported by Mohamed (1994) for Sudan Desert goats.

On the other hand, the ash content was significantly (P<0.001) higher in entire bulls (Table 11) than castrates. This could be related to the high protein content of meat from intact bulls as compared to the higher intra-muscular fat content of meat from castrates. Fat was lost during ignition. It is known that protein contains more minerals than fat (Potassium, Phosphorus, Sodium, Sulfur, Ferrous, …etc). Duckett et al. (1993) found that increase in fat content resulted in decreased concentrations of moisture, protein and ash in the Longissimus dorsi muscle.
The sarcoplasmic and myofibrillar proteins and non-protein nitrogen values were significantly higher (P<0.001) in entire than castrated bulls. Similarly, Morgan et al. (1993) reported bulls accreting more myofibrillar protein than steers. Mohamed (1994) and Eldow (2001) found significantly higher sarcoplasmic and myofibrillar proteins for entire than castrated group. This could be due to the stimulation effect of testosterone hormone to anabolic agents responsible for protein synthesis in intact bulls (Lawrence and Fowler, 1997) compared to the castrated ones.

5.8. Objective evaluation of meat quality attributes:

5.8.1. Colour and pH:

Hunter colour components indicated that castrated bulls had significantly (P<0.001) lighter red colour, and that meat from intact bulls had stronger red colour meat (P<0.05) than from castrates (Table 12). The fact that castrates had more intra-muscular fat than entire bulls may partly explains these differences. In addition that the male sex hormone increases muscle accretion accompanied by increased myoglobin concentration. This is in agreement with the earlier finding of Hammond (1932) that castration decreased the intensity of the red colour of meat and also bulls had darker meat than females due to the effect of sex hormones. Supporting to this, Judge et al. (1989) reported that intact males have muscles that contain more myoglobin than do those of females or castrates. Knight et al. (1999b) reported that bulls had a darker Longissimus dorsi than steers. Similar results
have been reported for castrated sheep and goats (Mohamed, 1994 and Eldow, 2001).

On the other hand, castration significantly (P<0.01) reduced the pH of the meat (5.88 vs. 5.68) (Table 11). This agrees with the results of numerous studies in the field of beef production (Purchas and Grant, 1995; Knight et al., 1999a; Page et al., 2001; Purchas et al., 2002). The result may be explained in many ways. First; it could be due to increased aggressive and sexual activity of intact bulls, which reduces muscle glycogen concentration below the critical level necessary for lowering the post-mortem ultimate pH, compared to castrated bulls. Judge et al. (1989) and Tarrant (1989) reported that the deficiency of muscle glycogen of stress-related animals caused a slow rate and a limited extent of glycolysis after death, resulting in ultimate high pH. Secondly; it might be due to a reduction in the rate of temperature dissipation during chilling (subcutaneous fat insulation) that further promotes postmortem glycolysis and ultimately reduces pH in the castrated bulls.

5.8.2. Water holding capacity and cooking loss:

Castrates were superior (P<0.001) over intact bulls in water holding capacity and cooking loss (Table 12). However, this result could not be explained in terms of the low carcass protein and meat pH values of bulls compared to intact males. It could presumably be due to increased fat content of the slightly more tender meat of castrated animals. Lawrie (1991) reported that water holding capacity improved as meat fat increased. As water holding capacity improved cooking losses decreased. Purchas et al. (2002) reported that the low water holding capacity of bull beef may partially explains the lower levels of tenderness for beef from bulls relative to that from steers.

5.9. Subjective evaluation of meat quality attributes:
Sensory evaluation of quality attributes of the cooked meat showed that, meat of castrated bulls was juicier (P<0.05) and more acceptable (P<0.05) than of the intact group (Table 12). This could be related to the higher marbling content of the meat from castrates. Marbling has a stimulating effect on the production of saliva and the coating of fat that builds up on the tongue, teeth and other parts of the mouth. This is in agreement with the results of Purchase et al. (2002) who found bull beef was less juicy than that of steer because of the low intra-muscular fat (marbling) deposition in bulls. Moloney (1999) reported that the meat of young animals gives an initial impression of juiciness, however, this is followed with a dry sensation in the mouth, because of the relative absence of fat.

Tenderness was not significantly different between the two groups in this study, but tenderness scores were slightly higher in the castrated than entire bulls (3.00 vs 3.30). This is in line with the finding of Field et al. (1966) that beef was tougher for bulls aged 600 to 699 days relative to those aged 300 to 399 days, but was more tender for steers and heifers of similar ages. Similarly, Mohamed (1994) reported that though there was no significant difference in tenderness and juiciness scores of the cooked Longissimus dorsi muscle of entire and castrated animals, but tenderness and juiciness scores were slightly lower in the former group. Jacobs et al. (1977b) found no significant difference in taste panel scores for tenderness between bulls and steers (6.1 vs 6.6). This could be related to the fact that castration increases carcass fatness, which is known to dilute connective tissue content (Lawrie, 1991) (Table 10). On the other hand, carcass fat is also known to decrease the rate of temperature decline (insulation effect), enhances the activity of proteolytic enzymes or the duration of active proteolysis, lessens the extent of myofibrillar shortening and thereby increases the ultimate
tenderness of cooked meat from fatter carcasses compared to those with less fat (Smith et al., 1976). Similarly, Purchas et al. (2002) reported that beef from bulls was likely to be less tender than that from steers and he explained this for the lower proteolytic activity, slightly higher pH, lower levels of intramuscular fat, higher cooking losses and a greater contribution of connective tissue components. Moloney (1999) reported that increased tenderness is most likely due to an increase in intra-muscular fat deposition and a decrease in the heat stability of the muscle connective tissue.

There were no significant treatment differences in taste panel scores of the cooked meat flavour. Taste panel flavour score tended to be higher in the castrated than entire group (Table 12). Moloney (1999) reported higher sensory flavour intensity that was attributed to higher marbling scores. Mohamed (1994) found non-significant difference between castrated and entire kids in sensory scores, but meat from castrates had less male taint than that of entire kids.
SUMMARY

This study was conducted to investigate the effect of castration on live animal performance, carcass characteristics and meat quality. Twenty-four Western Sudan Baggara bulls ranging in live body weight from 175-185kg and age from 2.0-2.5 years were used in the study. The animals were divided by stratified random sampling into two groups and the groups were randomly assigned to either castrated or entire treatment. The groups were fed ad libitum molasses ration composed of 52% molasses, 39% wheat bran, 5% groundnut cake, 3% urea and 1% salt plus sorghum stover (1.5 kg/head/day). Berseem ‘Medicago sativa’ was offered at a rate of 2kg/head/2weeks.

Data on feed intake and live weight growth were collected on daily and weekly basis, respectively. A set of external live body measurements was recorded on each animal just before slaughter to the predetermined slaughter weight (250-265kg) at which the bulls were slaughtered; slaughter and carcass data were collected. Chemical composition and meat quality of cooked meat were also carried out.

The results indicated that castration tended to reduce growth rate to a non-significant level (0.89 vs. 0.82 kg/day). Though castrated bulls took significantly longer time to reach final weight (P<0.05), there were no significant differences between the two groups in all parameters of feed intake. External live body measurements, at slaughter, were non-significantly different between the intact and castrated bulls for heart girth, height at withers, height at hips, depth of hook and body length. Others differed such as: shoulder width and hump base length (P<0.05), heart girth around the hump (P<0.001) and height at tip of hump (P<0.01) and their values were
higher for the intact group. The intact group on the other hand, had lower value than castrated bulls (P<0.05) for the measurement length from patella to posterior midline and depth of patella from tail junction.

Castrated bulls scored significantly (P<0.001) higher percentage of genital fat, kidney and pelvic fat (P<0.01), omental (P<0.001) and mesenteric fat (P<0.05). In contrast, intact bulls had significantly heavier heads (P<0.05) and non-significantly (P>0.05) heavier hide. The total weight of the reproductive organs (excluding genital fat) was significantly (P<0.001) heavier in intact bulls than in castrated bulls. There were no significant differences between the intact and castrated bulls for the other parameters of non-carcass components.

Castrated bulls were found to have significantly (P<0.001) thicker subcutaneous fat depth. The rib eye area was slightly greater (P>0.05) in the intact bulls than castrates.

There were no significant differences between treatments in hot dressing percentage on both empty and live body weight basis as well as the cold dressing percentage on live body weight basis. However, castrated bulls scored higher value for cold dressing-out percentage on empty body weight basis (P<0.05) and for chiller shrinkage percentage (P<0.001).

The proportions of the various wholesale cuts were not significantly different between treatments, except for the neck and chuck and blade joints. The latter were heavier (P<0.05) in the intact animals. Intact bulls had also significantly more muscular tissue (P<0.05) in sirloin cut and higher muscle to fat (P<0.001) and bone to fat (P<0.001) ratios compared to castrates. But castrates scored higher fat percentage (P<0.001). Bone percentage was not significantly different between the castrated and intact animals.
Castration reduced moisture and protein percentages (P<0.05) and the reverse was true for the ether extract, which was higher in the castrated bulls (P<0.001). Ash, sarcoplasmic protein, myofibrillar protein and non-protein nitrogen percentages were significantly (P<0.001) higher in entire males than castrates. Castration reduced muscle pH (P<0.01).

The treatment affected meat colour. Hunter lightness value was higher (P<0.001) in castrated bulls, and entire bulls had higher redness value (P<0.05). The castrated bulls scored higher water holding capacity values and lower cooking losses (P<0.001) than entire bulls. Castrates had also juicier (P<0.05), tender cooked meat of better overall acceptability than the intact bulls.
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