THE EFFECT OF SELENIUM AND CHROMIUM ON STRESS LEVEL, GROWTH PERFORMANCE, SELECTED CARCASS CHARACTERISTICS AND MINERAL STATUS OF FEEDLOT CATTLE

by

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DECLARATION

I, Dibungi Luseba, hereby declare that the work on which this thesis is based is original (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree at this or any other University.

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SUMMARY

THE EFFECT OF SELENIUM AND CHROMIUM ON STRESS LEVEL, GROWTH PERFORMANCE, SELECTED CARCASS CHARACTERISTICS AND MINERAL STATUS OF FEEDLOT CATTLE

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Feedlot cattle are subjected to numerous stresses that impede on their growth performance and carcass quality. Stress also depletes the animal body with its nutrients subsequently leading to deficiencies. The aim of this study was to investigate the effect of selenium (Se) and chromium (Cr) on stress and subsequently on growth performance, carcass characteristics including meat colour and liver tissue minerals. It is thought that Se, as anti-oxidant and Cr effectiveness in glucose metabolism might be effective on these production parameters. Four experiments were conducted for that purpose.

The first experiment consisted in the assessment of the response of animals to dietary supplement of 0.3 mg.kg $^{-1}$ DM Se and 0.3 mg.kg $^{-1}$ DM Cr in a 3x4 factorial design. Seventy-two steers were allocated to 12 pens of six animals each. The results showed no statistical difference in blood cortisol levels on day 0 (d 0). On d 04, cortisol concentrations were lower than on d 0 ($P \leq 0.05$) except for treatment "Se X Cr combination" (SEL/CHR). On d 42, the values were high again except for SEL/CHR that had very low cortisol values ($P \leq 0.05$). The plots of blood glucose concentrations were

almost similar to those of blood cortisol. There was no carry-over effect of alleviation of stress on performance. It was suggested that the animal type used was not appropriate for feedlot. The carcass characteristics were not statistically different. Meat pH measurements were similar but the differences between pH taken on slaughter day (pH 1) and 24 hours later were different ($P \leq 0.05$) for CHR and SEL/CR. This suggests that Cr because of its effect on glycogen storage is more effective in maintaining an appropriate meat pH fall and subsequently a longer meat shelf life. The liver tissue mineral status of the animals was normal. However, supplemental Se increased significantly ($P \leq 0.05$) the liver tissue Ca, Mg, Co and Mn while Cr decreased the concentrations of Ca, Mg and Co. Selenium was positively correlated to Cu and P while Cr was negatively correlated to Co. There was no relationship between liver tissue mineral and production parameters.

The second trial dealt with the meat colour. Twenty-four prime rib samples were randomly collected from the animals described in Experiment-1 in a 2x3x4 factorial design (two samples per pen). Samples were treated as described by Buys *et al*. (2000). The readings of metmyoglobin as an indication of meat discoloration were not different between treatments. However, the ratio of metmyoglobin over the rest of meat components showed that supplemental chromium (CHR) had a lower value ($P \leq 0.05$). Chromium might have permitted a better glucose utilisation and glycogen storage in muscle of live animal. This might have maintained an adequate drop in meat pH subsequently lowering the lipid peroxidation and preventing the accumulation of metmyoglobin.

The third trial was aimed to verify the findings of Experiment-1 and to compare the effect of Cr sulphate to that of high-Cr yeast and their interactions with Se. Seventy-two weaner calves were allocated to six pens of 12 animals each. Cortisol and glucose concentrations were similar on d 0. On d 04 treatments SEL and Cr sulphate (ICH) had low values ($P \leq 0.05$) while on d 42, combined Se and organic Cr (SOC) tended to have low values. These results and those from Experiment-1 showed that Se is efficient in the alleviation of stress in the adaptation days on feed while combined Se and Cr treatments are more efficient in the production phase. The organic Cr is not more effective than Cr sulphate

in alleviation of stress. The combination "Se and inorganic Cr" (SIC) had higher ADG and better P-FCR (P≤0.05) and it tended to have better carcass characteristics. Mineral concentrations were normal and similar. As seen in Experiment-1, treatment SEL highly (P≤0.01) increased liver Ca concentration. Chromium and most other mineral concentrations were not affected by supplemental Cr. Overall, organic Cr was not superior to Cr sulphate.

Previous experiments indicated that combining Se to Cr might give better results. The fourth trial aimed to find the best combination. Thirty-six weaner steers were allocated to six pens of six animals each. There was no difference in cortisol levels but a tendency (P=0.1) was noted on d 47 with combined "sodium selenite x Cr sulphate" (ISIC) and "high-Se yeast x Cr sulphate" (OSIC) having low values. Blood glucose values were not different. Blood cortisol concentrations were positively correlated to glucose on d 47. Selenium and Cr did not significantly affect the overall growth efficiency of the steers but during the adaptation period, the controls and OSIC treatments had better ADG and PFCR. Treatments ISIC and "sodium selenite x organic Cr" (ISOC) had similar live weight whilst treatment OSIC had higher live weight than "organic Se x organic Cr" OSOC. The combined organic forms were better than the inorganic ones. The carcass parameters were not affected. However, ISIC tend to have higher carcass mass than ISOC; similarly, OSIC tended to perform better than OSOC. Higher liver tissue Se and Cr were due to supplemental Se and Cr (P≤0.05). Treatment ISIC had the highest liver Se levels (P≤0.05) in this experiment and in Experiment-3. Selenium did not interact with other elements. In contrast, Cr was negatively correlated to Fe and Mn and positively to Mg. Chromium tends to be negatively correlated to other minerals. Precautions might be recommended when feeding excessive Cr because Cr does not augment the liver concentration of other minerals (Chang *et al*., 1992; Anderson *et al*., 1997).

SAMEVATTING

Die effekte van selenium en chroom op stres vlakke, groei prestasie, geselekteerde karkas eienskappe en minerale status van voerkraalbeeste

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Voerkraalbeeste is onderworpe aan verskeie stresfaktore wat karkaskwaliteit en groeiprestasie belemmer. Stres verlaag voedingstofvlakke in diere wat lei tot voedingstoftekorte. Hierdie studie het beoog om die effek te ondersoek van selenium (Se) en Chroom (Cr) op stres en die gevolglike groeiprestasie en karkas eienskappe, insluitend vleis kleur lewerweefselminerale.

Die eerste eksperiment was die evaluering van die respons van diere op byvoeding van 0.3 mg.kg-1 DM Se en 0.3 mg.kg-1 DM Cr in ‘n 3 x 4 faktoriale studie-ontwerp. Twee-en-sewentig osse was geplaas in 12 hokke met ses diere in elke hok. Daar was geen statisties betekenisvolle verskille in bloed kortisolvlakke op dag 0 (d 0) nie ($P \leq 0.05$). Op d 4 was die kortisolvlakke laer as op d 0, behalwe vir die “Se x Cr kombinasie” behandeling (SEL/CHR). Op d 42 was die vlakke weer hoër, behalwe vir die SEL/CHR-groep wat baie lae kortisolvlakke gehad het ($P \leq 0.05$). Die bloed glukosevlakke het dieselfde patroon gevolg as díe van kortisolvlakke. Daar was geen oorgedraagde effek van stresverligting op prestasie nie. Die karkaskwaliteit was nie statisties betekenisvol vesrkillend nie. Vleis pH metings was soortgelyk, maar die verskil tussen pH op slagdag (pH 1) en 24 uur later was betekenisvol ($P \leq 0.05$) vir CHR en SEL/CHR. Dit ondersteun

die teorie dat die effek van Cr op glikogeenberging meer effektief is in die handhawing van ‘n vleis pH nodig vir ‘n verlengde raklewe. Die diere se lewermineraalstatus was normaal. Se byvoeding verhoog die vlakke van Ca, Mg, Co en Mn in lewerweefsel betekenisvol (P≤0.05) terwyl Cr die vlakke van Ca, Mg en Co verlaag. Se was positief gekorreleer met Cu en P terwyl Cr negatief gekorreleer was met Co. Daar was geen verwantskap tussen lewerweefselminerale en produksieparameters nie.

Die tweede eksperiment het vleiskleur ondersoek. Vier-en-twintig prima ribmonsters was ewekansig gekollekteer van die diere in die eerste eksperiment in ‘n 2 x 3 x 4 faktoriale studie-ontwerp met twee monsters per hok. Die monsters is behandel volgens die metode beskryf deur Buys *et al*. (2000). Die metings van methemoglobien, as aanduiding van vleisverkleuring, was nie verskillend tussen behandelings nie. Tog was die verhouding van methemoglobien tot die res van die vleiskomponente laer met Cr byvoeding (P≤0.05). Cr kon dalk ‘n beter glukose verbruik en glikogeenbergingsvermoë in die spiere van lewende diere tot gevolg gehad het. Dit kon ‘n voldoende daling in vleis pH onderhou wat sou lei tot ‘n verlaging in lipied peroksidasie en die voorkoming van methemoglobienakumulasie.

Die derde eksperiment het beoog om die bevindings van die eerste eksperiment te bevestig en om die effek van Cr-sulfaat met ‘n hoë-Cr-gis te vergelyk en om hul interaksies met Se te ondersoek. Twee-en-sewentig speenkallers was geplaas in 6 hokke met 12 diere per hok. Glukose- en kortisolvlakke was soortgelyk op d 0. Op dag 0 4 het SEL- en Cr-sulfaat (ICH)-behandelings laer vlakke getoon (P≤0.05), terwyl SEL- en organiese Cr (SOC) behandelings laer vlakke getoon het. Hierdie resultate, en díe van die eerste eksperiment, het getoon dat Se stres verminder tydens die aanpassingsfase op ‘n rantsoen terwyl ‘n kombinasie van Se en Cr stres beter verminder tydens die produksiefase. SOC was nie meer effektief as ICH nie. Die kombinasiebehandeling met Se en Cr (ISIC) het gelei tot ‘n groter gemiddelde daaglikse gewigstoename (GDT) en ‘n beter voedselomsetverhouding (VOV) (P≤0.05). Dit het ook geneig om beter karkaskwaliteit te lewer. Lewer mineraalkonsentrasies was normaal en soortgelyk aan die eerste eksperiment. Soos in die eerste eksperiment het Se behandeling tot verhoogde

lewer Ca-vlakke gelei. Cr en meeste ander minerale se lewervlakke was nie verander deur Cr byvoeding nie. Organiese Cr het nie beter resultate gelewer as Cr-sulfaat nie.

Vorige eksperimente het getoon dat ‘n kombinasie van Se en Cr beter resultate kan lewer. Die vierde eksperiment het beoog om die beste kombinasie te vind. Ses-en-dertig speen-osse was verdeel in ses hokke met ses diere per hok. Daar was geen verskil in kortisolvlakke nie, maar ‘n neiging van gekombineerde natriumseleniet met Cr-sulfaat (ISIC) en hoë-Se gis met Cr-sulfaat (OSIC) om kortisolvlakke te laat daal is op d 47 gesien (P=0.1). Bloed glukosevlakke was nie verskillend nie. Bloed kortisolvlakke was positief gekorreleer met glukosevlakke op d 47. Se en Cr het nie die oorhoofse groeiprestasie van die osse beïnvloed nie, maar die OSIC-groep en die kontrolegroep het beter GDT en VOV getoon. Die OSIC- en natriumseleniet met organiese Cr (ISOC)-groepe het soortgelyke lewende massa gehad, terwyl die OSIC-groep beter lewende gewig gehad het as die organiese Se met organiese Cr (OSOC)-groep. Die gekombineerde organiese formulasies was beter as die anorganiese formulasies. Karkasparameters was nie beïnvloed nie. Tog het die ISIC-groep geneig tot ‘n beter karkasmassa as die ISOC-groep; en die OSIC-groep het beter presteer as die OSOC-groep. Hoër lewer Se en Cr was as gevolg van Se en Cr byvoeding ($P \leq 0.05$). Die ISIC-groep het die hoogste lewer Se gehad ($P \leq 0.05$) in hierdie en die derde eksperimente. Se het nie ‘n interaksie met ander elemente getoon nie. Cr, darenteen, was negatief gekorreleer met Fe en Mn en positief met Mg. Cr neig om negatief gekorreleer te wees met ander minerale. Voorsorg behoort geneem te word tydens oormatige Cr-byvoeding, omdat dit nie die lewerkonsentrasie van ander minerale positief beïnvloed nie (Chang *et al*. 1992; Aderson *et al*. 1997).

"It is not the strongest of the species that survive, not the most intelligent, but the one most responsive to change"

Sir Charles Darwin

CHAPTER 1. INTRODUCTION

1.1. GENERAL CONSIDERATIONS

Scientific advances in beef production were affected by the Bovine Spongiform Encephalopathy (BSE) scare of 1997. Meat and bone meal has been used to reduce feed costs, diminishing raw material supply needs, which have been incriminated as carriers of BSE (Gadd, 1995; Lyons, 1997). Meat and bone meals have been banned from cattle feed inclusions in many countries and concerns about the use of antibiotic digestive enhancers (formerly called growth promoters) are increasing. It appears that the supplementation of domestic animal feeds, both pet and food animals, with products of animal origin is raising concern.

`Today's consumers monitor carefully what scientists are developing. The globalisation of the world has made new information readily available. In the meantime, those involved in meat production have to solve the dilemma of meeting the consumer's needs for this perishable and relatively costly product with regard to price, safety, and quality (Gadd, 1995) if they have to survive in the business. Traditional tools such as hygiene, vaccination programmes, and nutritional manipulations have been used to improve livestock production. Due to increased pressure upon available resources, new ways and means of animal husbandry are to be investigated. This research focuses on nutritional manipulation of growth using the trace minerals, selenium (Se) and chromium (Cr) in inorganic and organic forms.

Chromium and selenium are two essential micronutrients for animal production and health (NRC, 1980; NRC, 1997). Their individual and interaction effects on stress alleviation, growth performance, carcass quality, and mineral status of feedlot beef cattle have been examined in this research. The issue of the superiority of organic forms of these minerals was investigated. The inorganic Cr form as Cr sulphate has been introduced in feedlot

cattle feeding. The organic forms of Se and Cr have been investigated alone or in combination with the inorganic forms. As pointed out by Lee *et al*. (1999), there is a dearth of scientific data on the advantages of using the so-called organic trace mineral supplements. However, Mahan (1999) considers that organic Se may be one of the important nutritional keys to improved human and animal health of the 21st century.

It is well known that feedloting is a business where the margin of profit is very small. In order to survive, the feedlot industry must be competitive and responsive to changes arising as a result of the globalisation process, the rapid development of the information technology, and subsequently the new demands of the market. Macro and micro minerals could become very important feed additives in the replacement of traditional antibiotic additives for which consumer resistance has increasingly developed.

More importantly, the trace minerals are expected to interact with one another, with the potential of causing a toxicity or deficiency symptoms. Excessive levels of the nutrients may be easily diagnosed and prevented, but in contrast, deficiencies are frequently subtle, and difficult to control or to anticipate because an element may have a variety of functional roles. It cannot be assumed, therefore that the most significant consequence of deficiency is necessarily that it will produce the most obvious clinical signs of deficiency. Mills (1983) has observed that there are no reliable data available from which to assess the economic losses due to metabolic diseases caused by trace mineral deficiency diseases. Essentially, impaired productivity, or clinical manifestations of deficiency, may often not be evident when widely accepted criteria for assessing the trace mineral status of diets or animal tissues suggest the existence of deficiency. Selenium and Cr are important nutrients of cattle, and this study sought to evaluate their beneficial effects in the absence of their deficiency. Their interactions with other minerals and trace minerals were also investigated in detail.

Stress related conditions in the feedlot are common, and the bovine respiratory complex diseases which constitute close to 70 percent of the clinical cases in bovines are the main consequences. The discovery of factors such as disease resistance, which are adversely affected by trace mineral deficiencies, adds emphasis to the need to prevent deficiencies

from occurring (Suttle, 1983). Induced stress occurs from weaning, transportation to the saleyard and feedlot, to the adaptation to the new environment, crowding, management and most importantly in adaptation to the high-energy diet. Management of stress in the feedlot involves primarily the management of the environment (the stressor) and, secondly, management of the quantified changes seen in the animal (Grandin, 1997). Weaning is an unavoidable stress. Management techniques such as preweaning and preconditioning which have been cited as measures to alleviate stress, e.g. at entry in the feedlot, are however, not cost effective (Pritchard and Mendez, 1990). Feed and water deprivation during transportation may limit nutrient absorption not only in the adaptation phase but also during the whole feedlot period. Determination of stress detectors such as blood cortisol and glucose levels was undertaken and it constitutes an important phase of this study.

Beef quality, especially freshness, can be assessed by its colour. This is the main factor affecting beef product acceptability at retail points of purchase (Liu *et al*. 1996a). The appearance of the meat surface depends on the quantity of the myoglobin, the type, its chemical state and the chemical and physical condition of other components in the meat (Laurie, 1985). Vitamin E can prevent meat discoloration through the prevention of lipid oxidation and limitation of production of metmyoglobin (Liu *et al*. 1996b). As vitamin E was believed to act as a biological antioxidant preventing lipid peroxidation, it was felt that selenium would function in a similar way (MacPherson, 1994). Chromium is involved in carbohydrate metabolism (Burton *et al*. 1993; Depew *et al*. 1998) and it allows better storage of glycogen in muscle. It has been established that adequate residual muscle glycogen allows muscle to reach an adequate ultimate pH (Laurie, 1985). Under these conditions meat discoloration might be prevented. This study will also attempt to assess the effect of supplemental selenium and chromium on meat colour.

Moreover, the preparation of animal products, rich in selenium and chromium may impact on human requirements for these minerals. According to Pawlowicz *et al*. (1991), selenium has anticancer properties. Low blood or serum Se levels have been found in patients with various types of cancer. This finding suggests that Se exerts its effect on the molecular level in different ways such as a protective effect against the oxidative damage through

decreasing the amount of free radicals and increasing the synthesis of glutathione peroxidase. It is assumed that animal products that are rich in Cr may have an effect in preventing diabetes because of the effect of Cr on insulin sensitivity (Amoikon, 1995).

Supplemental Cr has also been associated with less body fat (leanness) and increased muscling in monogastrics (Lindemann *et al*. 1995). For that reason it has been included in different sport products. An example of such sport products is the Citri-Chromium PlusND (California Pharmaceutics, SA) which is a combination of chromium picolinate (500 mg), carnitine, hydroxy-citric acid and many vitamins, antioxidants and all the amino acids. It is clear that even though these minerals might not affect some animal performance criteria dramatically as used in this study, its inclusion in diets may have indirect application in human nutrition.

1.2. OBJECT AND SCOPE OF THIS STUDY

The most obvious function of macro-minerals and trace-minerals, as components of body organs and tissues, is to provide structural support for the body, in addition to their role as catalysts in both enzyme and hormone systems (Close, 1998). Selenium is widely used in different human medicines for its anti-oxidant activity. It is also approved in the Republic of South Africa (RSA) for use in livestock production as a feed additive (Act 36 of 1947). However, it is not used routinely because its inclusion in diets is seldom considered (Van Ryssen, 1996). This is probably due to the fact that typical Se deficiency or toxicity symptoms are rarely observed or reported in RSA. Its deficiency is however expected in South Africa (Cloete *et al*. 1994; Marnewick, 1995; Van Niekerk *et al*. 1995; Van Ryssen, 1996). Results of liver mineral concentration in feedlot beef cattle content compiled in nutritional laboratories (Medunsa and Onderstepoort) over six years for diverse farms (Table 2.2) confirm that. It is therefore important to undertake investigations that may contribute to the understanding of its properties and possible use.

Chromium was approved for use in the United States of America (USA), Australia, India, Malaysia, New Zealand, the Philippines, South Korea, Taiwan and Vietnam a few years ago (Lyons, 1997). Although the number of countries has not increased dramatically to date,

recent studies suggest that chromium may be important in ruminant nutrition (Burton *et al*. 1993; Burton *et al*. 1994; Moonsie-Shageer and Mowat, 1993). However, according to the National Research Council (NRC) (NRC, 1997), the literature related to chromium does not support a general recommendation for its use as a supplement in commercial ruminant diets due to inconsistency in the findings. Research in the use of Cr in the feed of newly arrived feedlot cattle appears potentially beneficial. This research project focuses on the management of the newly arrived feedlot cattle and subsequent growing-finishing phase including the evaluation of carcass characteristics. Only two studies (Chang *et al*. 1992; Mathison and Engstrom, 1995) evaluating carcass improvement by Cr supplementation are prominently quoted by the NRC (1997). Thus this present study constitutes pioneer work in this field.

The interaction between the two elements, the effect of chromium on meat colour and the use of inorganic chromium as chromium sulphate are among the most important investigations in this study. To our knowledge, studies involving chromium sulphate and the investigation of Se and Cr properties in meat colour improvement have not been reported. There is a considerable body of literature on selenium in human nutrition but much less in animal nutrition. Chromium has only recently been considered in animal feeding. The little that is known about work in the USA and Canada may not be applicable here in South Africa because of differences of breeds of steers available, basal diets used, climate and composition of feedstuffs.

1.3. HYPOTHESIS

The hypotheses are stated in the introductions of each experiment.

CHAPITER 2. LITERATURE REVIEW

2.1. SOUTH AFRICAN LIVESTOCK AND MEAT INDUSTRIES

The South African livestock industry is the country's biggest contributor to agricultural production. It represents approximately 43 percent of the agricultural gross revenue and serves as an important income stabiliser for extensive field crop production (Standard Bank, 2000). The gross value of the cattle industry during 1996/97 was estimated at R3 223 million (Anonymous, 1998). With an average of less than 500 millimetres of rainfall in the western half per year, South Africa can be regarded as a semi-arid or arid country. The physico-biological environment makes the country highly suitable for stock farming since approximately 60 % of the 122.3 million hectares of the land surface consist of grazing land (Grobler, 1998).

Cattle herd numbers in commercial areas amounted to 8,839 millions, and in developing areas to 4,827 million during 1997. There has been a decline in cattle slaughtering which is explained by herd building because of very good rainfall over the past three years in South Africa and Namibia (Standard Bank, 2000). For example, slaughtering amounted to 1,764 million in 1996 and 0,568 million in 1997. Herd-building resulted in the holding back of female slaughter stock, which in turn led to a drop in national slaughtering and strengthening of prices. A clear indication of this was an increase in weaner prices from R4.70 per kg live weight in June 1997 to R5.40 in December (Grobler, 1998).

Unlike in many other Southern African countries where the majority of cattle are raised in the communal areas under traditional peasant farming system (Mpofu, 1996), the South African feedlot industry produces approximately 70 % of all beef in the country. This represents about 1,35 million head of cattle and 254 000 tons of high grade beef per annum. The major feedlots are located close to maize-producing regions (e.g. North-West, Mpumalanga, Gauteng) and the large metropolitan areas. This means that they are located far away from grazing areas where calves are produced. Animals and feed are transported over long distances and it is estimated that for 1 kg of beef produced, a total of 6 to 7 kg of grain is moved (Ford, 1998).

South Africa remains a net importer of red meat and live animals. Imports outside the Southern African Customs Union (SACU) represent approximately 13 % of beef available in the country. The average producer prices of beef increased by 4.8 percent from R7.92 in 1998 to R8.30 per kilogram in 1999 (Standard Bank, 2000). The average beef consumer prices were R17-84/kg in 1996 and R19-13/kg for 1997. *Per capita* consumption of beef and veal was estimated at 12,4 kg/year for the period 0996/1997. It is also believed that the South African consumer shows a definite preference for younger more tender beef i.e. the carcass of A class, which comprises 67 % of the total slaughtering. Secondly, across all ages, carcass classes that consumers are willing to pay more for are those with lean to moderate fat coverage i.e. the 2 and 3 classes with between 1 - 5 mm of backfat as measured between the 10^{th} and the 11^{th} rib (Ford, 1998).

These considerations clearly show why beef production in South Africa is not an easy business. There are many constraints that are making the situation more complicated than in other countries where the feedlot industry is developed such as in the USA, Canada and Brazil. Grain to beef ratio in South Africa is estimated at 13:1 as compared to Australia with 22:1 and USA 24:1 (Ford, 1998). Other major limiting factors are the unstable and high costs of weaners, feed, and other supplements. The price of maize has been unstable due to unpredictable and sometimes excessive rainfalls in the production region. Maize (grain) and weaner prices are the two main costs that determine the viability of the operation and the type of cattle to feed. This situation opens the door to all types of manipulation aiming to compensate the low use of maize in feedlot animal diets. Risks and shortfalls for use of many other feedstuffs and additives narrow the magnitude of these maneuvers.

It is believed that minerals and, more particularly, trace minerals constitute a natural and safe way of supplementing animal feed in order to influence the growth rate. It also appears that animals are not fed only for productive and reproductive activities but also to minimise infectious diseases and their attendant effects. However, substantial changes were not expected due to supplemental minerals. It is well known that management and

husbandry have a greater effect on growth and development generally, than mineral supply (Smolders *et al*. 1993). This was ensured throughout the whole period of study as reported under materials and methods.

Selenium and chromium have been investigated as they have shown potential in the improvement of animal performance and carcass quality. The mode of action of Se element is not clearly understood. Thus, allowance of Se and its inclusion in animal feed is still debatable, and as pointed out by Van Ryssen (1996) its use is seldom considered in South Africa. Studies on the use of Cr in animal nutrition are more recent and the results in cattle are as yet inconclusive (NRC, 1997). There is a need for more research on the mode of action of these two elements (Se and Cr) and their interaction with other minerals and trace minerals in feedlot cattle. Some claims and considerations like those related to the superiority of any form of the two trace minerals over another, i.e. the inorganic forms versus the organic were tested.

2.2. MINERALS IN FEEDLOT CATTLE FEEDING

The most common minerals used in feedlot diet formulation are calcium (Ca), phosphorus (P), magnesium (Mg), potassium (K), sodium chloride (NaCl) and trace minerals copper (Cu), manganese (Mn), zinc (Zn), cobalt (Co) and ferrous (Fe). The properties and effects of these elements are outside the scope of this research. But details on the effects of any mineral or trace mineral will be discussed when the interaction or interference occurs with Se or Cr.

In summary, minerals act by virtue of their variable valency and complexing ability. The more abundant essential trace mineral functions in the living cell are the non-specific interactions that are determined primarily by the concentration of the element in the cell and its complexing ability relative to other ions (Rose, 1983). Such interactions can lead to modification of protein and nucleic acid structure, formation of porphyrin such as iron porphyrin and other non-protein complexes, e.g. cobalt in cyanocobalamin.

2.2.1. FEEDSTUFFS, DIETS AND LIVER MINERAL COMPOSITION

The mineral requirements and interactions for feedlot cattle diets are presented in Table 2.1. and Figure 2.1. The values of liver minerals content are summarised in Table 2.2. The Ca content of typical feedlot diets is about 0.6% of diet dry-matter (DM), ranging from 0.4 to 0.8% and not exceeding 2.0%. The average content of P is 0.3% of diet DM, ranging from 0.3 to 0.7% and should not exceed 1.0%. The ratio of Ca: P should not fall outside the range 1:1 to 7:1 (Henning *et al*. 1999). Salt is provided generally at the rate of 0.5% of DM. Trace mineral deficiency in animals invariably leads to loss of condition, retarded growth and development, poor reproductive success, impaired organ function and skeletal and tissue abnormalities.

During the feedlot phase, Zn, Cu, Fe and Se play an important role in the immune system. As pointed out by Miller (1985) the ability of animals to cope with infection may be influenced by mineral nutrition, in particular Mg and P of the macro-mineral, and Zn, Fe, Cu and Se of the micro minerals. This is very important during the adaptation phase in the feedlot, which as described elsewhere is very critical for animal health. But Cole *et al*. (1988) did not find significant differences in the blood mineral concentrations in 12 and 24 hours after transportation. Iron concentrations were lower in the 12 h transportation group as compared to the 24 h group, whilst serum Ca, Mg, Na and P concentrations were not affected by the duration of transport.

2.2.2. CHEMICAL FORMS OF MINERALS

Chemical forms of minerals also play an important role in their bioavailability. It is indeed believed that organic forms are more readily available than the inorganic forms (Gadd, 1995; Hemken, 1997). The theory behind the use or preference of organic forms is presented by Close (1998). When the traditional inorganic salts such as oxides, sulphate and carbonates are added to diets, they are broken down to a certain extent during digestion to free ions. The free ions hence formed are then absorbed and utilised by the organism.

Sometimes after digestion, the free ions may complex with other molecules and become difficult to absorb. They may also be completely complexed in which case they are totally unavailable to the animal. In contrast, organic or chelated forms of trace minerals are produced by, first, hydrolysing a protein source which results in the formation of a hydrolysate containing a mixture of peptides and amino acids. The hydrolysate will react under certain conditions with a metal sulphate to form a complex containing chelated metal ions.

Chelates may utilise peptide or amino acid uptake pathways; this prevents competition between minerals for the same uptake mechanism. It appears therefore that their bioavailability is higher due to transport readiness and subsequent increased intestinal absorption. They are more stable and are protected biochemically from the adverse reactions with other dietary nutrients, which could reduce their rate of absorption (Corah and Arthington, 1993).

However, sulphate forms, because of their high solubility, have been shown to be highly absorbable (Boyazoglu, 1997). Chromium sulphate is reported to be as available as Cr-picolinate (Merck & Co, 1996). Bio–availability studies with Cu–sulphate, for example, indicated that it was more available to pigs than the carbonate and oxide forms (Close, 1998) and in some studies it performed equally with the organic forms (Corah and Arthington, 1993). Although there might be some differences in availability of chelated versus the sulphate forms, these differences are not significant and it is questionable that the added expenses really justify the use of chelates (Wooden, 1990).

2.2.3. MINERAL STATUS AND INTERACTIONS

According to Rose (1983), the level of a particular trace mineral in animal diets depends on a number of factors including his stage of development, age, tissue reserves, dietary composition and the form of the trace mineral, its availability and interactions with other trace minerals. As noted by Suttle (1983) there are poor relationships between trace mineral status of the animal, its diet and the incidence of disease in ruminants. Stress, the absorption

process and functional activity in the animal and the fact that requirements change during the animal's life may also explain such discrepancies.

The interactions between minerals are presented in Figure 2.1. Littledike *et al*. (1995) studied the effect of breed, feed intake, and carcass composition on the status of several macro and trace minerals of adult beef cattle. There was no correlation between serum and liver Cu levels, but a negative correlation existed between serum and liver concentrations of Zn and a positive correlation existed between liver concentrations of Cu and Zn. Serum calcium concentrations were negatively correlated with liver Fe. Breed differences existed in liver Cu and liver Zn levels. Increased feed intake was associated with increased levels of liver Zn, decreased liver Fe and no change in liver Cu. Liver Fe concentration decreased with increased daily feed intake. Liver Cu concentration was more correlated with carcass lipid than it was with carcass protein. In another study in swine (Dowe and Ewans, 1990), increasing Cu was accompanied with decreased level of vitamin E in the diet. This demonstrates the complex nature of the interactions between minerals and the cause of variability in mineral metabolism.

2.2.4. TRACE MINERALS PROPERTIES, METABOLISM AND EFFECTS

2.2.4.1. COPPER

Copper is essential for proper synthesis and maintenance of elastic connective tissue, the mobilisation of iron stores, maintenance of mitochondria, melanin synthesis, and detoxification of superoxide (Wooden, 1990). Haemoglobin and enzyme cytochromes, catalases and peroxidases are iron containing compounds (Jackson, 1997). The Cu enzyme cytochrome oxidase is intimately associated with cellular organelles (mitochondria) involved in ATP synthesis and occupies a key position in maintaining cellular function and integrity (Mills, 1983). It appears that in case of Cu deficiency, cytochrome oxidase activity is reduced and thus a wide range of synthetic reactions depending upon ATP are compromised. Assessing Cu status in animal feed and body tissues is therefore very important.

According to Puls (1994), liver Cu levels appear to be more informative than serum Cu because not all Cu circulating in blood is bioavailable to the animal. Inorganic Se supplementation reduces serum Cu levels; this is a sparing more than antagonistic effect. Calves are born with a store of Cu characterised by lower serum Cu and higher red cell Cu than adults. This is converted, with age, to the Cu-dependent enzymes.

Calcium, Co, Fe, Mn, P, Se and Zn are among minerals that may reduce Cu utilisation. It also appears that Cu in silage is less available than in hay. Puls (1994) has also reported that high dietary protein reduces Cu absorption and inadequate energy intake enhances its deficiency. Inadequate Cu adversely affects Fe absorption, mobilisation and transformation into haemoglobin; Fe accumulates in the liver of marginally Cu-deficient cattle. Erythrocyte superoxide dismutase actively declines with Cu deficiency (<0.3 mg/g adult, <0.7 mg/g of haemoglobin in calves). This deficiency can be prevented by free choice trace mineral or salt mix into feed to provide 10 mg Cu/kg total ration. It appears that there are breed differences in Cu requirement. For example Simmentals cattle require twice as much Cu as Angus.

Supplemental monensin appears to enhance Cu uptake. Studies with different physical forms of the mineral have shown that Cu sulphate is more readily bio-available than chloride, nitrate or carbonate, with the oxide form being the least available. Cuprous oxide is more available than cupric oxide. Contradictory results have shown that Cu, as Cu-lysine appears to be equal to or more readily absorbed than Cu from sulphate. Inconsistently Cu absorption from proteinates appears to be less affected by molybdenum from sulphate. The absorption of Cu from herbage is dependent upon its Mo and S composition (Suttle, 1983).

2.2.4.2. IRON

Iron is essential as a component of haemoglobin in red blood cells and in muscle as myoglobin (Miller, 1985; Wooden, 1990). It is stored as ferritin and hemosiderin principally in the liver (Miller, 1985). Iron deficiency seldom occurs in mature cows but calves fed milk or replacer are frequently Fe-deficient. Milk replacer should contain more than 100 but less

than 1000 ppm Fe in dry matter. Anaemic calves have reduced immune response and reduced weight gain.

Ferrous salts are generally more available than ferric salts. Ferrous monohydrate is generally used in supplements. It appears that Co, Cu, Mn, Se, and Zn deficiencies can be induced by high Fe. Cadmium, Co, Cu, Mn, P and Zn reduce Fe absorption. Iron-deficient diets increase Cd, Co, Mn, Pb and Zn absorption (Pulls, 1994). Forages normally contain relatively high levels of Fe; grains also contain Fe, but to a lesser extent (Wooden, 1990).

2.2.5.3. COBALT

Cobalt is an integral part of the vitamin B_{12} molecule, and it is important in proper blood formation and function (Wooden, 1990). The levels of Cobalt in body tissues are not considered a good guide to Co status in animals because its determination is inconsistent. However liver Co concentrations reflect animal status better than serum. Vitamin B_{12} levels are more reliable indicators of the deficiency than Co levels. Rumen microorganisms use Co to synthesise vitamin B_{12}. More importantly, vitamin B_{12} is involved in the metabolism of propionate to produce glucose. Thus Co deficiency leads among other signs to thiamine deficiency, reduced plasma glucose and alkaline phosphatase levels, elevated pyruvate and pyruvate kinase. Cobalt deficiency reduces the storage of Cu in the bovine liver and possible Co antagonists are Mn, Zn and Iodine (I) (Puls, 1994).

Monensin is reported to increase the need for Co which in turn may replace Zn in carboxypeptidase. Cobalt chloride, nitrate and carbonate are equally bio-available and Co oxide is less bio-available. Cobalt sulphate monohydrate is more effective in this regard. High concentrate diets reduce the availability of Co. Because ruminants synthesise B_{12} from Co, they can utilise dietary Co. Cobalt must therefore be administered orally and preferably continuously because little is stored in the tissues (Puls, 1994).

2.2.4.4. MANGANESE

Manganese is important in carbohydrate and lipid metabolism (Wooden, 1990). The best known function of Mn is its role in bone formation. It is also known as an activator of several enzymes such as arginase, thiaminase, carnosinase and deoxyribonuclease. It is

required for oxidative phosphorylation in the mitochondria, and thus, it is involved in regeneration of ATP from ADP (Jackson, 1997). Monitoring dietary intake is the best indicator aid of deficiency even though signs of deficiency are rare in cattle. Manganese interacts with Ca, Cd, Co, Fe, P and Zn that are antagonistic to Mn. High Mn intake causes reduced Fe absorption and reduced excretion of Cu with a subsequent increase in liver Cu (Puls, 1994). Interactions exist between Fe and Mn, and between Fe and Cu (Johnson & Korynta, 1992).

Dietary requirement of Mn for adult cattle is 40 – 60 ppm DM and for calves on milk replacer, it is 40 ppm. Manganese in silage is less bio-available than in hay and Mn sulphate ($MnSO_4$) is more bio-available than MnO, MnO_2, and $MnCO_3$. Manganese methionine bioavailability appears to be higher than MnO. Pasture Mn uptake is reduced by liming and corn silage is generally low in Mn (Puls, 1994). According to Corah and Arthington (1993), Mn is poorly utilised from the diet by animals. It is estimated that only 14 to 18 percent of ingested Mn is actually absorbed.

2.2.4.5. ZINC

Tissue levels are not a good indicator of Zn status in cattle. It is poorly stored in body tissues and therefore it should be incorporated in correct amounts in the diet (Puls, 1994). Poor basic nutrition, trauma, stress or bacterial diseases and endotoxins which cause fever may lower liver and serum Zn levels to as little as 0.20 ppm but increase kidney Zn. Paradoxically liver Zn levels may also increase with bacterial infections. Interleukin 1 released by activated phagocytes may be responsible for sequestering Zn in the liver where it is required for the synthesis of protein essential for normal host defence. One of the most important signs of deficiency in cattle is weak hoof horn with increased susceptibility to interdigital dermatitis or foot rot. Prevention and treatment of Zn deficiency by ad lib lick or 40 g per head per day of trace mineralised salt mix containing 0.5 – 0.8% Zn is therefore recommended (Mills, 1983).

Zinc interactions with Ca and Cu have been reported by Jackson (1997). High levels of Ca and Cu in the ration was reported to reduce Zn absorption and increased levels of protein or

increased protein intake has been shown to reduce Zn absorption from the gut and increase Zn excretion through the kidney (Jackson, 1997). Excessive Zn reduces Ca metabolism and vice versa. Compromised Zn status in rats was shown to adversely affect Ca metabolism and hence has a detrimental effect on platelet aggregation (O'Dell and Emery, 1991). Zinc, Cu and Fe are mildly antagonistic. High dietary Cu reduces Zn levels in the liver, and reduces hoof strength. Acute infections may alter mineral metabolism and sometimes there is sequestration of Fe and Zn (Miller, 1985) which may complicate the interpretation of the results. Zinc deficiency inhibits utilisation of vitamin A stores, but low dietary P increases tissue Zn levels. Monensin appears to enhance Zn absorption from the gut. Stress increases urinary excretion of Zn but Cr may help alleviate Zn loss in stressed calves. The bioavailability of Zn appears to be similar for all its forms (Zn oxide, carbonate, sulphate, and methionine).

2.2.5.6. SELENIUM

Selenium is a semi – metal that is very similar to sulphur in its chemical properties. Schwartz and Foltz discovered selenium essentiality as a trace nutrient in 1957 when they found that it was an active component of Factor 3, which prevented liver necrosis in vitamin E-deficient rats (MacPherson, 1994). It is an essential constituent of glutathione peroxidase and Se deficiencies leave cells vulnerable to oxidation and increase the requirement for vitamin E (Puls, 1990; Mahan, 1999). Selenium functions as a component of cytosolic glutathione peroxidase (GSH-Px) enzyme that reduces peroxides before they can attack the cellular membranes (Levander, 1986). According to Mahan (1999) recent studies involving the organic selenium functions have demonstrated that other benefits can arise. The organic form has shown some effect such as enhanced meat quality, maturity of feathers, increased milk production and animal fertility and conception rate.

Different dietary forms of Se used in feed are inorganic sodium selenite (Na_2SeO_3) and sodium selenate (Na_2SeO_4). It appears that these two forms are similarly efficient. Selenium concentrations in skeletal muscle and liver, and serum GSH-Px of sheep were not different between Se compounds (Podoll *et al*. 1992). The most used organic forms in cattle are selenomethionine and high-Se yeast. The high-Se yeast is obtained by

growing yeast (*Saccharomyces cereviciae*) in Se-enriched media (Nicholson *et al.* 1991a). Currently the most complete Se manufactured product is Sel-Plex (Alltech, Inc, USA). It includes selenomethionine at 50%, selenocystine and selenocysteine at 15 % each, selenocystathione and methylselenocysteine at 10% each and an infinite proportion of inorganic Se (0.1%) (Mahan, 1999). The bioavailability of selenomethionine is 200% greater than the inorganic forms (Puls, 1994) such as sodium selenite (100%) and sodium selenate (>100%).

Selenium is involved in the protection of biological membranes against oxidation by hydrogen peroxide and other oxidising agents, e.g. free radicals, superoxide and organic hydroperoxide (Charmley *et al*. 1993; Cuesta *et al*. 1993; Nicholson *et al*. 1991a; Pehrson, 1998; Underwood, 1977). Selenium is required for growth and fertility, and for the prevention of various diseases, including nutritional muscular dystrophy or white muscle disease (Arthur and Boyne, 1983; Boila *et al*. 1993). According to Weiss (1998), selenium deficiency does not cause specific clinical signs in cows. General signs of Se deficiency include unthriftiness, reduced productivity, increased susceptibility to infectious diseases and reproductive disorders.

Selenium concentration and GSH-Px activity in blood components and tissues are used for monitoring the Se status of livestock. The level of Se in blood correlates well with Se in tissues (Sankari, 1993a; Sankari, 1993b). The liver is the most labile body tissue for most of the minerals (Boyazoglu, 1997). The highest concentrations of Se occur in the liver and kidneys but the largest total amount of Se is obviously in the muscle mass. Selenium concentrations in the tissues reflect the level of dietary selenium over a wide range. Zachara *et al*. (1993) showed that Se concentrations in the liver increases linearly with the Se level in the diet.

It is estimated that 0.25 mg/kg DM is critical for the development of Se deficiency and 0.4 mg/kg DM as borderline Se deficiency (Binnerts *et al*. 1993). Selenium deposition in tissues bears a direct relationship to the inorganic Se in the diet, up to levels of 0.2 to 0.3

mg/kg of the diet. Intakes that maintain blood Se level of 0.10 or over are sufficient for GSH-Px function (Levander, 1986).

Gerloff (1992) studied the effect of Se supplementation on dairy cattle and found that a reference range of 70 to 100 ng/ml of serum is an acceptable target concentration. A study of tissue selenium concentrations in pigs by Mahan and Kim (1996) showed that a relatively rapid response to glutathione peroxidase (GSH-Px) production from either Se source or Se level was observed. Serum Se concentrations were positively related to the Se inclusion levels from both inorganic and organic sources, and Se-enriched yeast source also substantially increased the animal's tissue Se content beyond that provided by sodium selenite.

According to Jelinek *et al*. (1985) there is an inverse relationship between Se uptake and both the level of dietary selenium and the selenium status. Erythrocyte GSH-Px activity provided a good indication of the selenium status of animals and the level of dietary selenium. Glutathione peroxidase activity in tissues of chickens supplemented or not with dietary Se from baker's yeast (*Saccharomyces cerevisiae*) increased significantly, but lipid oxidation in plasma, blood glucose and plasma α-tocopherol concentrations were not different (Arai *et al*. 1994). In contrast, Miklos *et al*. (1999) found that GSH-Px activity itself is not an adequate indicator for the evaluation of Se status in bulls. (Lockwood and Eckhert, 1992) reached the same conclusion with rats fed sucrose supplemented with Se. However, supplemented rats did not develop microvascular injury, abnormal glucose clearance and hyperinsulaemia whilst the control animals developed these pathologies. Cardiac and skeletal myopathies of cattle due to Se and vitamin E deficiencies were reported (Fenimore *et al*. 1983).

Bioavailability of organically bound Se and some forms of inorganic Se sources differ. The organic form is suggested to be absorbed efficiently (Malbe *et al*. 1995; Pehrson, 1998; Weiss, 1998). According to Pehrson (1998), this fact can be explained by the active transport mechanism of selenomethionine and the biochemical form of selenium in high-Se yeast, as compared to the passive diffusion of inorganic forms of the element. This study

suggested that a higher proportion of dietary Se is retained when it is supplied in an organically bound form. The increased retention is concentrated in the non-GSH-Px selenoproteins in both erythrocytes and organ tissues.

Positive responses to the Se supplementation in terms of performance (ADG and FCR) have been reported in sheep (Van Ryssen, 1992), goat (Wichtel *et al*. 1996) and cattle (Smyth *et al*. 1990). On the other hand, no treatment effects on rate of weight gain or efficiency of feed conversion by the calves were noted in the study by other researchers (Nicholson *et al*. 1991a; Nicholson *et al*. 1991b) even though the Se status was improved. Other investigators (Culleton *et al*. 1993) indicated that performance was not affected in cows on the low-selenium diets. This suggests that despite biochemical evidence of deficiency, animals need not necessarily be affected functionally (Ehret *et al*. 1989).

Beneficial effects of Se on health have been noted, with regard to prevention of respiratory disease and myopathy (Makimura *et al*. 1993; Stabel *et al*. 1989). In other cases, no additional effects due to Se supplementation were noted. For instance, supplemental Se and vaccination with intranasal infectious bovine rhinotracheitis virus vaccine showed no effect on the production of antibody (Eversole *et al*. 1992; Swecker *et al*. 1989). Also Stabel *et al*. (1989) observed varying degrees of morbidity in stressed beef calves fed Se and challenged with *Pasteurella hemolytica*.

2.2.5.7. CHROMIUM

Chromium was first isolated from brewer's yeast in 1959 by Schwarz and Mertz cited by Burton *et al*. (1993). The main action of chromium is thought to be exerted through the regulation of blood sugar. Its deficiency is associated with diabetic-like symptoms. Chromium appears to be an integral part of the glucose tolerance factor (GTF), which facilitates the cellular binding and action of insulin (Depew *et al*. 1998).

The most common chromium forms used in animal feeding are the inorganic chromium, such as chromium chloride, and organic chromiums such as Cr picolinate (Cr-Pic), Cr-nicotinic (Cr-Nic) and High-Cr yeast. The use of the inorganic sulphate form has not been

reported in animal feeding, and the oxide form is very seldom used. Chromium oxide is practically insoluble in water, alcohol and acetone. Chromium chloride ($CrCl_3$) is a violet, lustrous substance with an extremely low rate of solution in water, acids and organic solvents. The commercially available dark green salt is dichlorotetraaquochromium. It is used in chromising, manufacturing of Cr metal and compounds and as catalyst for polymerisation of olefins and other organic reactions, as textile mordant, in tanning, in corrosion inhibitors and as waterproofing agent (Merck & Co, 1996)

Chromium sulphate ($Cr_2(SO_4)_3$) is obtained by preparation of anhydrate salt by dehydration of hydrated forms. Hydrates are known in both green and violet modifications, and have several degrees of hydration up to $18H_2O$. The end product is a finely granular dark- green flake or powder readily soluble in water, which is almost insoluble in alcohol. It is used in insolubilisation of gelatine and also, like the previous form, in catalyst preparation; as mordant in textile industry and in tanning (Merck & Co, 1996).

Chromium picolinate is the biologically active form of chromium. It has a clinical effect on insulin metabolism, and it has been widely used in many studies. This organic form is more readily absorbed than the chloride form, which is absorbed at very low levels (3 – 4%). Chromium absorption is inversely related to dietary intake. That is why the content of total Cr in a diet has little relationship with its effectiveness as biologically active Cr. It is believed that the improved performance with chelated Cr or high-yeast Cr as observed in different trials (Anderson *et al.* 1997; Moonsie-Shageer and Mowat, 1993; Mowat *et al.* 1993) may be related, in part, to improved absorption of Cr. It is suggested that when minerals are chelated properly they are not precipitated and non-gut ionisable, and are absorbed at a more rapid rate than minerals from equivalent metabolic salts (Corah and Arthington, 1993; Mowat *et al.* 1993). But sulphate salts are very soluble and therefore they may have similar bioavailability, such as organic or protected minerals (Boyazoglu, 1997). This is the case with Cr sulphate, which is as soluble as Cr picolinate (Merck & Co, 1994). Differences can be seen also among different organic forms of Cr. Mowat *et al.* (1993) found that chelated Cr was more effective than high-Cr yeast in their trial.

Supplemental Cr has been shown to improve glucose tolerance and a number of production parameters in swine (Southern & Page, 1992; Lindemann *et al*. 1995; Anderson *et al*., 1997). In contrast, supplemental Cr did neither alter growth performance nor did it lower plasma cortisol and insulin/glucose ratio in weanling pigs (Lee *et al.* 1997). Fasting plasma glucose and total protein concentrations in pigs are not affected by dietary treatment with Cr-Pic (Amoikon *et al*. 1995). No differences in performance were observed in pigs fed different forms of Cr, i.e. chromium from Cr-Cl3, Cr-Pic and CR-Nic acid (van Heugten and Spears, 1997).

Positive production responses (increased ADG) to supplemental Cr have been reported in cattle (Chang & Mowat, 1992; Moonsie-Shageer & Mowat, 1993). It appears that these responses depend on the presence of stressors (Depew *et al*. 1998) such as weaning and transportation. Although equivocal, it has been suggested that chromium can lower cortisol level, improve performance and enhance the immuno-competence of stressed feeder calves (Moonsie-Shageer and Mowat, 1993; Mowat *et al*. 1993). Improved feed efficiency (Mowat, Chang *et al.* 1993), decreased plasma cholesterol and increased rate of glucose clearance (Bunting *et al*. 1994) were observed in weaned, stressed calves. Short-term decrease in serum cortisol following infectious bovine rhinotracheitis (IBR) infection in preweaned calves was observed in another study (Kegley *et al*. 1996). There are however, more studies reporting the lack of responses to Cr supplementation in terms of improved live weight gain or feed conversion efficiency (Bunting *et al*. 1994; Chang *et al*. 1996; Kegley and Spears, 1995; Mathison and Engstrom, 1995; Wright *et al*. 1994).

Burton (1995) reported that cattle might be Cr-deficient during stressful periods. The effect of Cr in lowering cortisol could be due to improved insulin or insulin-like growth factor I sensitivity in target tissues such as muscle, mammary gland and the immune system. This sensitivity, as shown elsewhere, is age related as older animals are insensitive to insulin (Depew *et al*. 1998). They observed enhanced insulin sensitivity in calves fed milk replacer or starter supplemented with Cr-tripicolinate in their study. But concentrations of plasma cortisol were not affected by Cr supplementation.

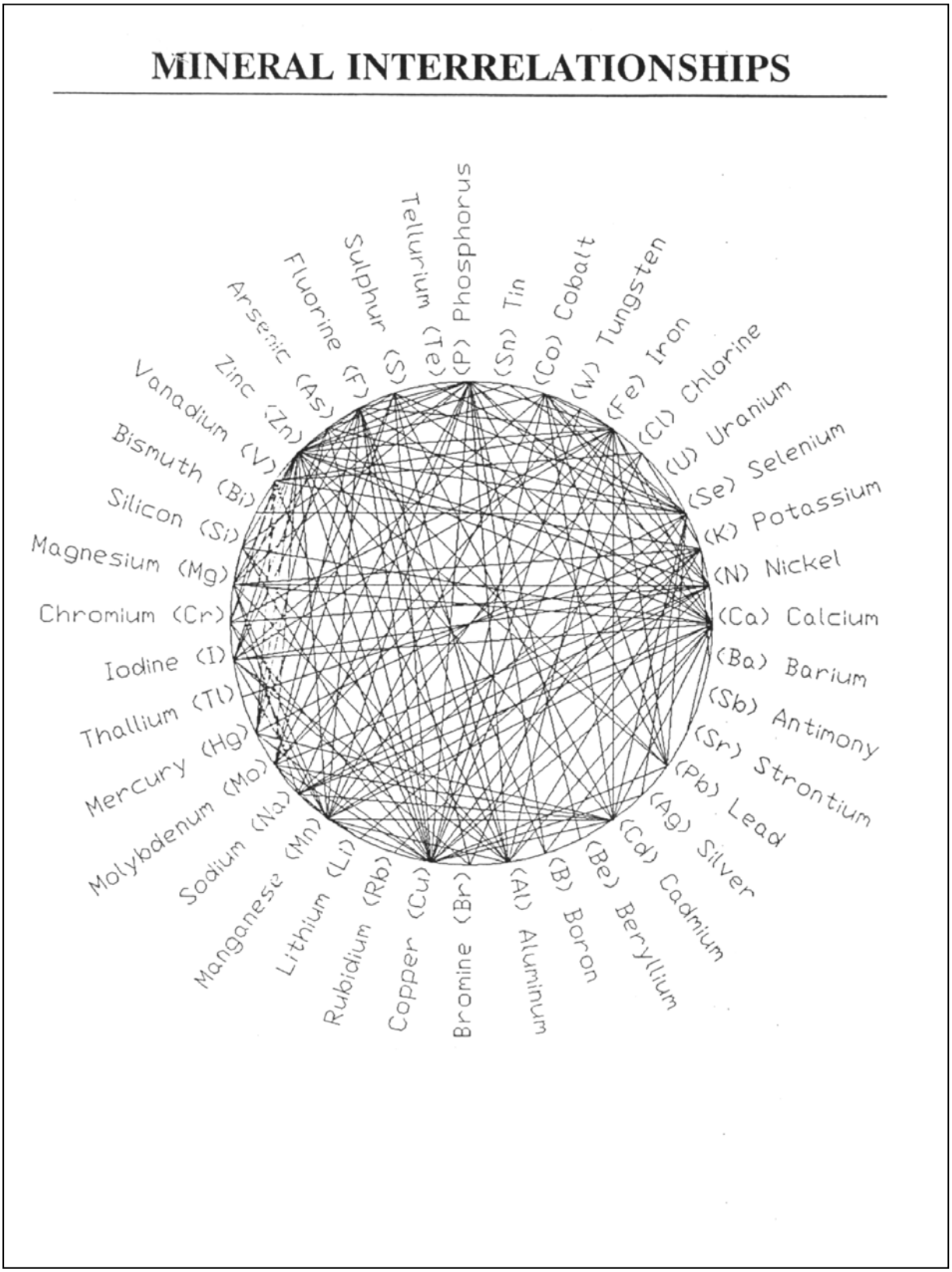
There is a link between cortisol and glucose metabolism that may be considered when assessing stress in animals especially in young calves. Depew *et al* (1998) have demonstrated that cortisol concentrations could be important in the neonate that is susceptible to stress. It seems that there is site between the point of entry of glucose into the cells and its final degradation. Cortisol directly slows the rate of glucose utilisation. It is plausible that neonate calves would be more metabolically responsive to Cr supplementation than adult.

Supplemental Cr decreased blood glucose level (Anderson *et al*. 1997; Depew *et al*. 1998) suggesting that energy has been used efficiently and redirected to lean deposition. But modest effects of supplemental Cr were seen on glucose tolerance or other indices of glucose metabolism in adult ruminants. Average daily gain and gain:feed ratio, average plasma concentrations of glucose, creatinine, urea, total protein or insulin were affected by treating steers and heifers with Cr-picolinate (Bunting *et al*. 1994). Kegley & Spears (1995) compared the effect of different forms of Cr, such as Cr chloride hexahydrate, high-Cr yeast, and Cr nicotinic acid complex in respect of performance and cortisol levels. They found no significant effect of Cr supplementation on performance and cortisol levels. However, steers supplemented with Cr nicotinic acid had greater serum insulin concentrations and tended to have a more rapid glucose clearance rate.

Depew *et al.* (1998) in a recent study of performance and metabolic responses of young dairy calves to supplementation with 1 mg/kg DM of Cr-tripicolinate showed a higher growth rate in males than females. Glucose tolerance rate was increased in heifers and neonates but aged calves were less sensitive to insulin. Kegley *et al.* (1996) fed weaner steers with maize silage supplemented with 0.4 mg per kg DM of Cr-nicotinic acid complex (Cr-Nic). They found that ADG was only improved before the animals were submitted to challenge. In an earlier study (Kegley and Spears, 1995) with 7day old calves fed milk substitute both supplemental $CrCl_3$ and Cr-Nic did not alleviate Cr lowering on day 5 after challenge. Arthington (1997) did not observe a good performance response to chromium supplementation. Chromium as High Cr yeast did not decrease stress in experimental calves (van Heugten and Spears, 1997).

Stress may induce or confound a Cr deficiency state because trauma, disease, and physical exertion cause increases in glucose metabolism and cause mobilisation and urinary loss of Cr. Therefore, Cr supplementation may have a significant effect during stress. Chromium supplementation is thought to prevent other mineral losses during stressful conditions (Schauzer *et al.* 1986 cited by Moonsie-Shageer and Mowat, 1993). However, the magnitude of the response to supplementation is correlated to the degree of depletion of chromium, time/dose effects and, most importantly, to the big extent of the target tissue which is the muscle (Lindermann, 1996). This explains why results with supplementation have been variable (Bunting *et al*. 1994; Moonsie-Shageer and Mowat, 1993; Mowat and Chang, 1992).

FIGURE 2.1: MINERAL INTERACTIONS (Source: Puls, 1994)



2.3. STRESS PHYSIOLOGY

According to Cole *et al*. (1988) feeder calves encounter numerous physiological and psychological stresses during movement from one production point to another. These stresses include feed and water deprivation, weaning, inclement weather, antagonistic encounters, infectious agents, confined environment and transport. The stresses induce hormonal, anorexia, exhaustion and nutrient losses, altered nutrient metabolism, dehydration, behavioural changes, as well as suppressed immune response. Most importantly animals are subjected to a hypermetabolic state in which nutrient balance is reduced, even without a decrease in nutrient intake. In general, corrective measures aimed at adjusting the loss of nutrients are inefficient because of low feed intake caused by a combination of factors, such as poor ruminal function and metabolic adaptations that occur during stress.

Among all these stresses, transportation stress alters rumen function, serum biochemical constituents and serum cortisol concentration more than does fasting alone (Cole *et al*. 1988). In this study, transportation caused a significant increase in shrinkage compared to fasting alone in the first 12 hours and affected the average daily gain and gain-to-feed ratio during the first 28 days in the feedlot. It is obvious that calves suffer the associated losses of shrinkage, inefficient gain and occasional death when they first enter the feedlot. The magnitude of these losses and the public concern about indiscriminate use of antibiotics make it imperative that better methods be developed to control bovine respiratory disease (Mowat *et al.*, 1993) through the minimisation of the main cause, which is stress. Trace minerals constitute one of the safer ways of dealing with this problem. But protein and mineral requirements of stressed cattle do not appear to be higher than those of non-stressed calves even though the concentrations in the receiving diet must be increased to compensate for reduced intake (Cole, No date).

In feedlot practice, stress is assessed by the degree of shrink or weight loss which is due primarily to losses of body and digestive tract water (Hutcheson, 1992). This loss is accompanied by depletion of body minerals and vitamins. Increased chromium excretion in urine has been reported (Burton, 1995). The plasma concentration of cortisol has been

widely used to reflect the effect of different stresses (Jensen-Waern and Nyberg, 1993). Cortisol is a useful indicator of short-term stresses such as transport and handling. It is a time-dependent measure that takes 10 to 20 minutes to reach peak values (Grandin, 1997). Long-term stresses like environment, and the effect of different housing (and probably feeding) are much more complex and difficult to assess according to Grandin (1997). That is why other indicators such as blood glucose level and liver minerals, will be employed in the present study. In fact, during stress, glucose metabolism increases simultaneously with increased secretion of cortisol, as well as an elevation of blood glucose and increased urine chromium secretion (Burton, 1995).

It is believed that during stress cortisol acts antagonistically to insulin, preventing entry of glucose into muscle and adipose tissue and sparing it for tissues of high demand (e.g. liver and brain). Given that Cr enhances the activity of insulin, a potential "anti-stress" role for Cr could be hypothesised (Burton *et al*. 1993). Cortisol is a glucorticoid hormone produced by the adrenal cortex. Like all the steroid hormones, which are not stored in the body, cortisol is synthesized and secreted on demand. The liver converts cortisol to cortisone, but cortisone does not enter the circulation, therefore, the amount of cortisol determined in the blood reflects the actual level of this hormone.

Cortisol secretion is regulated by the hypothalamic-pituitary-adrenal axis. Various factors that affect the secretion of cortisol include the circadian rhythm, stress factors and negative feedback. The highest cortisol concentration occurs in the morning and the lowest concentrations occur around midnight. That is why blood sampling for cortisol determination should be done at the same time each day. Stress factors affecting cortisol secretion in feedlot are physical or psychological.

The physical stress is manifested by hypoglycaemia due to lack of feed during transportation, trauma in trucks, handling at arrival, cold and heat exposure. Long distance travels, in overcrowded trucks, with additional fumes, dust and pain during processing (castration, dehorning etc…) can be added to this long list. Psychological stress is due to weaning, new environment, new handlers, new diets and commingling of

animals of different origins. Negative feedback loops are seen when an increased concentration of cortisol feeds back to the anterior pituitary to reduce its production and release of ACTH or feeds back to the hypothalamus to reduce the production and release of CRH (corticotrophin releasing hormone). According to Jensen-Waern & Nyberg (1993), cortisol is transported to its target cells bound to proteins. Thus, only 5 % of the cortisol in blood is in the free state and only free cortisol produces physiological effects.

Cortisol is a lipid soluble hormone that exerts its primary effects through the gene expression on the skeletal muscle, liver and adipose tissue. In the skeletal tissue, it increases protein catabolism and decreases protein synthesis and thus raises the plasma amino acid concentration. Cortisol also reduces the glucose uptake, which, in return, raises the plasma glucose concentration. In the liver, it increases the gluconeogenesis by which Amino Acids (AA) are converted to glucose therefore raising the plasma glucose concentration. In the adipose tissue, it reduces glucose uptake, thus increasing the glucose concentration of the plasma. It provokes the increase of lipid mobilisation and lipolysis in which case the free fatty acid concentration in plasma is increased. The free fatty acid thus formed can be used for cell oxidation needs and this spares the use of glucose for metabolism purposes. It shows however that the overall effect of cortisol is to raise the glucose concentration of the plasma, to shift the energy metabolism to lipid oxidation and to make the amino acids available for tissue repair.

Cole *et al.* (1988) investigated the stress level in calves during the first days in a feedlot. They found that blood cortisol, albumin, cholesterol and many other parameters were not altered. They concluded that the animals had become used to the regular monitoring and handling. However, the serum glucose concentration increased as the duration of transport increased. According to Chang & Mowat (1992), stress often leads to elevated glucose metabolism and utilisation. The increased utilisation of glucose leads to the mobilisation of Cr in the blood. It appears that, if Cr is mobilised, it is not reabsorbed, but it is excreted in the urine. This mechanism explains how Cr deficiency occurs during stress in the feedlot. Chromium is a nutritional substance and not a therapeutic product. As such, it will act during the period of deficiency such as during stress. Because stress in a feedlot is

constant, i.e. more physical during the adaptation period but dietary later, it is believed Cr would be beneficial to feedlot animals for the whole feeding period.

Selenium has been very rarely investigated for its effect on stress alleviation. Data related to cortisol and glucose metabolic changes due to Se supplementation is scarce. However, there is indication that glucose concentration might be positively related to Se status. Blood glucose was decreased in Se deficient cows (Salewski and Seegers, 1994). In contrast, Klawonn *et al*. (1996) found a little difference between Se deficient and adequate cows. Giurgia and Roman (1992) found that Se given alone or in combination with vitamin E was associated with increased glucose absorption. Pigs injected with sodium selenate with or without vitamin E failed to show an increase in serum cortisol following exercise (Jakubowski *et al*. 1989). The effect of supplemental Se and vitamin E was also investigated in fighting cows by Garcia-Belenger *et al*. (1991). They noted an increase in GSH and serum activity of the muscle enzymes was lower in supplemented cows. This short review shows that Se might be involved directly in stress alleviation. The mechanism of action is probably through its effects on stress oxidation.

2.4. MEAT COLOUR

Consumers judge meat quality by the three sensory properties, i.e. the appearance, texture, and flavour (Laurie, 1985). Of these three meat attributes, appearance is the most important one since it influences the initial decision to purchase or reject the product (Liu *et al*. 1996a; Sheehy *et al*. 1997). Fresh beef is cherry-red in colour, but with time this is followed by a brownish discolouration of the meat surface, which may be interpreted as unwholesomeness (Liu *et al*. 1996b).

The quantity of myoglobin and the type of myoglobin molecule, its chemical state and the chemical and physical condition of other components in the meat determine the meat colour. Of these components, myoglobin, oxymyoglobin and metmyoglobin are the main components of fresh meat colour. Myoglobin is obtained by the reduction of metmyoglobin or de-oxygenation of oxymyoglobin; it determines a purplish-red colour. Oxymyoglobin is the bright red pigment, derived from the oxygenation of myoglobin; it

is the most important in determining the colour of fresh meat. Metmyoglobin comes from the oxidation of myoglobin and oxymyoglobin; this is accelerated by any factor which causes denaturation of the globulin (Laurie, 1985; Liu *et al.*, 1996b).

One of the main factors which lead to this denaturation and limits the acceptability of meat and meat products is the process of lipid oxidation. Lipid oxidation may also have food safety implications because there are concerns about the possible atherogenic effects of lipid oxidation products like malondialdehyde and cholesterol oxides in the body. Preventing lipid oxidation during processing, storage and retail display is essential in order to maintain the quality, wholesomeness, and the safety of the meat, so as to ensure that customers will make repeat purchases (Sheehy *et al.*, 1997).

Shelf life of meat is more likely assessed by the proportion of metmyoglobin. It is the most commonly occurring undesirable pigment on meat surfaces and it is noticeable when about 60 percent of myoglobin exists in this form. Besides the pH, other factors like heat, salts and ultra-violet light are implicated in metmyoglobin formation. Prolonged storage can cause surface desiccation and increasing salt concentration, which will promote the formation of metmyoglobin. Once formed, metmyoglobin is reduced both anaerobically and aerobically by surviving enzymes of the cytocrome system (Laurie, 1985).

Ground beef tends to become brown and rancid more rapidly than whole muscle cuts. Grinding exposes a greater surface to the air for microbial contamination, and accelerates the loss of intracellular reductants, which help to minimise metmyoglobin formation (Mitsumoto *et al.* 1991). Vitamin E was effective in lowering initial and final percentage of metmyoglobin in Holstein beef patties and thereby extending shelf life (Mitsumoto *et al.* 1993).

The oxidative stability of meat is low and difficult to predict accurately for the retailers (Sheehy *et al.* 1997). Attempts have been made to avoid browning due to metmyoglobin formation by incorporating ascorbic acid in meat products to reduce the oxidised

pigment, but this was forbidden in the United Kingdom in the seventies (Laurie, 1985). Most importantly, reduced metmyoglobin does not automatically take up oxygen to form the oxymyoglobin. The relative absence of muscle glycogen in the immediate pre-mortem period, to which a high ultimate pH is usually due, is also responsible for failure to produce an appreciable quantity of glucose post-mortem. That is why it is assumed in the present study that, chromium, by improving glucose utilisation in cattle, will produce a low meat ultimate pH and therefore it will maintain a low level of metmyoglobin thereby allowing a longer storage of meat and a better shelf life.

Lipid oxidation in meat is initiated in the phospholipid fraction of subcellular membranes probably by Fe. This fraction is characterised by the presence of relatively high levels of polyunsaturated fatty acids (PUFA). It appears that some low-molecular weight water soluble chelated Fe facilitates the generation of radical species that abstract loosely bound hydrogens from the PUFA. Some high molecular Fe such as hemoglobin and myoglobin can directly catalyse lipid oxidation (Sheehy *et al.*, 1997). Thus, Fe released from ferritin during storage, processing and cooking may also catalyse lipid peroxidation in muscle foods. The rate and extent of oxidation may also be influenced by pre- and post-slaughter events such as stress, rate of pH fall, carcass temperature and by the disruption of muscle membrane integrity by mechanical deboning, mincing, restructuring or cooking (Sheehy *et al*, 1997).

According to Aass (1996), the heritability of meat colour is very low (0.27) and the growth rate is negatively related to the meat colour. It has also been demonstrated that meat from animals with a high growth rate had an undesirable low percentage of intramuscular fat and marbling and a paler than average colour. It appears that adequate means have to be used in order to improve the meat colour and extend its shelf life.

Lipid oxidation can be prevented or at least retarded. In living animals, an enzymatic system including for example glutathione peroxidase protects against the formation of free radical known to initiate the oxidation reaction. After slaughter, the anaerobic

glycolysis results in the accumulation of lactic acid in the tissue. This lowers the pH to approximately pH 5.5. which is the ultimate pH for meat (Laurie, 1985).

Studies have shown that vitamin E can delay or reduce the lipid oxidation in fresh meat during the display (Buys *et al.* 2000; Sheehy *et al.* 1997). But the reduced lipid oxidation did not influence pork color (Cannon *et al.* 1996). Liu *et al* (1996a) investigated the colour stability in different muscles including Longissimus lumborum, semimembranosus and gluteus from Holstein steers fed different doses of vitamin E for 14 d. The effects of vitamin E were determined on retention of the redness, the yellowness and the colour saturation as well as the proportions of redness and yellowness. They found that the dietary vitamin E supplementation stabilised the redness, and colour saturation. It decreased the yellowness, and extended the colour display life of fresh beef. In a subsequent study, Liu *et al.* (1996b) found again that vitamin E extended the colour display life of fresh beef but the efects of dose and duration of supplementation were noted as well. Increasing the dose and the duration of vitamin E supplementation delayed the formation of metmyoglobin.

Both the rate and the extent of the postmortem pH fall are influenced by intrinsic factors such as species, type of muscle and variability between animals; and by extrinsic factors such as the administration of drugs preslaughter (Laurie, 1985). When the pH fall is slow, the stiffening of the muscle is delayed and this has implication on meat tenderness. The loss of muscle extensibility reflects the actomyosin formation; it happens sooner if there is little glycogen stored. The onset of rigor mortis (stiffening) is accompanied by lowering in water capacity (Laurie, 1985). It is obvious that any treatment, which allows better storage of glycogen in the muscle and maintains adequate water-holding capacity is recommendable for the eating quality of meat such as tenderness. Thus because Cr supplementation was shown to increase the incorporation of glucose into glycogen in rats (Rosebrough & Steele, 1981), it is believed that Cr supplementation would be beneficial in this regard.

TABLE 2.1: SUGGESTED TRACE-MINERAL LEVELS (mg/kg DM) IN FEEDLOT CATTLE STARTER DIETS

Mineral	**Range (1)**
Copper	10 -15
Iron	100 - 200
Manganese	20 - 30
Zinc	50 - 70
Cobalt	0.1 – 0.2
Selenium	0.1 – 0.2

Sources: (1)Wagner *et al*. (No date)

NB. Vitamin A is supplemented at the rate of 1000-1500 IU/kg.

TABLE 2.2: MEAN VALUES OF LIVER MINERAL CONCENTRATIONS (PPM) FOR FEEDLOT BEEF CATTLE ON WET BASIS

Mineral	Concentrations			Observation
	Deficient(1)	Adequate(2)	LAB (3)	
Calcium	40	30 - 200	50	Adequate
Phosphorus	2000 - 4400	2000 - 4000	2200	Adequate
Magnesium	<40 - 200	100 – 250	150	Adequate
Cobalt	0.005 - 0.017	0.020 – 0.085	4.80	High
Copper	0.5 – 10	25 - 100	40	Adequate
Iron	<30	45 - 300	120	Adequate
Manganese	<1.0 –3.0	2.5 – 6	4	Adequate
Zinc	<20 – 40	25 - 100	45	Adequate
Potassium	<1400	1400 - 4000	2000	Adequate
Sodium	<800	900 - 1800	500	Deficient
Selenium	0.02 – 0.25	0.25 – 0.50	0.20	Marginal
Chromium	<0.04	3.8	0.20	Adequate

Sources:

(1)(2) Puls, 1994

(3) Animal Nutrition laboratories, Medunsa and Onderstepoort (South Africa) (Mean values)

"Give us the tool and we will finish the job"

Winston Churchill

CHAPTER 3. MATERIALS AND METHODS

This section describes general procedures used in all the experiments. In those instances where other procedures were used, the methods applied are given in the relevant experiments. However, feed and liver sample preparation methods are those accredited by the Agricultural Laboratory Association of South Africa (ALASA)(ALASA, 1998).

Owing to the complexity of the study and due to financial limitations, the research was carried out over three years, i.e. in 1996, 1997 and 1999. The first experiment aimed to compare the effect of sodium selenite and high-Cr yeast, and their combination on performance, carcass characteristics and liver tissue minerals. Meat colour improvement study was carried out as a separate experiment only in 1996 because of the high costs involved. Organic forms of minerals have been quoted as more available to the animal and therefore more effective sources (Corah and Arthington, 1993; Gadd, 1995; Mahan, 1999). Thus, in the third experiment, an inorganic and cheaper (Boyazoglu, 1997) form of Cr as Cr sulphate was added to the basal diet.

The 1996 and 1997 experiment results indicated that combining Se and Cr was more effective in stress alleviation and subsequently improved the animal performance. It was assumed that the combined selenium-chromium premix was more effective than single elements. In the third experiment, different forms of combined selenium-chromium premixes were used. For the purpose of clarity and due to the fact that these experiments were not repetitive, these four experiments are presented in different chapters in this thesis.

3.1. EXPERIMENTAL ANIMALS

Animals were handled and cared for according to the norms established and accepted by the Medunsa Animal Care and Ethics Committee. They were weaners at six to nine months of age in all the four experiments. They were processed in accordance with usual feedlot management procedures which included: deworming, tick control, immunisation

against bovine respiratory disease, anthrax, botulism and clostridial diseases. Castration and horn tipping were done where applicable. All animals were implanted with two different growth promoters, i.e. on d 0 with RalgroND (Hoechst, SA) and 7 weeks later with RevalorND (Hoechst, SA).

3.2. FEED AND FEEDING MANAGEMENT

Fresh feed was mixed regularly at the Farm Animal Production Unit of the University. Feeding was ad libitum. Special care was taken to provide only fresh feed and fresh water. Any left over or spoiled feed was collected and weighed in order to determine the correct consumption of the group. Individual predicted feed conversion ratio (P-FCR) was computed with the following formula proposed by Meissner (1998).

P-FCR: 13.33 – 6.2 ADG + 0.855 ADG^2 (R^2 = 0.91)

Where:

P-FCR is Predicted Feed Conversion Ratio; ADG is Average Daily Gain; ADG^2 is Average Daily Gain square; R^2 is Coefficient of Determination. 13.33, 6.2 and 0.855 are constants.

Feed samples were regularly taken and checked for major nutrients, namely: DM, crude protein and crude fibre, calcium, phosphorus and magnesium. Premixes were prepared by Neuvet (Pty) Ltd (RSA).

Table 3.1 presents the composition of the basal premix used in all the trials. The control ration was a basal diet providing required levels of energy, protein, crude fibre, calcium and phosphorus. A specific treatment diet consisted of the basal diet to which 0.3 ppm of selenium or 0.3 ppm chromium or combined selenium (0.3 ppm) x chromium (0.3 ppm) in different chemical forms according to the experimental design was added. Selenium is approved in the Republic of South Africa (RSA) for use in livestock production as a feed additive at 0.3 ppm (Act 36 of 1947) (van Ryssen, 1996). For Cr, since no specific dose has been defined in the country, it was suggested to use an arbitrary dose of 0.3 mg. However, this dose has been widely used among other treatments in some prominent studies

(Moonsie-Shageer, 1993; Wright *et al.* 1994; Bunting *et al.* 1994; Chang *et al.* 1995; Kegley *et al.* 1996).

3.3. PERFORMANCE MONITORING AND SLAUGHTERING

Daily feed intake and live weight gain were used to monitor performance. Feed intake was recorded on a pen basis daily and feed conversion was computed when necessary. Animals were weighed full stomachs on specific days according to trial time schedule. Slaughterings were done the next morning after the experiment was completed at specialised abattoirs. Specialised personnel at the abattoirs did carcass classification and measurements. A minimum of 200 g of fresh liver tissue was obtained from each steer and stored for at least two weeks in 10 % formalin before further processing. These samples were preferred to biopsies as suggested in the defence of the research protocol because Millar and Meads (1988) indicated that there is no pattern of distribution of selenium throughout the liver. They suggested that the analysis of liver biopsy samples give only an approximate assessment of the mean hepatic concentration.

3.4. SAMPLE PREPARATIONS AND ANALYTICAL PROCEDURES

3.4.1. BLOOD SAMPLES

Blood samples were obtained by jugular vena puncture on d 0, d 14 and d 42. These blood samples were collected into evacuated glass tubes containing sodium fluoride-potassium oxalate for glucose, and plain silicone coated tubes for cortisol determinations. Plasma glucose determination at the Medunsa/Chemical pathology department was made using the SYNCHRON SYNCHRO System SYNCHRO MULTI Calibrator (Beckman Instruments, 1993). Quantitative determination of cortisol levels in serum was made using the Clinical Assays GammaCoat Cortisol Radioimmunoassay Kit (Incstar Corporation - Stillwater, Minnesota, USA).

3.4.2. LIVER SAMPLES

Liver samples of approximately 200 g of parenchyma tissue were used. Precaution was taken to avoid large blood vessels. Liver samples were only processed after, at least, 10 days of fixing in 10% formalin. Ten to 20 g of fresh liver was cut into small pieces and

allowed to dry (air) for 3 to 4 days before grinding as described by ALASA (1998). The ground liver samples were kept in sealed plastic containers until digestion for the determination of minerals was done. For selenium analysis, small blocks of fresh liver tissue were kept in 10% formalin until digestion.

3.4.2.1. LIVER PREPARATION FOR MINERALS DETERMINATION

Reagents: concentrated HNO_3 and H_2SO_4.

Description:

To get an equivalent of 2 g wet liver, 0.6 g of dry ground liver sample was weighed and placed into a long necked digestion tube. Thirty (30) ml of concentrated HNO_3 and 3 ml of H_2SO_4 were added; the tubes were boiled continuously but cautiously to ensure that the content did not boil over. Three (3) ml of concentrated HNO_3 was added when the preparation was starting to blacken. If the sample did not clear, boiling with the addition of HNO_3 was continued. When 1 to 3 ml of clear liquid was formed at the bottom of the digestion flask, the preparation was transferred to a 50 ml volumetric flask and made up to 50 ml mark with distilled-deionised water.

3.4.2.2. FEED PREPARATION FOR MINERAL DETERMINATION

Reagents: concentrated HNO_3, concentrated HCl, 10% HCl

Description: One g of milled feed was accurately weighed into a porcelain crucible and ashed at 600^{o} C overnight in a muffle furnace. The ashed sample was then cooled and moistened with 1 ml concentrated HNO_3, dried on a boiling water-bath and ashed again for 60 minutes at 520^{o}C. Two (2) ml of concentrated HCl was added to the ash and the crucible was placed in the water bath to evaporate to dryness. Finally 20 ml of 10% HCl was added and the sample left to evaporate to dryness. The residue was transferred to a 100-ml volumetric flask and made up to full volume with deionised water. Aliquots of the final solution were used for the determination of minerals.

For calcium and magnesium measurements on the Atomic Absorption Spectrophotometer, 1 ml of the sample was mixed with 9 ml of 0.1% Lanthanum Chloride and well vortexed.

3.4.3. FEED AND LIVER PREPARATIONS FOR SELENIUM DETERMINATION

Reagents:

(1) Digestion mixture: 1:4 mix of $HClO_4$ and HNO_3, (2) 10% v/v HCl.

Description:

Due to variation in results, probably due to the difficulty to homogenise the temperature in the dry digestion block, the method was modified to a digestion system in a glycerol water bath under reflux. This method consisted in the digestion of 2 g of the small blocks of wet liver sample or 1 g of the milled feed in a digestion flask in the presence of 30 ml of the digestion mixture (1). The first heating took approximately 120 minutes. Without stopping the process, 10 ml of 10 % HCl was added to the preparation and heated for a further 60 minutes. Flasks were removed to cool down if more samples were to be processed or otherwise the water bath was switched off and the flasks allowed to reach room temperature. The preparation was transferred to a 50 ml volumetric flask with 10% HCl and made up to full volume.

Standard and blank preparations were carried out along with the sample. A blank preparation was carried out each time. For the standard (1ppm) preparation, 0.5 ml of the 100 ppm Se standard dilution was used as sample.

3.4.4. ANALYTICAL METHODS FOR FEED AND LIVER SAMPLES

Feed samples were analysed by proximate procedures for nutrients:

- The nitrogen (N) content, as an indication of crude protein (CP) of the feed samples was determined on the FP 428 NITROGEN DETERMINATOR (LECO Corp.);
- Dry Matter (DM), Ash and crude fibre (total) as per laboratory methods by ALASA (1998);
- Crude fat as per modified Soxhlet Method with hexane as an extracting solvent.

Mineral determinations in feed and liver were done using specialised laboratory procedures. The Ca, Mg, Cu, Fe, Mn, Co, Cr, Zn content of feed and liver samples were determined on a Flame Atomic Absorption Spectrophotometer (FAAS) (Perkin Elmer, Model 5100 PC). The P content of the feed samples was determined by spectrometry

(Sequoia - Turner Corp.). The anhydride generator for atomic absorption was used for Se (FIAAS 100, Perkin Elmer).

3.5. STATISTICAL ANALYSIS

An extensive appendix enclosing all the raw data is collated at the end of this study. The data was analysed by Analysis of Variance (ANOVA) using the General Linear Models (GLM) procedure of SAS version 8.3 (SAS Institute Inc., 1999). It should be noted that unless stated otherwise, tabulated data are least square means. Discrepancies may arise if it is attempted to calculate one value from another through simple arithmetic. Student's t test was used for comparisons of two means. The 5% probability ($P \leq 0.05$) was used as the significance level.

TABLE 3.1: PREMIX FORMULATION FOR TON LOTS – EXPERIMENT 1, 3 AND 4

Item	Amount
Vitamin A	5,000, 000 IU
Copper	10 g
Manganese	10 g
Zinc	20 g
Cobalt	0.50 g
Magnesium	150 g
Ferrous	20 g
Iodine	1 g
Se and/or Cr ([1])	0.3 g

([1]) Selenium and/or chromium were added or not in accord with each trial design.

CHAPITER 4: SELENIUM AND CHROMIUM INTERACTION EFFECT IN STRESS ALLEVIATION, PERFORMANCE AND CARCASS CHARACTERISTICS OF FEEDLOT CATTLE – EXPERIMENT 1

4.1. INTRODUCTION AND AIM

The dietary supplements of Se and Cr have been described separately in animal production. Studies using Se only have been conducted on cattle feeding (Counotte and Hartmans, 1989; Essig *et al*. 1993; Eversole *et al*. 1992; Kincaid *et al*. 1999; Lawson *et al*. 1990; Swecker *et al*. 1989; Weiss, 1998).

Chromium has been investigated in weaned, stressed and growing cattle (Burton *et al*. 1994; Chang and Mowat, 1992; Chang *et al*. 1996; Kegley and Spears, 1995; Moonsie-Shageer and Mowat, 1993; Mowat *et al*. 1993; Mowat and Chang, 1992; Mowat *et al*. 1994; Wright *et al*. 1994). But none of these studies have investigated the effects of the interaction between the two elements.

This preliminary study in feedlot cattle was therefore designed:

- To assess the effect of supplemental selenium and chromium on stress alleviation during the adaptation period in the feedlot
- To determine the magnitude of the response to supplementation on animal performance and carcass characteristics
- To determine the status and interaction of major minerals and trace minerals in feedstuffs, the feed rations and the bovine liver tissue samples.

4.2. HYPOTHESIS

It is proposed that dietary supplements of Cr and Se:

- Alleviate stress by decreasing the blood cortisol and glucose levels
- Improve the performance and carcass characteristics, e.g. increased growth rate, higher carcass mass for lower carcass fat
- Improve the mineral status by increasing the liver tissue retention of minerals and trace minerals.

4.3. MATERIALS AND METHODS

4.3.1. ANIMALS AND EXPERIMENTAL DESIGN

The animals were from Gillimberg Farms; a governmental cooperative situated 250-Km north of Pretoria in the Northern Province of the Republic of South Africa. Four weeks before weaning, a homogenous group of 75 Brahman-Bonsmara-Nguni cross male calves were selected. They were seven to nine months old and weighed between 150 and 180 kg. They were randomly sorted into twelve groups of six and the different groups were allocated at random to the different treatments. The animals were then ear-tagged according to the experimental design shown in Table 4.1. The blood samples were collected for antibody determination and thereafter the animals were vaccinated with three different batches as described in the experimental design (Table 4.1). The vaccine batches were part of a separate clinical trial.

At weaning, the animals were transported to the Medunsa experimental feedlot. They were processed after two days of adaptation to the standard diet (control) and hay. The processing on d 3 was done according to the general procedures described in Chapter 3. Specific procedures for this trial were sorting the 12 treatment groups, the inoculation with one of the three batches of Leukotoxin/IBR/PI^{3} (for a separate clinical trial), botulism and anthrax vaccines (Onderstepoort, SA), tick control with Ectoline ND (Bayer, (Pty) Ltd) and deworming with ValbazenND (Pfizer, (Pty) Ltd). The diets were supplemented according to treatment groups with 0.3 mg of sodium selenite per kg DM and 0.3 mg of high-Cr yeast per kg DM.

4.3.2. PERFORMANCE AND CARCASS PARAMETERS

The animals were weighed full stomachs on d1 and fortnightly subsequently. On d121, they were weighed and transported to the Johannesburg City Deep Abattoir (approximately 90-km from Medunsa) for slaughtering the next day. The liver samples were taken and kept in 10 % formalin solution for further processing.

Trained personnel recorded the warm and cold carcass weights at the abattoir as per routine. The meat pH measurements were performed 60 minutes and 24 hours after

slaughter by insertion of the probe in the cut of *m. longissimus*. The pH-meter Hanna Instruments HI 8424 Microcomputer[ND] was used in this trial. The carcass classification and measurements in this trial were done according to the criteria used in the carcass competition in South Africa.

The following measurements were taken: the prime-rib fat thickness (X1) taken 2.5 cm lateral to midline; the short-rib fat thickness (X2): 5.0 cm lateral to midline; the 3rd/4th lumbar vertebrae fat thickness (X3) and the fat codes (X4). The meat yield (Y) could be computed from these measurements using the formula presented below (Meat Board, SA, unpublished).

$Y = 80.302 - 0.098X1 - 0.092X2 - 0.052X3 + 0.193X4 \ (R^2 = 0.80)$

NB. R^2 is the coefficient of determination

4.3.3. PARAMETERS MONITORED

The following parameters were monitored:

- Proximate analyses (feed samples)
- Blood cortisol and glucose level on d1, d28 and d 42
- Minerals and trace minerals including chromium and selenium concentrations in liver, feedstuffs and rations
- Feed dry matter intake daily
- Live weight gain fortnightly
- Feed conversion efficiency
- Carcass parameters: warm and cold weight, dressing percentage, fat thickness (twenty-four hours after slaughtering with a calliper) and dressing percentage.

4.3.4. STATISTICAL ANALYSIS

Data from two animals, which died, were removed from the analysis of growth but they were included in the stress assessment because they were still alive during this initial period. One animal died when attempt was done to repair a fistula and the second died towards the end of the trial due to acidosis (bloat).

TABLE 4.1: EXPERIMENTAL DESIGN OF FEEDLOT CATTLE FED A SUPPLEMENT OF SE AND CR – EXPERIMENT 1

ANIMALS		PEN NO	TREATMENT		
TOTAL	PER PEN		GROUP	VACCINE BATCH	ABBREVIATION
72 ANIMALS	6	1	CONTROL	1	CON1
	6	2		2	CON2
	6	3		3	CON3
	6	4	SELENIUM	1	SEL1
	6	5		2	SEL2
	6	6		3	SEL3
	6	7	CHROMIUM	1	CHR1
	6	8		2	CHR2
	6	9		3	CHR3
	6	10	SELENIUM X CHROMIUM	1	SELCHR1
	6	11		2	SELCHR2
	6	12		3	SELCHR3

TABLE 4.2: DIET COMPOSITION IN A TON OF FEED – EXPERIMENT 1

Ingredients	Inclusion (Kg)	Inclusion (%)	Observation
Yellow maize meal	450	45	Grade 2
Wheaten bran	100	10	
Yeast	50	5	
Malt dust	50	5	
Eragrostis meal	260	26	
Molasses	50	5	Liquid
Urea	10	1	
Limestone powder	10	1	SavannahND
Mono Ca P	5	0.5	
Salt	10	1	
Premix	5	0.5	Neuvet, SA

TABLE 4.3: AVERAGE CONCENTRATION OF NUTRIENTS - EXPERIMENT 1

ITEM	Treatment				AVERAGE	STANDARD [1]
	CON	SEL	CHR	SEL/CHR		
DM %	90.16	90.04	90.7	90.75	90.41	
ASH %	6.49	6.54	5.91	6.68	6.40	
CP %	13.76	14.94	14.09	15.44	14.56	13.0[(1)]
FAT %	3.05	2.93	2.90	2.80	2.99	
CF %	14.4	12.8	13.38	12.43	13.25	
Ca %	0.51	0.57	0.58	0.55	0.55	0.50[(1)]
P %	0.48	0.48	0.47	0.44	0.47	0.28[(1)]
Mg %	0.2	0.2	0.22	0.22	0.21	0.12[(1)]
Co, ppm	2.6	4.2	1.6	2.3	2.7	
Cu, ppm	14.3	12.3	13.8	11.2	12.9	10.00[(1)]
Fe, ppm	552.3	555.9	514.7	627.2	562.5	62[(1)]
Mn, ppm	97.6	120.4	117.5	116.1	112.9	50[(1)]
Se, ppm	0.3	2.35	1.24	2.29	1.48	0.3 – 1.0 [(2)]
Zn, ppm	57.1	48.9	50.8	51.1	52	38[(1)]
Cr, ppm	2.8	1.6	3.45	5.75	3.4	

Sources: ([1]) Cole, (no date) ([2]) Puls, 1994

4. 5. RESULTS AND DISCUSSION

4.5.1. STRESS, CORTISOL AND GLUCOSE LEVELS

Stress depletes the animals of their essential nutrients (Cole *et al*. 1988). The measures to correct the subsequent loss of condition include mineral supplementation. The dietary supplements of Se and Cr at a level of 0.3 mg/ kg DM each may have a beneficial effect on the alleviation of stress in the first two to four weeks in the feedlot. However, the supplementation effects of Se and Cr on stress alleviation and subsequent performance are not consistent (NRC, 1980; NRC, 1997).

The data related to blood cortisol and glucose concentrations is presented in Table 4.4. Figures 4.1 and 4.2 present the effects of dietary Se and Cr on cortisol and glucose over time. For data analysis, the model used includes the cortisol and glucose levels as dependent variables on d 0, d 14, and d 42. Treatments and vaccine batches are used as independent variables. For the changes overtime, the differences between two consecutive measurements e.g. cortisol d 14-d 0, d 42- d 14 are considered as dependent variables.

4.5.1.1. BLOOD CORTISOL CONCENTRATIONS

The least-square means of the blood cortisol measurements (nmol/L of blood) across the different treatments in this trial were 73.31, 65.79 and 78.60 respectively on d0, d 14 and d 42. These values are higher than those reported by Moonsie-Shageer and Mowat (1993) and Grandin (1997). Values higher than 70 nmol/L have been suggested by Grandin (1997) as a sign of stressful handling and at a level of 90 nmol/L, it was assumed that there was an extreme stress upon that animal. But in the study by Moonsie-Shageer and Mowat (1993), the cortisol values were below the mark line of 70 nmol/L for three out four treatments. It was assumed, nevertheless, that the higher the value of cortisol for a specific treatment, the higher was its stress level. The same approach was taken in the current assessment.

It seems that the animals were more stressed on d 0 and d 42 because of the higher cortisol values. Obviously on d 0, all the stressors as indicated in the literature review are

related to transportation, handling and other management procedures (Cole *et al*. 1988; Grandin, 1997). But values may also differ according to breeds. Brahman-cross cattle have been reported to have a high cortisol level during handling (Grandin, 1997). Cattle used in the present trial were Brahman-cross. It is therefore possible that values reported here are higher than those of Moonsie-Shageer and Mowat (1993) who used Charolais-crosses in their research.

Paired-T test was used to compare the different treatments. There was no statistical difference between treatments on d 0 although treatment SEL had the highest blood cortisol level ($P=0.09$). On d 14, all the treatments resulted in lowered cortisol levels except for the treatment SEL/CHR for which a peak in the cortisol concentration ($P\leq0.05$) was noted. On d 42, the SEL/CHR treatment group had significantly ($P\leq0.05$) les cortisol compared to CON and SEL treatment groups (Table 4.4. and Figure 4.1).

The dietary Se and Cr may have been effective in lowering blood cortisol in this study. Other investigators (Burton *et al*. 1993; Moonsie-Shageer and Mowat, 1993) reported similar results with Cr supplementation. It is also probable that the animals became used to handling which is in agreement with Cole *et al*. (1988). But after settlement in the new environment for two weeks (d 14), the increased cortisol level on d 42 might have been a sign of the dietary stress (Anderson *et al*. 1997). This implies a direct positive effect of treatment SEL/CHR on stress alleviation when the dietary stress is prominent. This can be confirmed by lowered glucose concentration ($P\leq0.05$) as shown in Table 4.4.

Despite a slight increase in feed intake towards d 42 (Appendix A.3), it was speculated that there was a more efficient use of feed and accumulation of energy by the animals as they were growing. According to Chang and Mowat (1992), the increased utilisation of glucose was shown to provoke the mobilisation of Cr and its loss through urinary excretion. This might allow the increase of blood cortisol. It appears therefore that the effect of combined Se and Cr is probably more effective than Se and Cr alone during this growing phase.

The literature related to the effect of Se on stress and cortisol levels is scarce. However, Garcia-Belenger *et al*. (1991) found that serum activity of muscle enzymes was lower in fighting cows supplemented with Se. Selenium and vitamin E relationship is also well established (Pollock *et al*. 1994; Walsh *et al*. 1993). Vitamin E was shown to decrease the stress-related metabolites in heifers (Nockels, 1988; Nockels *et al*. 1996). It was therefore proposed that Se, because of these related properties would be able to act similarly. However, Se did not affect the stress related metabolites (cortisol, glucose) in this study.

The vaccine batches did not affect the cortisol levels (not reported). This again suggests that there was no pen effect on cortisol levels since these batches corresponded to pen allocation.

4.5.1.2. BLOOD GLUCOSE LEVELS

Data related to blood glucose is presented in Table 4.4 and Figure 4.2. The mean glucose values across treatments in this study were 4.99, 5.02 and 5.12 respectively for d 0, d 14 and d 42. These values are within the normal range of the blood glucose concentrations in cattle (Kaneko, 1997). The blood glucose concentrations were not different between treatments at the beginning of the trial (P=0.08). However on d 14, these concentrations were highly significantly lowered ($P \leq 0.01$) compared to d 0 except for treatment SEL. On d 42, the blood glucose values were again higher and tended to differ between treatments (P=0.07) with the treatments SEL and SEL/CHR having the lowest values.

The plots of the blood glucose concentrations (treatment effects) (Fig. 4.2) were almost similar to those of blood cortisol concentrations (Fig. 4.1). However, the differences in glucose concentrations from d 0 to d 14 differed very significantly between treatment groups ($P \leq 0.05$). From d 14 to d 42, the treatments affected very significantly the glucose levels ($P \leq 0.01$). The same reasons that were proposed for cortisol changes may be applied here. It is believed that after the adaptation on d 14, the dietary related stress has been quoted as the cause of increased values on d 42 in agreement with Anderson *et al*. (1997).

In previous research, the dietary supplement of Se was shown to decrease the blood glucose in Se deficient cows (Salewski and Seegers, 1994). Others also showed similar effects with dietary supplement of Cr (Mowat *et al*. 1993). The relationship between cortisol and glucose has already been defined by Jensen-Waern and Nyberg (1993). It is therefore possible that these elements have acted indirectly on the blood glucose concentration through their effects on blood cortisol.

The conflicting results with chromium supplementation have been also attributed to the difference in stress level, the chromium status of animals and the amount of bio-available chromium in the feedstuffs (NRC, 1997). Arthington *et al*. (1997) assessed the cortisol level on d53, when animals were probably well adapted to the feedlot conditions. The absence of stress could have been the cause of the negative response in that research. No consistent response to treatment with Cr was observed with regard to the glucose metabolism by Chang *et al*. (1995). The expected interaction between $CrCl_3$ and niacin did not occur probably because of the low insolubility of $CrCl_3$ (Merck & Co, 1996).

The physical stress enhanced by hunger or thirst (Grandin, 1997) may also be at the origin of other conflicting results in some studies (Chang and Mowat, 1992; Mowat *et al*. 1993). In the studies quoted above, animals were starved for up to 24 hours and kept without water for 16 hours. Stress due to these depravations was not seemingly considered in the interpretation of the results.

Glucose metabolism differs between ruminants and non-ruminants. The ruminants derive most of their glucose requirements from the hepatic gluconeogenesis rather than from the intestinal absorption and their tissues seem to be more refractory to insulin than the tissues of non-ruminants (Bunting *et al*. 1994). According to Jacques and Stewart, (1993), change in nutrient utilisation is brought about by a more efficient use of blood glucose by peripheral tissues. Following these arguments, it appears, that Cr would not act effectively as part of GTF in ruminants compared to non-ruminants. Nevertheless, Amoikon *et al*. (1995) observed that Cr picolinate decreases the hepatic storage of glucose and increases glucose utilisation by other tissues.

TABLE 4.4: BLOOD CORTISOL (NMOL/L) AND GLUCOSE (MMOL/L) CONCENTRATIONS (±SEM) OF FEEDLOT CATTLE FED A SUPPLEMENT OF SE AND CR – EXPERIMENT 1

Treatment	Day 0		Day 14		Day 42	
	Cortisol	Glucose	Cortisol	Glucose	Cortisol	Glucose
CON	63.39±5.8	4.88±0.2	54.05 [a] ±6.6	4.82 [b] ±0.1	88.72 [a] ±7.3	5.31 [a] ±0.1
SEL	82.28±6.0	4.91±0.2	70.39 [ac] ±6.8	5.44 [a] ±0.1	82.13 [a] ±7.5	5.00 [b] ±0.1
CHR	70.86±6.0	5.13±0.2	60.83 [a] ±6.8	4.94 [b] ±0.1	82.94 [a] ±7.5	5.19 [a] ±0.1
SEL/CHR	71.94±5.8	5.04±0.2	79.17 [bc] ±6.6	4.87 [b] ±0.1	61.28 [b] ±7.3	4.98 [b] ±0.1

NB. Values with different superscripts differ significantly between treatments (P≤0.05) within a column

4.5.1.3. STRESS AND PERFORMANCE RELATIONSHIPS

It was also proposed that by lowering the cortisol levels in the animals, the dietary supplements of Se and Cr could improve the animal performance. The Pearson's correlation coefficient was used to analyse the relationships between the independent variables (cortisol and glucose concentrations) and the dependent variables (performance parameters). It was found that there was no correlation between the independent variables and the dependent variables such as live weight, ADG, predicted FCR on d 0, d 14 and d 42.

This compares with studies by Mowat *et al.* (1993) and Bunting *et al.* (1994) where the stressed weaner cattle were fed high-Cr yeast but no positive response was noted. Kegley and Spears (1995) fed 0.4 mg/kg of $CrCl_3$, high-Cr yeast and Cr nicotinic but there was no positive response. Others (Chang and Mowat, 1992; Mowat *et al.*, 1993) who investigated the finishing-growing phase reported similar results: no carryover effect of decreased cortisol was noted on growth rate and feed efficiency.

In contrast, Moonsie-Shageer and Mowat (1993) reported the carryover effect of the decreased cortisol concentrations on the performance during the adaptation period. Although it is accepted that the content of total diet Cr in a diet bears little relationship to its effectiveness as biologically active Cr (NRC, 1997), it was reported that the highest dosage (1 mg of Cr per kg DM of feed) was more effective than the adequate levels.

FIGURE 4.1: CORTISOL LEVELS(nmol/L) OF FEEDLOT CATTLE FED A SUPPLEMENT OF Se AND Cr

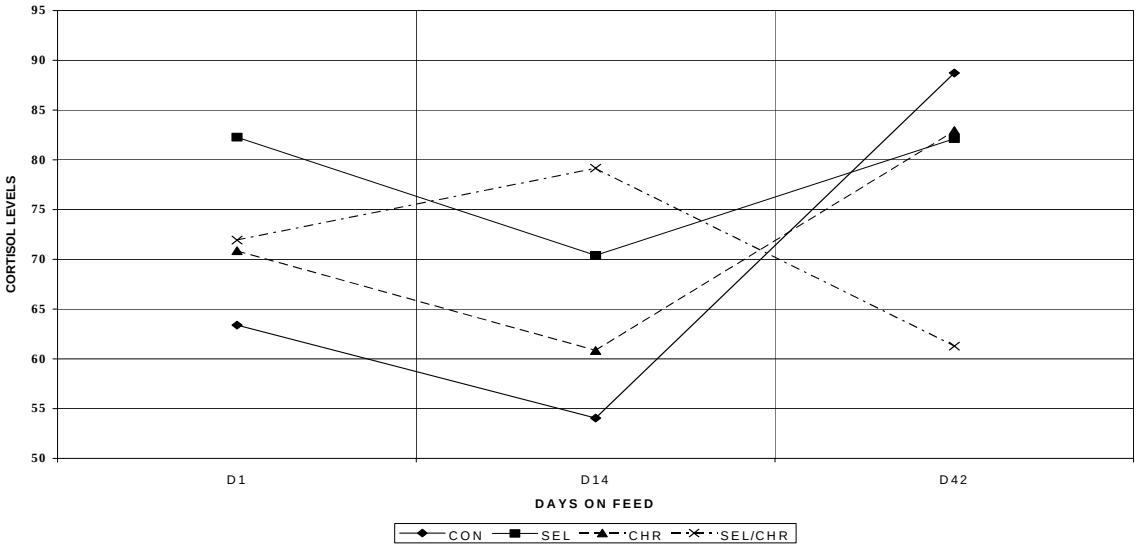
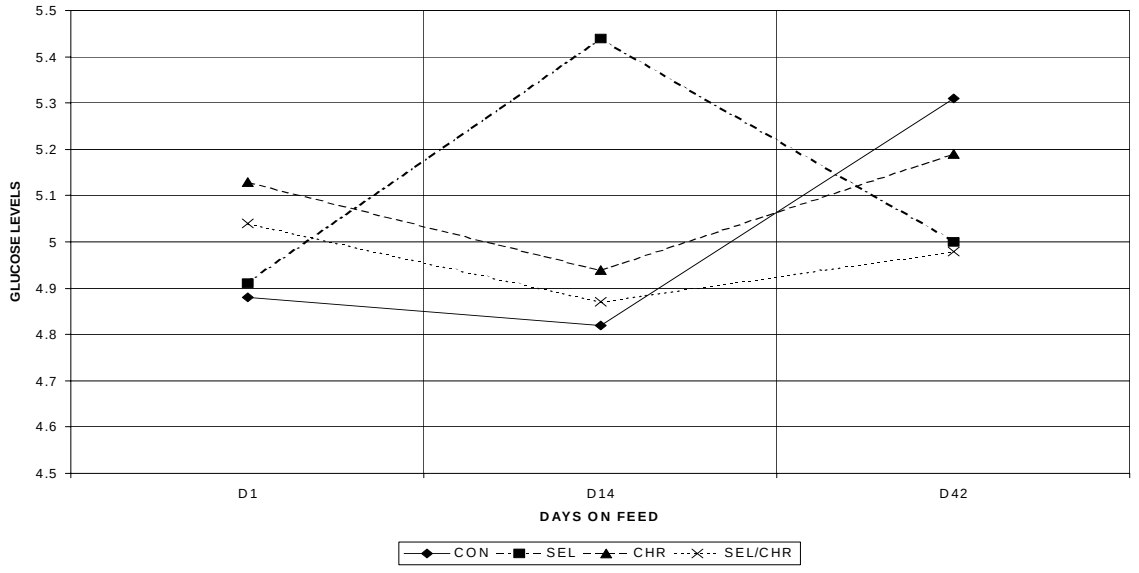


FIGURE 4.2: BLOOD GLUCOSE LEVELS OF FEEDLOT CATTLE FED A SUPPLEMENT OF SELENIUM AND CHROMIUM



4.5.2.1. LIVE WEIGHT AND AVERAGE DAILY GAIN

The data related to the growth rate of the steers is presented in Table 4.5. Repeated measures of analysis of variance showed that the effect of supplemental Se and Cr were affected by days on feed ($P \leq 0.05$) and by the interaction days x treatment ($P \leq 0.05$). It was clear that all the animals were in a sustained phase of growth, which started to flatten around d112 (Fig. 4.3). The contrast between live weight taken on d120 and d112 tended to be significantly different ($P=0.10$). The decision to stop the trial on d120 was thus justifiable because there was need to analyse all the growth parameters at a similar date of maturity.

The animals attained in average 345.5 kg live weight. The mean final ADG across treatments was 1.3 kg per day. These values are lower than the standards in the South African feedlot industry estimated to be around 420 kg for the live weight and an ADG of 1.700 to 1.800 kg live weight (or even 2.000 kg) per day (Henning *et al*. 1999). It was assumed that Nguni crossbred steers have low genetical potential to perform efficiently in the feedlot. Although it was not statistically significant, the treatment SEL/CHR had the highest ADG (1.393 kg) as compared to treatments CON and CHR that gained 1.321 kg per day (5.37% less) and treatment SEL with 1.311 kg per day (6.26% less) (Table 4.5).

It is known that the mature size and genetic potential of the animal establish the patterns of daily lean (protein) accretion and the nutritional level with other factors such as sex and use of growth promotors determine the extent to which these potentials are achieved (Slabbert, 1989). The steers used in the present trial were Brahman x Nguni x Bonsmara crosses. The Brahman is a medium frame and early maturing type of cattle. The Nguni cattle are of small frame and early maturing type while the Bonsmara is of medium frame and medium maturity type. The Brahman cattle were used in the breeding programme for their hardiness and resistance to tropical diseases. The Nguni and Bonsmara cattle are related breeds. The heterosis effect is therefore small on growth since only the Bonsmara contributes to the improvement of the growth rate.

Because the genotypes that have excellent adaptability traits for the tropical and sub tropical climates do not perform well under feedlot conditions (Bosman, 1998), it was

concluded that these animals achieved their full growth potential and the values reported here reflect the reality. The minimal growth potential and the feed intake restriction could have also been the cause of the lack of growth rate improvement in different studies using Se in young animals (Ammerman *et al*. 1980; Kincaid *et al*. 1999).

4.5.2.2. SELENIUM SUPPLEMENTATION EFFECTS ON PERFORMANCE

Treating the animals, neither with Se alone (treatment SEL), nor in combination with Cr (treatment SEL/CHR) did not give a positive response with regard to performance. A functional selenium deficiency has been suggested as the major factor affecting the response to supplementation and the major challenge to Se activity is the level of oxidant stress presented by the diet or metabolism (Van Ryssen *et al.*, 1992). As shown earlier (Table 4.3.), the animals in this trial had a high Se intake therefore eliminating any possibility of Se deficiency.

However, it was shown that even in the presence of Se deficiency, there is not always a positive response to supplementation. For example, Droke and Loerch (1989) did not demonstrate the improvement of the animal performance. Arthur and Boyne (1983) also did not find a difference in the growth rate in Friesian calves fed for 30 weeks with a diet supplemented with 0.1 mg Se/Kg as sodium selenite. It has been agreed with Smolders *et al*. (1993) that the management and animal husbandry have generally a greater effect on the growth rate and development than does mineral supply.

The difference in species and breeds in the absorption of Se has been reported (Van Niekerk *et al*. 1990). Gerloff (1992) demonstrated that variations in genetic ability to absorb or retain Se may be present in cattle, and variations of genetic lines on different farms may result in differences in response to selenium supplementation. It has also been shown that the feed intake and subsequent growth rate of the animals can be depressed by a high intake of Se in pigs (Meyer *et al*. 1981) and in sheep (Echevarria *et al*. 1989). Meyer *et al.* (1981) also indicated that there is a physiological capacity of the body to retain the absorbed Se, which may be exceeded at a daily intake level of 20 ppm in pigs. In the present study, it was suggested that the growth rate would have also been

depressed because of a high Se intake. And more importantly, growth rate as an indicator of Se supplementation is an inaccurate measure because it is easily masked by such factors as sex and breeds (Van Ryssen *et al.*, 1992).

Direct improvement of the growth can be easily attained by improving the digestibility of the nutrients. The dietary supplement of Se does not affect the digestibility of the nutrients (Nicholson *et al*. 1991a). However, it seems that the Se concentration in South African feedstuffs correspond with the protein concentration of the feeds (Van Ryssen, 1996). Providing a good source of protein may therefore be recommended when Se supplementation is considered.

4.5.2.3. CHROMIUM SUPPLEMENTATION EFFECTS ON PERFORMANCE

Treating steers with Cr as high-Cr yeast alone (treatment CHR) or in combination with Se (treatment SEL/CHR) did not affect the performance (Table 4.5.). Many other studies cited in the literature review reported similar results and different reasons were noted. According to Pollard and Richardson (1999), research pertaining to chromium in the diets of beef cattle have been less consistent in its effect on performance and growth parameters.

The high-Cr yeast and $CrCl_3$ dietary supplements did not alter the ADG and feed efficiency of weaned stressed calves (Chang *et al*. 1995; Kegley and Spears, 1995). Feeding weaned stressed calves with a supplement of chelated Cr was ineffective in experiments by Wright *et al*. (1994) and Mathison and Engstrom (1995). Bunting *et al*. (1994) suggested that the lack of the physiological stress during the growing phase can explain the absence of dietary chromium effect. Following this argument, it could be deducted that this was the case in the two trials by Chang and Mowat (1992) and Chang *et al*. (1992) because they were conducted during the most moderate season in Canada. However, this present study was conducted during the South African winter, which is harsh and stressful weather. As indicated previously in the present study, the performance of the cattle was not improved.

Many other factors can be considered when interpreting the results. But the age of the animal is a very important factor. Kegley *et al.* (1996) used calves of less than 7 days. Arthington *et al.* (1997) used calves aged 3 to 4 weeks. Pollard and Richardson (1999) also used suckling calves. The growth pattern of any animal as seen in the well-known growth curve is minimal at this stage. The exponential growth pattern is seen in the feedlot after seven to nine weeks on feed when the cattle are brought in after weaning.

Kegley and Spears (1995) used young calves on milk replacer supplemented with Cr-Nicotinic acid complex (Cr-NAC) or Cr-Cl_3 that failed to improve the performance. These negative results could have been due to the lack of stress, the early stage of the digestive system development and the use of the inorganic form (Cr-Cl_3) known to be less absorbable (Merck & Co, 1996). Under most circumstances, the energy is the first limiting nutrient in the diet of the market/transport-stressed calves. This is primarily due to their low feed intakes and the functional ability of the rumen, which is also disturbed during this period (Cole, no date).

In another research (Kegley *et al.* 1996), it was pointed out that the cattle may have not been stressed because they were only shipped from 100 km as compared to studies showing Cr effects (Moonsie-Shageer and Mowat, 1993) where the cattle were shipped much greater distances and were severely stressed before the initiation of the study. In the present study, cattle were shipped over a much longer distance (approximately 200km) and the calves were noticeably stressed. The performance was nevertheless not improved.

However, in other species, the results were more variable with some studies reporting positive results. Negative responses were obtained in other species fed Cr. Depew *et al.* (1998) did not find an improvement of growth rate in lambs. Lindemann *et al.* (1995) and Amoikon *et al.* (1995) did not find a positive effect of dietary supplement of Cr in pigs. But in another trial, Lindemann (1996) found an interaction between Cr and lysine, which explained a certain tendency in the improvement of the gain:feed ratio. Also feeding CrNic tended ($P<0.10$) to improve performance without improving feed efficiency (Kegley *et al.* 1997) in pigs.

TABLE 4.5: PERFORMANCE OF FEEDLOT CATTLE FED A SUPPLLEMENT OF Se AND Cr – EXPERIMENT 1

Item	Treatment			
	CON	SEL	CHR	SEL/CHR
LWT1(kg ±SEM)	185.3 ± 5.242	187.1 ± 5.414	185.3 ± 5.414	182.5 ± 5.242
LWT120 (kg±SEM)	343.9 ± 3.631	344.7 ± 27.184	343.5 ± 23.436	349.7 ± 37.08
ADG120	1.3 ± 0.099	1.3 ± 0.066	1.3 ± 0.042	1.4 ± 0.094
ADMI	8.0 ± 0.174	7.9 ± 0.316	7.7 ± 0.113	8.3 ± 0.248
ADMI:ADG([1])	6.1 ± 0.483	6.1 ± 0.083	5.9 ± 0.143	6.0 ± 0.368

Where: LWTD1 = live weight on d 0, LWTD120 = live weight on d 120, ADG = average daily gain ADMI = average dry matter intake

([1])Feed conversion (Arithmetic mean)

FIGURE 4.3: GROWTH EFFICIENCY OF FEEDLOT CATTLE FED A SUPPLEMENT OF SELENIUM AND CHROMIUM

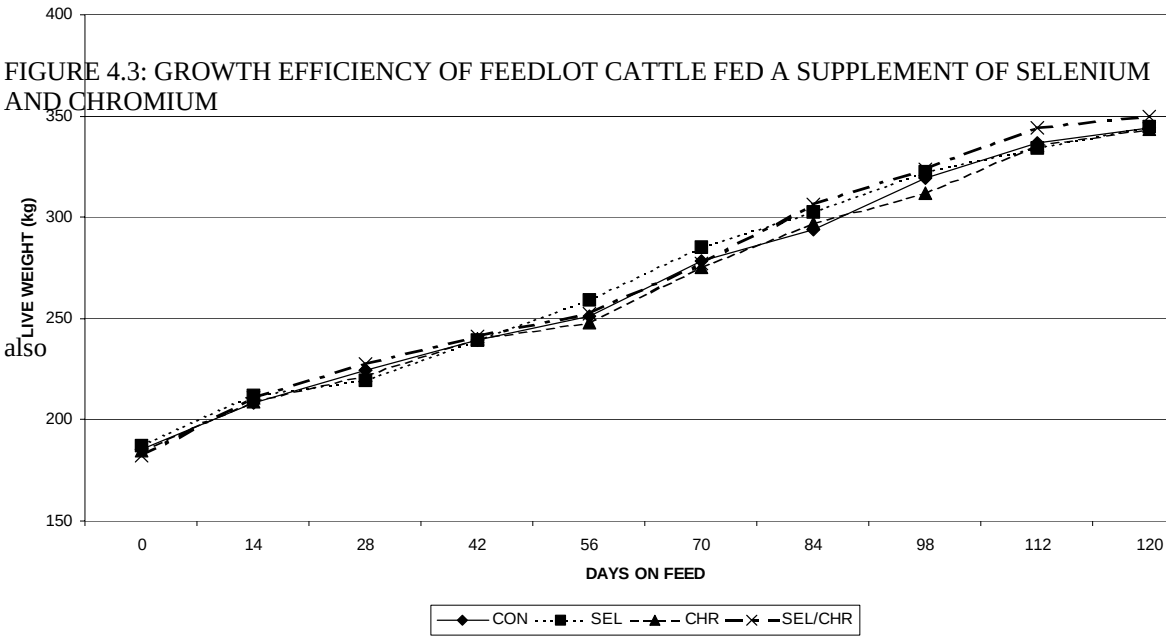


FIGURE 4.3: GROWTH EFFICIENCY OF FEEDLOT CATTLE FED A SUPPLEMENT OF SELENIUM AND CHROMIUM

also

4.5.2.4. FEED INTAKE AND FEED CONVERSION RATIO

The data related to feed intake was recorded on a pen basis (Table 4.4). Due to the small size of the sample (12 pens), no meaningful statistics could be fitted to the data. Simple arithmetic was instead used. However, during the course of the experiment, the information derived from the formula of P-FCR as reported in Chapter 2 was used. Therefore data related to P-FCR are reported as least-square means but the ADMI and ADG:ADMI ratio are arithmetic means.

The animals consumed in average 8.85 Kg of concentrate feed DM per day, which represents approximately 2.6 % of body mass. Muir *et al*. (1992) reported a similar value. Given the mean ADG of 1.300 kg, the feed:gain ratio was estimated to be 6.8:1. This figure is higher compared to the average feed conversion ratio of 5:1 reported by Henning *et al*. (1999) and it indicates obviously that the operation was not economically efficient.

The effect of breed as noted earlier for ADG was presumed to be the main cause. Because Se is also known to be ineffective in the improvement of the digestibility of the nutrients (Nicholson *et al*. 1991a), it is accepted that it would not improve the intake. It was previously noted that high dietary intake of Se depresses the feed intake (Echevarria *et al*. 1989; Meyer *et al*. 1981). Likewise, others (Arthur and Boyne, 1983; Droke and Loerch, 1989; Nicholson *et al*. 1991a; Nicholson *et al*. 1991b) did not find a positive effect of dietary Se supplement on feed intake and feed conversion.

The main action of Cr is thought to be its involvement in glucose metabolism (Burton, 1995; NRC, 1997). However, it seems that adult ruminants derive a major portion of their glucose requirement from hepatic gluconeogenesis (Samsell and Spears, 1989). Therefore, there is no high expectation of Cr effect on the digestibility of the nutrients and subsequent improvement of feed intake. The NRC (1997) recorded only two studies reporting positive responses by Chang and Mowat (1992) and Mowat *et al.* (1993). As for the present study, more negative responses to Cr supplementation have been reported, for example in growing finishing cattle: Mathison and Engstrom, 1995 and Mowat *et al*. 1993).

4.5.3. CARCASS EVALUATION

The model for carcass evaluation included warm carcass mass (WCM), cold carcass mass (CCM), meat pH taken 60 minutes after slaughter (pH1) and meat pH 24 hours after slaughter (pH2), meat yield percentage, sub-cutaneous fat measurement (x3) as dependent variables. The treatment, vaccine and interaction treatment x vaccine were taken as independent variables. Carcass parameters are presented in Table 4.5. and 4.6.

4.5.3.1. CARCASS WEIGHT AND DRESSING PERCENTAGE

The mean warm and cold carcass masses of the steers across the 4 treatments were respectively 185.343 ± 2.076 and 180.697 ± 2.022 kg. The cold carcass mass especially was 15.17% lower than the national (South African) average carcass mass in feedlot cattle, estimated to be 213 kg (Grobler, 1998). The mean DP across treatments was 52.32 ± 0.27%. It is slightly lower than the national average of 55% (Ford, 1998). It should also be noted that these steers were weighted full stomachs. The confounding effect of gut-fill on the dressing percentage (Preston and Willis, 1976 cited by Luseba, 1995) could have been the cause of shortfall in addition to other factors such as breed and age at slaughter effects.

It was reported earlier that these animals were crosses from cattle of medium to small frames and medium to early maturity. It is also possible that these animals had not attained their full maturity at slaughter. Because the majority of the carcasses were classified in lean classes A1 and A2 (92.85%), it was understood that these animals were still in the growing phase and they would have attained higher masses with time. A few more days on feed would have been effective in increasing the body mass and thereby the carcass weight even though not in the magnitude of reaching the national average carcass weight.

No statistical differences were observed between treatments and vaccine batches (pens) for warm and cold masses. But a slight higher cold carcass mass of the treatment SEL/CHR was observed, i.e. 3.4%, 2.8% and 2.2% compared respectively to the CON, SEL and CHR treatments. The dressing percentage (DP) tended to differ (P = 0.08)

statistically between treatments and vaccines. The slight advantage of treatment SEL/CHR could be attributed particularly to one pen (Pen 11, vaccine batch 2) that was different from pens 1, 4, 6 and 8. No clear explanation could be given. Nevertheless this could have been also attributed to the effects of this treatment (SEL/CHR) on stress as previously observed and its advantage on carcass mass.

These results are consistent with previous findings of Chang *et al.* (1992) and Mathison and Engstrom (1995) who reported respectively that high-Cr yeast and chelated Cr did not alter carcass characteristics in cattle. In contrast a recent study by Pollard and Richardson (1999) reported positive results. Dietary supplement of feedlot cattle with 0.2 ppm Cr using Bio-Chrome (Alltech Inc) increased the hot carcass weight over the 0.4 ppm Cr supplement. But the dressing percentage, the marbling score and the final yield grade decreased with 0.4 ppm treatment as compared to the 0.2 ppm and control. It is difficult to attribute this achievement to the sole superiority of the Bio-Chrome (Alltech Inc.) as supported by Pollard and Richardson (1999) because in other studies (Chang *et al.*, 1992; Mathison and Engstrom, 1995), the organic Cr forms were used as well but no positive changes were noted.

Available literature has not been explicit on the effect of Se on beef carcass. However, a few studies reported in pigs have been especially directed to the carcass fat cover and muscling. For example, it was reported that water-holding capacity of pork was affected by supplementation of antioxidant (Mahan, 1999). It seems as the antioxidant capacity of Se is not effective on meat characteristics assessed in this study.

4.5.3. 2. FAT CODE, CARCASS CONFORMATION AND MEAT YIELD PERCENTAGE

Fat code, carcass conformation frequencies and meat yield percentage (MYP) are presented in Tables 4.6 and 4.7 The age, feeding regime, gender and breed or maturity types are the major factors directing the rate and the magnitude in the composition of the carcass (Schonfeldt *et al*. 1997). The carcass fatness is an indicator of meat yield and age is an indicator of meat quality; they are the most important characteristics used in the beef carcass classification in South Africa (Slabbert, 1989)

The frequency of the carcass conformation was 92.86% for the class 3 and no statistical difference was noted between treatments. The majority of the carcasses (85.71%) were classified within the fat code A2 and no statistical difference was seen between treatments. According to Bosman (1998), if the oxen are slaughtered when they reach an A2-3 class, the better-feed converters should be the most profitable. It is clear that all the animals in the present study achieved an almost similar level of fatness and thus no better converter could be easily identified. Nevertheless, it appeared that treatment SEL/CHR had the highest number of carcass as classified within the fat code A3 and conformation code 4. This is probably an indication that this treatment was the most efficient in economic terms because the South African consumer is willing to pay more for the beef within this classification (Ford, 1998).

The fat thickness measurements were within the range of 1 – 5 mm. With reference to the carcass classification, this measurement is comprised within the fat codes 2 and 3. This concurs with the measurements of fat thickness reported above. There was no statistical difference between treatments. The meat yield percentage was also similarly not affected by treatments. No noticeable differences could be expected because the fat measurements from which this information was derived (see formula, Chapter 3) were not different. In general terms, the breed effect was believed to be predominant in these results. The genotypes that have excellent adaptability traits for the tropical and subtropical climates do not perform well under feedlot conditions (Bosman, 1998).

4.5.3.5. MEAT pH

The mean meat pH values were 6.00 ± 0.04 (pH1) and 5.77 ± 0.02 (pH2), respectively 60 minutes and 24 h after slaughter. Meat pH2 value is close to the value of ultimate pH 5.5 in mammalian muscles. At this ultimate pH, it is estimated that the conversion of residual glycogen to lactic acid stops because the enzymes affecting the breakdown are inactivated (Laurie, 1985). The extractability of myofibrillar proteins is also affected by the ultimate pH of the muscle, a high ultimate pH tending towards greater extractability (Laurie, 1985). The pH abnormalities such as a higher level may lead to the DFD (dark –

firm – dry) syndrome in beef. In this study, it was suggested that the combination Se - Cr had beneficial effect on meat quality because it maintained adequate meat pH.

Both the rate and the extent of the post-mortem pH fall are influenced by intrinsic factors such as species, type of muscle and variability between animals; and by extrinsic factors such as the administration of drugs preslaughter. When the pH fall is slow, the stiffening of the muscle is delayed and this has implication on meat tenderness. The loss of muscle extensibility, which reflects actomyosin formation, happens sooner if there is little glycogen stored. The onset of rigor mortis is accompanied by lowering in water-holding capacity (Laurie, 1985). It is obvious that any treatment, which allows better storage of glycogen in the muscle and maintenance of adequate water-holding capacity is recommendable for the improvement of eating quality of meat such as tenderness. Thus, because Cr supplementation was shown to increase the incorporation of glucose into glycogen in rats (Rosebrough and Steele, 1981), it was also speculated that Cr supplementation would be beneficial.

The analysis of meat pH fall in this study was carried out by t-test for paired samples but also non-parametric tests were used. The results were the same for both methods. The differences between pH1 and pH2 were statistically different ($P \leq 0.01$) for treatments CHR and SEL/CHR. These results suggest that Cr by its effect on glycogen storage is more effective in maintaining an appropriate meat pH fall. The meat pH values were still higher ($P \leq 0.05$) for these two treatments as compared to CON and SEL treatments. This again implies that although the post-mortem glycolysis was still in process for all the treatment groups, meat from treatments CHR and SEL/CHR was going to reach the ultimate pH later than other treatments. The meat pH fell and therefore the post-mortem glycolysis was delayed, hence giving an advantage on such meat with regard to its shelf-life.

TABLE 4.6: CARCASS CHARACTERISTICS OF FEEDLOT CATTLE FED A SUPPLEMENT OF SE AND CR - EXPERIMENT 1

Item	Treatment			
	CON	**SEL**	**CHR**	**SEL/CHR**
WCM (Kg)	182.8 ± 4.132	183.3 ± 4.267	185.8 ± 4.267	189.2 ± 4.132
CCM (Kg)	178.2 ± 4.025	178.7 ± 4.157	181.2 ± 4.157	184.5 ± 4.025
DP	53.16 ± 0.52	53.26 ± 0.54	53.99 ± 0.54	54.16 ± 0.52
MYP	79.85 ± .07	79.95 ± 0.08	79.94 ± 0.08	79.90 ± 0.08
SCF	3.88 ± 0.11	3.74 ± 0.12	3.86 ± 0.11	3.86 ± 0.11
pH 1	5.81^{a} ± 0.08	5.90^{a} ± 0.08	5.98^{a} ± 0.08	6.29^{b} ± 0.08
pH 2	5.72^{a} ± 0.03	5.85^{b} ± 0.03	5.69^{a} ± 0.03	5.84^{b} ± 0.03

Where: WCM = warm carcass mass, CCM = cold carcass mass, DP = dressing percentage, MYP = meat yield percentage, SCF = sub-cutaneous fat, pH 1 = pH 60 min after slaughter, pH 2 = pH 24 hours

NB. Values with different superscripts differ significantly (P≤0.05) within a row

TABLE 4.7: FREQUENCIES OF FAT CODE AND CARCASS CONFORMATION - EXPERIMENT 1

Treatment	Fat Code (1)				Carcass conformation (2)			
	A1	**A2**	**A3**	**A4**	**1**	**2**	**3**	**4**
CON	2	16	0	0	0	0	18	0
SEL	1	16	0	0	0	0	16	1
CHR	2	14	1	0	0	0	16	1
SEL/CHR	0	14	4	0	0	0	15	3

(1) In the South African Carcass classification system, carcasses are graded in age groups (A, AB, B, C) due to meat tenderness being highly age dependant and (2) classified in carcass fatness conformation groups (0 - 6) due to lean yield of carcass being highly correlated with carcass fatness (Ford, 1998)

4.5.4. MINERALS AND TRACE MINERALS STATUS

The univariate procedures of the GLM (SAS, 1999) were used for each mineral under investigation in order to test the distribution. Data was analysed with or without the outliers defined here as the 5 highest and the 5 lowest values. The results were the same and therefore all variables were included in the interpretations of the results. Furthermore, these interpretations are limited to minerals and trace minerals status as defined in the research design. Pearson's correlation coefficients were used to study the interactions between different elements.

Table 4.8 presents the liver mineral and trace element concentrations. With the exception of Se and Co that had high concentration and Cr with low concentrations, all the values recorded in this experiment were within the normal range for cattle (Puls, 1994).

4.5.4.1 LIVER SELENIUM CONCENTRATIONS

The average Se concentrations recorded for the feed samples on wet basis (Table 4.3) were higher than the normal ranges of 0.1 - 0.3ppm (NRC, 1980) and 0.3 - 1.0ppm (Puls, 1994) except for the control diet that was Se adequate. This was however, translated as already indicated, by a certain overall higher Se status as indicated by the high levels of liver Se for all the treatments.

Although the Se feed content was in average 5 to 8-fold higher than the normal range, the liver content was only 3-fold higher than the normal liver concentration. It seems that a proportion of Se consumed by the ruminant is reduced in the rumen to unavailable forms depending on the rumen degradability of the protein sources that contain the Se (Van Ryssen, 1996). Net Se absorption was reported to be about 35 percent in sheep (NRC, 1980). Moreover, higher doses ranging from 4 to100 mg/kg DM are likely to produce chronic Se poisoning (AFRC, 1988). In other words, 10 to 50 times higher than normal doses are considered to be toxic (NRC, 1980). There is, therefore, a limit to the body Se absorption making the Se intoxication rare in cattle. Probably that is why Se deficiency or toxicity symptoms are rarely reported in South Africa (Van Ryssen, 1996) though losses as a result of marginal deficiency for instance could occur unnoticed.

An inverse relationship between the Se uptake and the levels of dietary Se and the Se status was also reported by Jelinek *et al*. (1985). In contrast, Zachara *et al*. (1993) showed that Se concentration in the liver increased linearly with Se level in the diet of goats. Others (Lowry *et al.*, 1985) reported that higher dietary Se resulted in increased Se concentrations in all pig tissues. Ammerman *et al*. (1980) found that the added Se tended to increase the concentrations of Se in the plasma, milk and liver of the cows.

The fact that the control group (treatment CON) had similar liver Se concentration with other treatments could be deduced from assumptions by Ullrey (1987). He reported that the diets that were adequate in natural Se had liver and skeletal Se concentrations that were higher than those resulting from equal intakes of Se principally from sodium selenite. It was also indicated that it is nearly impossible to establish the status of an individual with certainty. Due to the liability of tissue Se, the losses of Se from the body are rapid initially and then slower later. It is therefore possible that in 120 days on feed in this trial, the Se losses that could have been enhanced by stress were recovered and the trace-element status stabilised. According to Mahan (1985), Se retention increases with time after the initial depletion.

Treating cattle with sodium selenite (treatment SEL) increased dramatically the liver Ca, Mg, Co, and Mn contents ($P \leq 0.05$). Treatments CHR and SEL/CHR had significantly ($P \leq 0.05$) lower Ca, Mg and Co as compared to treatment SEL. These results would suggest that dietary supplement of Se is more effective than supplemental high–Cr yeast in the improvement of the general status of minerals and trace minerals in feedlot cattle. Chromium supplementation has been shown to prevent the loss of other minerals (Schauzer *et al.* cited by Moonsie-Shageer and Mowat, 1993).

4.5.4.2. LIVER CHROMIUM CONCENTRATIONS

Liver Cr concentrations were higher than the average of the values recorded in the Onderstepoort Laboratory (South Africa) (0.2 ppm) but still, they were lower than the recommended values of 3.8 ppm (Puls, 1994). Exceptionally, the Cr concentration for the treatment CHR was the closest (2.8 ppm) to the normal value and the highest ($P \leq 0.05$). It

seems that the dietary supplement of Cr above the recommended values does not necessarily lead to higher liver concentrations. Also Puls (1994) had suggested that the total dietary Cr may only become toxic at a dose of 40 times than the normal.

Anderson *et al* (1997) reported that supplemental Cr led to increased liver Cr concentration and total liver Cr in pigs. Contrary to Se, the results from the above-cited study suggest that the dietary supplement of Cr was more efficient than the native Cr in the diet. It should once again be noted that Cr like any mineral is a nutrient and not a therapeutic agent. The dietary Cr supplementation would be beneficial only to animals when the growth retardation is due to Cr deficiency (Anderson, 1990). In this trial, both diet and liver Cr concentrations were adequate.

The findings in this study contradict those of Anderson & Kozlovsky (1985) who reported that Cr absorption is inversely related to dietary intake and that excessive Cr is not absorbed efficiently. Others (Anderson *et al*. 1997) reported that in studies where Cr was assumed to be absorbed, the total tissue Cr was not related to the biological activity of the trace-element. However, they found that in contrast with pigs, the supplemental Cr raised the concentration of Cr in liver tissue.

In many studies, only total Cr content of tissues is measured and not the bio-available Cr concentration. It was shown however that total Cr is not related to biological activity (Chang *et al*. 1992). They suggested that if a more bioavailable form of Cr like high-Cr yeast is supplemented to the animals, it could increase the proportion of biologically active Cr in tissues, thus producing a natural Cr-enriched food that is able to improve the marginal Cr intake in humans who apparently consume 50 to 60% of their requirements (NRC, 1997).

4.5.4.2. INTERACTION BETWEEN MINERALS

The correlation coefficients and statistical significance of the minerals are presented in Table 4.8. As described in Figure 3.1, the mineral interrelationships are complex. Most of the interactions presented in Table 4.8 are those described by Puls (1994) and in other

studies such as Littledike *et al*. (1995). It is evident that minerals act directly and indirectly on one another. Such interactions tend to occur when chemical forms or electronic structures of the various ions are similar (Johnson and Korynta, 1992). The interrelating and antagonistic effects of the elements have to be considered if more than one element is added to the diet (AFRC, 1988). But contamination or losses during the processing and interference or affinities should also be considered in the interpretation of the results.

In the present study, liver Se was positively correlated to Cu ($P \leq 0.01$) and P ($P \leq 0.01$). At its turn, Cu had a positive relationship with Fe and Mn and negative correlation with Co ($P \leq 0.05$). Phosphorus also had a positive correlation with Mg, Cu, Fe and Zn. In turn, Cr was negatively correlated to Ca, Mg and Co. Both Ca and Mg were positively correlated to Mn and Zn. Besides the relationship with Cr, Co has shown an affinity with Ca, Mg, Cu and Mn.

4.5.4.2.1. SELENIUM INTERACTIONS

The interaction between Se and Cu or P is presented in the following regression formula:

$$\mathbf{Se = 0.115^{a} + 0.005^{b} (Cu)^{c} + 0.0003^{d} (P)^{e}} \quad R^2 = 0.25$$

Where ^{a} = intercept of parameter estimate; ^{b} = Cu parameter estimate; ^{c} = mean concentartion of Cu; ^{d} = P parameter estimate and ^{e} = P mean concentration

It is therefore estimated that for each Se unit increase, Cu (mean = 40 ppm) increased by 0.315 units and P (mean = 0.0022 ppm) increased by 0.115 units.

These results are not in consonance with those of Cloete *et al*. (1994) who did not find a positive relationship between Se and Cu. They supplemented sodium selenite to sheep and found no interaction between Se and Cu because the combination Se-Cu did not affect performance whilst Cu or Se supplemented alone affected the animal performance. This conclusion may lead to confusion because mineral interactions as shown by Puls

(1994) are numerous and many interrelating factors can explain the absence or presence of its effects.

Selenium and P were decreased in Se deficient cows (Salewski and Seegers, 1994; Klawoun *et al*., 1996). This confirms the positive correlation demonstrated in this study. The regression between Se and P presented in the formula above also shows a weak relationship ($R^2 = 0.25$). In contrast, Lowry *et al*. (1985) reported that the dietary P levels above the pig requirements would reduce both the absolute and the percentage of Se tissue retention. In this experiment, the dietary P concentrations were slightly high, but did not affect the liver concentrations.

Copper interaction with Mn has been reported with Cu depressing absorption of Mn and accelerating its turnover (Johnson and Korynta, 1992). As shown in Table 4.8, multi-dimensional interactions could be seen between diverse elements making it difficult to separate the effect of an element from a specific one. These indirect interactions may explain Cu effect reported on Zn by Miller (1985). According to Littledike *et al.* (1995), the relationship between Cu and Zn demonstrate competitive binding of Cu and Zn for binding sites on a cytosolic protein shown to be metallothionin.

The existence of interactions between Fe and Mn metabolism is well known (Puls, 1994). Iron and Mn are antagonistic towards one another. It has also been shown that high dietary Fe could decrease the absorption of Mn (Johnson and Korynta, 1992). This could have been the case in this study because, although the dietary Fe was high (555 ppm), liver Mn level was adequate (4.93 ppm) whilst mean liver Fe content (81.90 ppm) was below the average of 120 ppm recorded in the laboratory (Onderstepoort, RSA). Because the high dietary Fe was not reflected by high tissue retention, it would imply that it had effectively interacted with other molecules.

4.5.4.2.2. CHROMIUM INTERACTIONS

The low liver concentrations of Ca, Mg and Co as already mentioned in this study were lower than the values recorded in the laboratory (Onderstepoort Nutrition Laboratory).

This might have been due to the negative correlation between liver Cr and liver Ca, Mg and Co concentrations. Others also (Chang *et al*. 1992) demonstrated that the dietary Cr did not augment the tissue concentrations of Zn, Fe, Mg, Ca and P except for Cu. Copper susceptibility to be affected has been pointed out by some other studies (Littledike *et al*. 1995) as compared to Ca and Zn because their homeostasis is relatively effective in ruminants (Littledike and Goff, 1987). Liver is not a storage site for Zn as in contrast with Cu for which it is a major storage site; the high concentration represents increased storage of available dietary Cu (AFRC, 1995). For Fe, the liver content does not drop even if diet is low in Fe. Excess dietary Cu, relative to Fe reduces the accumulation of Fe in liver tissue and vice-versa (Boila *et al*. 1993). However in this study, the excessive dietary Fe content did not affect the concentration of Cu.

The regression between the liver tissue Cr and Co was computed according to the formula presented below. No other variable (Ca, Mg) met the 0.1500 significance level for entry into the model used. Likewise, Anderson *et al*. (1997) did not find a significant effect between supplemental Cr and other liver minerals such as Cu, Fe or Zn.

$Cr = 2.119^{a} – 0.08^{b}$ (Co mean)

Where ^{a} is the estimate of the intercept and ^{b} the estimate of variable Co.

Thus, it is estimated that for each Cr unit increase, Co decreased by 1.735 units. This is quite a considerable decrease given the low liver Co mean (4.8 ppm). However, in the present study, it was shown that all the liver mineral concentrations were optimal.

4.5.4.3. EFFECT OF MINERALS ON PERFORMANCE OF FINISHING CATTLE AND CARCASS CHARACTERISTICS

The correlation procedures and stepwise and non-stepwise regression were used to study the relationships between the liver minerals in one hand, and the growth parameters in finishing steers and the carcass characteristics including all the measurements of fat on the other hand. It was assumed that a significant positive correlation between gain and mineral concentration in liver indicated a beneficial effect of a trace mineral. A

significant negative correlation was an evidence of a detrimental or non-beneficial effect of the supplementation of a mineral.

But like during the adaptation - production phase, Se and Cr did not affect the growth rate. Carcass characteristics were also not affected. Others also (Chang *et al*. 1992) did not find the effect of supplemental Cr on ADG and carcass characteristics including the dressing percentage and the backfat thickness in steers fed 0.2 mg per kg DM from high-Cr yeast. A recent study by Pollard and Richardson (1999) showed that cattle supplemented with 0.4 ppm Cr yeast had larger longissimus muscle areas but the final yield grades, hot carcass weights, and marbling scores were decreased. When the animals were supplemented with 0.2 ppm, the hot carcass weight and longissimus area were increased.

Results with finishing pigs fed a dietary supplement of Cr have been more positive though it was indicative of a dose-effect response as well. Increased loin muscle area and reduced tenth rib backfat depth was seen in different studies (Lindemann *et al*. 1995; Lindemann, 1996; Southern and Page, 1992).

TABLE 4.8: LIVER MINERAL CONCENTRATIONS ON WET BASIS (PPM ±SEM) OF FEEDLOT CATTLE FED A SUPPLEMENT OF SELENIUM AND CHROMIUM – EXPERIMENT 1

Mineral	Treatment				AVERAGE	P-Value
	CON	SEL	CHR	SEL/CHR		
Ca	85.05 ^{a} ± 5.48	153.00 ^{b} ± 5.66	49.08 ^{c} ± 5.66	43.21 ^{c} ± 5.48	82.15	0.001
P	3580.56 ±03.34	3036.96±210.01	3091.00±210.01	2921.06 ±3.34	3159.44	0.119
Mg	149.54 ^{a} ± 8.46	220.92 ^{b} ± 8.74	111.62 ^{a} ± 8.74	100.28 ^{a} ± 8.46	144.4	0.001
Co	1.79 ^{a} ± 0.48	8.38 ^{b} ± 0.49	1.69 ^{a} ± 0.49	0.93 ^{a} ± 0.48	3.161	0.0001
Cu	88.91 ^{a} ± 7.21	67.07 ^{b} ± 7.44	80.03 ^{ab} ± 7.44	95.50 ^{a} ± 7.21	82.87	0.0475
Fe	81.85 ± 5.43	77.96 ± 5.61	87.29 ± 5.61	81.64 ± 5.43	81.9	
Mn	4.33 ^{a} ± 0.26	5.66 ^{b} ± 0.26	4.38 ^{a} ± 0.26	5.35 ^{b} ± 0.26	4.934	0.001
Zn	50.12 ± 3.40	48.68 ± 3.51	41.85 ± 3.51	44.94 ± 3.40	46.33	
Se	1.74 ± 0.16	1.48 ± 0.17	1.44 ± 0.17	1.70 ± 0.16	1.597	
Cr	1.70 ^{a} ± 0.14	1.31 ^{a} ± 0.15	2.79 ^{b} ± 0.15	1.73 ^{a} ± 0.14	1.87	0.0001

NB. Values with different superscripts differ significantly (P≤0.05) within a row

TABLE 4.9: CORRELATION COEFFICIENT BETWEEN LIVER MINERALS AND TRACE ELEMENTS ON WET BASIS

Item $(R^2/P)^X$	Se	Cr	Ca	P	Mg	Co	Cu	Fe	Mn	Zn
Se				0.44			0.31			
				0.0001			0.01			
Cr			-0.546		-0.30	-0.34				
			0.0001		0.01	0.005				
Ca		--0.546			0755	0.685			0.25	0.23
		0.0001			0.0001	0.0001			0.04	0.05
P	0.44				0.23		0.25	0.31		0.30
	0.0001				0.06		0.04	0.01		0.01
Mg		-0.30	0755	0.23		0.700			0.39	0.31
		0.01	0.0001	0.06		0.0001			0.001	0.01
Co		-0.34	0.685	0.700	0.700		-0.24		0.28	
		0.004	0.0001	0.001	0.001		0.04		0.02	
Cu	0.31			0.25		-0.24		0.31	0.26	0.28
	0.01			0.04		0.04		0.01	0.03	0.02
Fe				0.31			0.31		0.32	0.46
				0.01			0.01		0.01	0.0001
Mn			0.25		0.39	0.28	0.26	0.32		0.49
			0.04		0.001	0.02	0.03	0.01		0.001
Zn			0.23	0.30	0.31		0.28	0.46	0.49	
			0.05	0.01	0.01		0.02	0.0001	0.001	

NB. (^{X}) R^2 = Correlation coefficient and P = statistical significance

CHAPTER 5. THE EFFECT OF DIETARY SUPPLEMENT OF SELENIUM AND CHROMIUM ON MEAT COLOUR OF FEEDLOT CATTLE – EXPERIMENT 2

5.1. INTRODUCTION AND AIM

Meat discoloration is a serious problem that is associated with packaged fresh meat. It causes meat retailers to remove up to 10 % of their unspoiled packaged fresh meat in South Africa (Buys *et al*. 2000). Vitamin E has been used to improve meat colour and preservation, mainly because of its anti-oxidant properties (Liu *et al.*, 1996(a)(b); Mitsumoto *et al.*, 1991; Mitsumoto *et al.*, 1993; Hoving-Bolink *et al*., 1994; Sheehy *et al.*, 1997). The properties of vitamin E as an antioxidant and its ability to prevent lipid oxidation has been reviewed (Sheehy *et al*. 1997). Other investigators (Manu-Tawiah *et al*. 1991) have reported maintenance of meat colour with tetrasodium pyroposphate, sodium erythroborate and citric acid combined with modified atmosphere. But, there is no related literature on the use of Se in meat colour and meat shelf-life improvement despite its antioxidant capacity and its interaction with vitamin E (Makimura *et al*. 1993). Both Se and vitamin E are essential nutrients and both are involved in, and play complementary roles as biological antioxidants protecting against the damage done to the body by the production of free radicals (MacPherson, 1994).

The role of Se in membrane protection to oxidation is due to glutathione peroxidase. A deficiency of Se leaves the cell membranes vulnerable to oxidation and precipitates drip loss in meat. After drip loss, meat does not look appealing and there may be an off - flavour to it. There is also a considerable loss of carcass weight and an increase in bacterial contamination (Close, 1998). This is also one of the ways the intervention of Se in meat colour and preservation could be explained.

It has also been shown that Se alone or with vitamin E is associated with increased glucose absorption in the chicken (Giurgia and Roman, 1992). Given the involvement of Cr in glycogen and lipid metabolism (Anderson *et al*., 1997; NRC, 1997), it is thought that it may lower meat pH, thereby improving meat colour by delaying meat discoloration that is caused by lipid oxidation (Laurie, 1985). Also the resistance by consumers to the

use of synthetic antioxidants in foods has increased (Laurie, 1985) and there has been an interest in replacing them with natural substances possessing antioxidant properties. Vitamin E has been shown to increase the stability of lipids in meat systems and protect them against off-flavour development, myoglobin oxidation and other manifestations of lipid breakdown (Liu *et al.*, 1996(a)(b)). It has a stabilising effect on meat colour (Hoving-Bolink *et al*. 1994). This experiment was aimed therefore at determining the factors that may explain the improvement of meat colour in feedlot cattle supplemented with selenium and chromium.

5.2. HYPOTHESIS

It was proposed that:

- Selenium is a potent antioxidant that decreases lipid oxidation and extends meat colour display-life;
- Chromium by its effect on glucose and lipid metabolism affects meat pH and delays meat discoloration;
- Both Se and Cr interact with different minerals that affect carcass characteristics thereby improving meat quality including meat colour.

5.3. MATERIALS AND METHODS

5.3.1. EXPERIMENTAL ANIMALS AND SAMPLING

The animals used are those described in experiment-1 (Chapter 4). Twenty-four meat samples were collected at random per treatment, i.e. 2 samples per vaccine batch within each treatment. The evaluation of meat colour was done therefore on 6 samples for each treatment, and the vaccine effect was assumed to be constant in the analysis of the results. The limited number of samples was due to the high cost of this experiment. The prime rib is one of the most expensive beef cuts in South Africa. The value of the carcass that been processed may be also lowered at the carcass auction because any cut on a carcass is considered automatically as a bruising by the meat grading personnel at the abattoir.

Meat samples were taken at slaughter and consisted of the left prime-rib cuts. This cut included three ribs i.e. the 7^{th}, 8^{th} and 9^{th} ribs cut at the level of the line joining the

symphysis pubis and the middle of the first rib. Individual rumps were then sectioned into three steaks. The steaks were packaged and conserved as described by Buys *et al*. (2000). The steaks were placed in shallow Styrofoam trays and each over-wrapped with polyvinyl chloride (PVC). On d 0 after slaughter, the colour assessment was done 1 hour after opening the pack in order to allow for oxygenation of the myoglobin (bloom) and the remaining samples were displayed for 7 or 21 days, in open-deck retail display cabinet at 4 ± 2^{0}C. The PVC-over wrapped samples were displayed under continuous illumination with a soft fluorescent white light. Steaks were randomly relocated within the display cabinet on a daily basis to avoid non-uniform light and temperature exposure.

Readings of the meat components by spectrophotometer reflectance (Philips spectrophotometer, Unicam Limited, Cambridge, United Kingdom) on d 0 and after 7 and 21 days display at 4^{0}C were used to calculate the content of myoglobin (deoxymyoglobin, metmyoglobin and oxymyoglobin) in the meat. The discoloration of the meat was assessed as the percentage of the metmyoglobin portion.

Treatments were compared by analysis of variance (ANOVA). The model used included main effect of day, treatment, day by treatment and metmyoglobin percentage as covariates.

5.4. PARAMETERS MONITORED

The parameters monitored were the:

- metmyoglobin percentage
- interaction between meat pigment content and fat thickness, meat pH, warm and cold carcass masses, liver mineral content including Se and Cr.

5.5. RESULTS AND DISCUSSION

As indicated in the literature review, meat colour is determined by the proportional amount and the physical state of meat pigments, namely: metmyoglobin, oxymyoglobin and myoglobin (Laurie, 1985). The smaller the proportion of metmyoglobin, the brighter the meat will be. But Liu *et al* (1996b) argue that estimates of meat colour display life

based on metmyoglobin are not very accurate because metmyoglobin content on its own is not a descriptor of the spectral reflectance of meat. Results are also compromised in this method because it does not take into account the dose effect of the meat stabiliser utilised. Therefore, an attempt was made in this study to minimise that by using the proportion of different meat colour components rather than using the metmyoglobin percentage alone. More importantly, there was no concern over any dose effect in this study since it was not designed to address that. Again in other techniques such as by Arnold *et al.* 1992 cited by Liu *et al.* (1996b), the early accumulation of metmyoglobin in gluteus medius muscle can affect the results. In the present study, the values that are reported are the means of two measurements taken on two different muscle sites in order to overcome, if not to minimise, this shortfall.

Results of the colour readings are presented in Table 5.1 and Figure 5.1. Different models were used to analyse the data. The first results, based on the amount of each meat colour component, showed that neither the dietary supplement of Se and chromium nor the day, or day by treatment interactions affected the metmyoglobin accumulation ($P=0.15$). Contrary to Faustman and Cassens (1991) who showed that storage time increases the percentage of metmyoglobin, Buys *et al*. (2000) did not find a positive effect of supplemental vitamin E on meat colour display as determined by metmyoglobin measurement. For this reason and given the assumption by Liu *et al.* (1996b) that metmyoglobin is not an accurate measure of meat discoloration, the analyses were further done with the ratio of metmyoglobin over the rest of meat component.

The second model used in the analysis of data compared different meat colour component proportions by treatments and over time. Treatments affected significantly ($P\leq0.05$) the proportion of metmyoglobin with treatment CHR having lower values on d 7 and d 21 compared to other treatments (Fig. 5.1). It appears that part of the hypothesis explaining the effect of supplemental Cr on meat colour due to better glucose utilisation and glycogen storage in muscle of live animal might have been the most probable. Rosebrough & Steele (1981) showed that Cr supplementation increases the conversion of

glucose into glycogen. The antioxidant capacity of selenium may not act in the same way as vitamin E does. Selenium maintained very high proportions of metmyoglobin.

As shown earlier in this study, Cr storage in liver is increased if it is supplemented alone (treatment CHR) than when in combination with Se (SEL/CHR) (Table 4.8). But it was difficult to speculate that the positive effects of treatment CHR were due to the increased retention of Cr in the muscle. Anderson *et al.* (1997) showed that muscle Cr concentrations were not affected even though the liver concentration was increased. Therefore, the effect of Cr in meat colour could be explained by any factor other than the increased Cr in muscle tissue, as stated in the hypothesis.

Other factors that might affect meat colour are the meat pH, animal growth, carcass weight and mineral status. The different regressions of meat colour on these parameters were not significant. Besides, Sakurai *et al*. (1993) found that meat colour score was negatively correlated with marbling, texture, firmness and fat colour score, the darker meat having lower carcass grades. Other studies indicated that there was no significant breed difference in meat colour in cattle (Aass, 1996; Alonso *et al*. 1991) and pigs (Maassen-Frankle *et al*. 1991). In contrast, Faustman & Cassens (1991) reported that Holsteins had higher values for metmyoglobin percentage compared to crossbreeds. Others (Gigli and Iacurto, 1997) reported that carcass weight had a minor effect on meat colour whilst Pratchett *et al*. (1992) indicated that dressing percentage, fat thickness, fat colour, ultimate pH and meat colour were similar for two steer genotypes.

Smith *et al.* (1996) reported that there was a highly significant positive association between meat pH and meat colour; at a pH above 5.8 most carcasses were in the darkest meat colour category. The average meat pH in this study was above 5.8. But the metmyoglobin percentage was still not high enough to darken the meat, and probably as noted by Muir *et al* (1992), the diet based on grain produces bright lean meat colour.

According to Anderson *et al* (1997), trace metals Cu, Cr and Zn have been shown to have beneficial effects on glucose and lipid metabolism. It was also shown in this study that Se

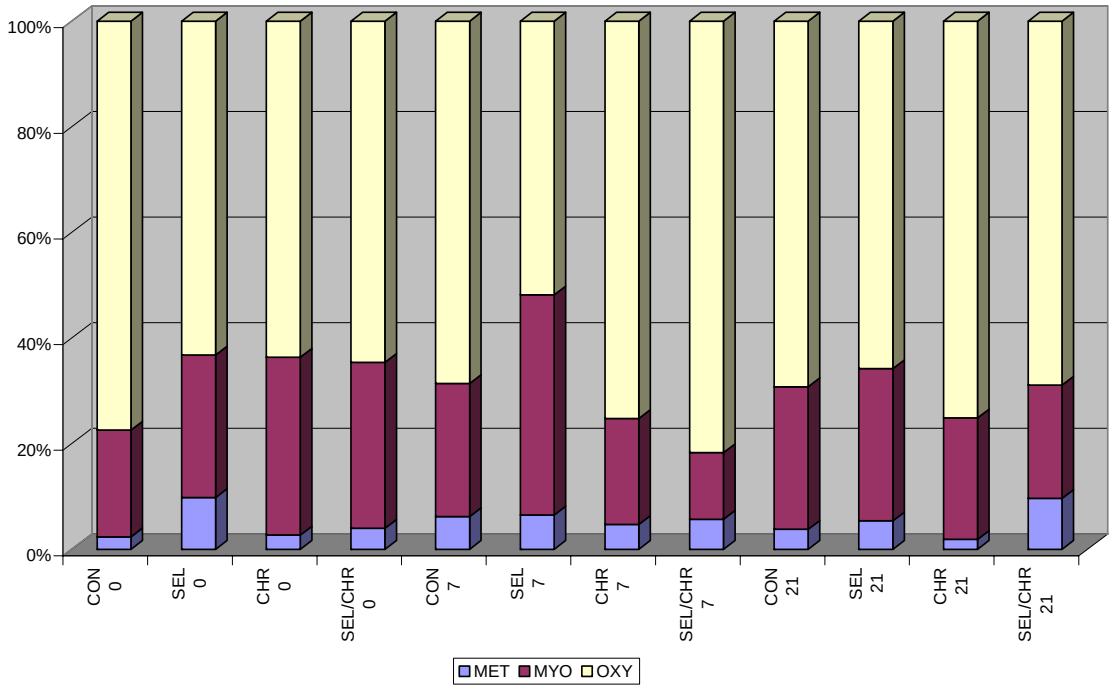
positively correlated with Cu, which in turn had a positive effect on Fe accumulation. Iron increases the catalysis of lipid peroxidation (Sheehy *et al*. 1997). Lapierre *et al*. (1990) reported that concentrates containing 100 – 200 mg/g of Fe exceed the Fe concentration required to produce light meat colour. In this experiment, the red bright colour was preferred and the diet used in this experiment contained on average 560 mg/g. Although the regressions of liver mineral concentrations on meat colour components was not significant, Fe involvement in meat colour is established. Wensing *et al*. (1991) reported a positive relationship between liver Fe concentration and the colour of meat. Meat colour depends on the amount of Fe and on the duration of supplementation (Knaus *et al*. 1997).

It is concluded that Cr is more efficient than Se in improvement of meat colour-display based on the proportion of metmyoglobin over other meat colour components. It probably acts through the improvement of glucose incorporation in muscle as glycogen. This maintains an adequate drop in meat pH and therefore, lowers the lipid peroxidation and prevents the accumulation of metmyoglobin, which is responsible for meat discoloration.

TABLE 5.1: MEAT COLOUR COMPONENTS (%) - PER DAY BY TREATMENT – OF FEEDLOT CATTLE FED A SUPPLEMENT OF SE AND CR – EXPERIMENT 2

Day	TREATMENT	MEAT COLOUR COMPONENT		
		METMYOG	MYOGL	OXYMYOG
0	CON	2.40±2.24	20.60±6.11	79.00±5.83
0	SEL	9.80±2.24	27.00±6.11	63.20±5.84
0	CHR	2.71±1.90	33.71±5.16	63.57±4.93
0	SEL/CHR	4.00±2.04	31.50±5.57	64.83±5.33
7	CON	6.20±2.24	25.20±6.11	68.70±5.84
7	SEL	6.50±2.24	41.80±6.11	52.00±5.84
7	CHR	4.71±1.90	20.00±5.16	75.14±4.93
7	SEL/CHR	5.67±2.06	12.58±5.57	81.83±5.33
21	CON	3.80±2.24	27.00±6.11	69.30±5.84
21	SEL	5.40±2.24	28.80±6.11	65.80±5.84
21	CHR	1.86±1.90	23.29±5.16	76.07±4.93
21	SEL/CHR	9.58±2.04	21.42±5.57	68.83±5.33

Figure 5.1. Meat colour component - Experiment 2



CHAPTER 6: THE EFFECT OF SUPPLEMENTAL SELENIUM AND DIFFERENT FORMS OF CHROMIUM IN FEEDLOT CATTLE – EXPERIMENT 3

6.1. INTRODUCTION AND AIM

Preliminary results from experiments 1 and 2 suggest that Se and Cr would be beneficial to the beef industry. These elements have been shown to have positive effects on the alleviation of stress and subsequently, the improvement of the performance and some carcass characteristics. Their effects on mineral status of feedlot cattle have also been investigated and the results were not conclusive.

It has been reported that organic forms of minerals are more efficient than the inorganic forms (Gadd, 1995; Hemken, 1997; Close, 1998), but controlled experiments have continued to report conflicting results (Arthington *et al.*, 1997). The inorganic form, such as Cr sulphate is cheaper (Boyazoglu, 1997), and it is highly absorbable (Merck & Co, 1996). However, the use of $CrSO_4$ in the feeding of livestock has not been documented.

The aim of this experiment was therefore:

- To verify some of the findings of experiment 1.
- To compare the effect of Cr sulphate with high-Cr yeast and their interactions with Se (sodium Se) in order to find the more effective combination on stress, growth performance, carcass characteristics and mineral status.

6.2. HYPOTHESIS

It was proposed that:

- Chromium sulphate is as effective as the high-Cr yeast.
- The effect of combined Cr sulphate and sodium Se is comparable to that of combined high-Cr yeast and sodium Se.

6.3. PARAMETERS MONITORED

The parameters monitored were:

- blood cortisol and glucose levels on d 0, d 04 and d42;

- live weight, feed intake and gain:feed intake ratio;
- carcass characteristics: warm and cold carcass weight, carcass shrink, dressing percentage (DP%) and meat pH;
- liver mineral levels: Ca, P, Mg, Cu, Fe, Mn, Zn, Co, Se and Cr on wet basis..

6.4. MATERIALS AND METHODS

6.4.1. ANIMAL AND EXPERIMENTAL DESIGN

The animals were once again from Gillimberg farms. Calves were weaned on the 18 June 1997. On the 19 and 20 June, a group of 75 weaners was selected. They were all Bonsmara-Brahman-Nguni crosses and weighed on the average 196 kg. On the 23 June, they were transferred to the Medunsa feedlot. On arrival, the animals were consigned to different pens and were fed Eragrostis hay ad libitum over night; fresh water was also available. Six different starter-production rations corresponding to six treatments were provided the following day after processing. The processing was conducted as described in experiment-1. But only one batch of the IBR/PI3/Leukotoxin (Pasteurella) vaccine was used this time.

The animals were sorted at random into 6 homogenous groups of 12 animals each, ear-tagged accordingly and allocated randomly to pens. The experimental design was a blind set-up because the premix formulations were not revealed until the last day of the experiment in order to avoid any bias for any particular treatment. All the rations were designated by letters, i.e.: F, G, H, K, S and W. The corresponding treatments as revealed at the end of the trial are presented in Table 6.1.

The general health status of the animals was good. Two cases of Bovine Respiratory Disease (BRD) and three cases of digestive problems (two cases of colic and one of diarrhea) were treated successfully and animals were not removed from the trial because of quick recovery. However, a steer, which had a blocked preputial opening, complicated by an erosive and necrotic posthistis, died under anesthesia during the operation to correct the problem. Another animal died of bloat towards the end of the finishing period probably due to a low level of fibre in the finisher diet (9.6%).

6.4.2 FEED AND DIETS

Table 6.2 and 6.3 present the diet formulations and compositions. In this trial, two-stage diets were used. A finisher ration was formulated on d43 because of the bulkiness of the starter-production ration and the high level of fibre (14.8 % DM).

TABLE 6.1: EXPERIMENTAL DESIGN FOR FEEDLOT CATTLE FED A SUPPLEMENT OF SE AND CR –EXPERIMENT 3

ANIMALS		TREATMENT		PEN NO.	DIET
TOTAL	PER PEN	GROUP	ABBREVIATION		
72 animals	12	CONTROL	CON	3	H
	12	SELENIUM	SEL	5	S
	12	INORGANIC CHROMIUM	ICH	4	K
	12	ORGANIC CHROMIUM	OCH	6	W
	12	SELENIUM X INORGANIC CHROMIUM	SIC	1	F
	12	SELENIUM X ORGANIC CHROMIUM	SOC	2	G

TABLE 6.2: DIET COMPOSITION AND NUTRIENTS IN ½ TON OF FEED - EXPERIMENT 3

INGREDIENTS	Inclusion (kg)			
	Starter-Production (kg - %)		Finisher (kg - %)	
Yellow maize meal	125	25	175	35
Eragrostis hay	130	26	90	18
Defatted Germ (DFG)	100	20	90	18
Wheaten Bran	50	10	50	10
Molasses	25	5	25	5
Malt Dust	25	5	25	5
Yeast	25	5	25	5
Limestone	5	1	5	1
Salt	5	1	5	1
Urea	5	1	5	1
Mono-Calcium-Phosphate	2.5	0.5	2.5	0.5
Premix[1]	2.5	0.5	2.5	0.5
NUTRIENTS				
Dry Matter (DM)	90.7		88.3	
Fibre	14.8		9.6	
Protein	13.0		14.0	
Calcium	0.76		0.54	
Phosphorus	0.49		0.52	
Magnesium	0.26		0.21	
Copper	17.9		21.1	
Iron	647.2		415.3	
Manganese	123.2		80.8	
Zinc	64.5		72.1	
Cobalt	2.07		2.4	
Selenium	2.2		2.97	
Chromium	4.1		8.3	

[1]Six different mineral-vitamin premixes for the six treatments as indicated in experimental design

TABLE 6.3: MINERAL CONCENTRATION (PPM) OF DIETS I (STARTER – PRODUCTION) AND II (FINISHER) – EXPERIMENT 3

TREATMENT	Diet & PEN	Mineral									
		Ca	**P**	**Mg**	**Co**	**Cu**	**Fe**	**Mn**	Se	**Zn**	**Cr**
ICH	**F-1**	0.94	0.68	0.27	2.3	11.7	482.5	137.5	1.6	67.9	3.5
SIC	**G-2**	0.71	0.47	0.25	2.9	12.3	537.5	99.7	2.4	60.4	4.1
OCH	**H-3**	0.67	0.51	0.26	2.3	31.3	437.1	112.9	2.1	59.2	2.9
SOC	**K-4**	0.77	0.48	0.27	1.4	26.9	572.8	149.1	2.4	96.8	6.4
CON	**S-5**	0.80	0.41	0.26	2.1	14.0	1415.0	130.7	2.2	50.7	4.8
SEL	**W-6**	0.64	0.40	0.25	1.4	11.4	438.8	110.0	2.6	52.5	3.0
AVERAGE FOR DIET I		**0.76**	**0.49**	**0.26**	**2.07**	**17.9**	**647.2**	**123.3**	**2.2**	**64.5**	**4.1**
ICH	**F-1**	0.46	0.48	0.18	3.2	30.5	358.9	80.3	1.8	64.4	8.4
SIC	**G-2**	0.55	0.53	0.24	1.2	23.8	401.2	88.3	3.4	76.7	13.3
OCH	**H-3**	0.63	0.52	0.18	3.0	16.3	432.9	77.8	2.2	76.8	6.9
SOC	**K-4**	0.50	0.56	0.20	2.5	16.3	396.3	72.2	3.1	67.3	9.1
CON	**S-5**	0.59	0.49	0.22	1.8	18.5	437.9	86.4	3.5	75.8	5.8
SEL	**W-6**	0.54	0.51	0.21	2.9	21.4	464.8	79.8	3.8	71.8	6.4
AVERAGE FOR DIET II		**0.54**	**0.52**	**0.21**	**2.4**	**21.1**	**415.3**	**80.8**	**2.97**	**72.1**	**8.3**

6.5. RESULTS AND DISCUSSION

6.5.1. THE EFFECTS OF STRESS ON BLOOD CORTISOL AND GLUCOSE LEVELS

Data related to stress assessment are presented in Table 6.4 and Figures 6.1 and 6.2. To overcome the problem of outliers, an arbitrary decision was taken to discard the five lowest and five highest observations as highlighted in the analytical programme (SAS, 1999). The results obtained did not differ from those including all the values and therefore, all the values were used in statistical analysis.

The mean values for cortisol level were high probably for the same reasons pointed out in experiment- 1 that breed types influence the level of blood cortisol. The cattle were from the same farm and of the same breed. Although stress due to transportation and handling could have been of the same magnitude as for experiment-1, it was believed based on assumption from Grandin (1997) that the pre-handling cortisol levels recovered within an hour. This meant that the actual values reported in Table 6.4 were related to those before handling and not only to handling stress. This supports the view that the breed of cattle used is highly susceptible to stress and therefore it is not suitable for feedlot production. In contrast, glucose concentrations were in the normal range. But as shown later, glucose concentrations were not related to those of cortisol, stress was instead assessed as a measure of cortisol level.

As seen in experiment-1, there were no differences between treatment groups for cortisol and glucose levels on d 0. On d 14, treatments SEL and ICH tended to have low (P=0.1) cortisol levels. Glucose levels, did not statistically differ from the control. Furthermore, values for combined Se and Cr, i.e. treatments SIC (P=0.11) and SOC (P=0.10) tended to have the highest glucose concentrations. On d42, cortisol levels did not differ, but although not statistically significant (P=0.1), treatment SOC tended to have the lowest cortisol level. As noted in experiment-1, it appears that the effect of combined Se and Cr is more beneficial on the alleviation of stress after the settlement of the animals in the feedlot and when dietary stress is prominent. This observation agrees with that of Anderson *et al* (1997).

In this experiment, treatment SIC had the highest glucose concentrations (P=0.03) on d42 while treatments OCH (P=0.06) and SOC (P=0.11) tended to have higher values as compared to CON. Nevertheless, there was no correlation between cortisol and glucose levels, making it difficult to support the hypothesis of the treatment effect on cortisol and subsequently on glucose. Consistently, these results and those from experiment-1 indicate that sodium selenite is efficient in the alleviation of stress in the initial days in the feedlot (adaptation phase). The combined Se and Cr works better in the production phase. Stress in the production phase is more related to increased efficiency of utlisation of highly energetic rations (Anderson *et al.* 1997).

These results also showed that the organic Cr is not superior to the inorganic form (Cr sulphate) in alleviation of stress. Most of the studies comparing the effects of inorganic with the organic forms of Cr, e.g. Southern and Page (1992), have been conducted with Cr chloride which is less soluble than Cr sulphate (Merck & Co, 1996). It appears that the solubility of the element affects its bioavailability and efficiency.

TABLE 6.4: BLOOD CORTISOL (NMOL) AND GLUCOSE (MMOL) LEVELS OF FEEDLOT CATTLE FED A SUPPLEMENT OF SE AND CR – EXPERIMENT 3

Treatment	CONCENTRATIONS					
	DAY 1		DAY 14		DAY 42	
	CORT1	**GLUC1**	**CORT14**	**GLUC14**	**CORT42**	**GLUC42**
CON	105.14±8.65	4.43±0.24	110.53±10.59	4.73±0.13	87.63±15.4	4.20±0.11
SEL	102.50±8.65	4.51±0.24	76.26±10.59	4.64±0.13	86.81±15.4	4.32±0.11
ICH	98.26±8.65	4.32±0.24	79.86±10.59	4.72±0.13	97.96±15.4	4.18±0.11
OCH	81.68±9.03	4.82±0.24	94.47±11.06	4.68±0.14	93.94±16.1	4.51±0.12
SIC	91.78±8.65	4.45±0.24	101.92±10.59	5.03±0.13	108.35±15.4	4.55±0.11
SOC	82.89±9.03	4.25±0.24	101.26±11.06	5.05±0.14	70.84±16.1	4.46±0.12

FIGURE 6.1: BLOOD CORTISOL LEVELS (nmol/L) OF FEEDLOT CATTLE FED A SUPPLEMENT OF SELENIUM AND CHROMIUM

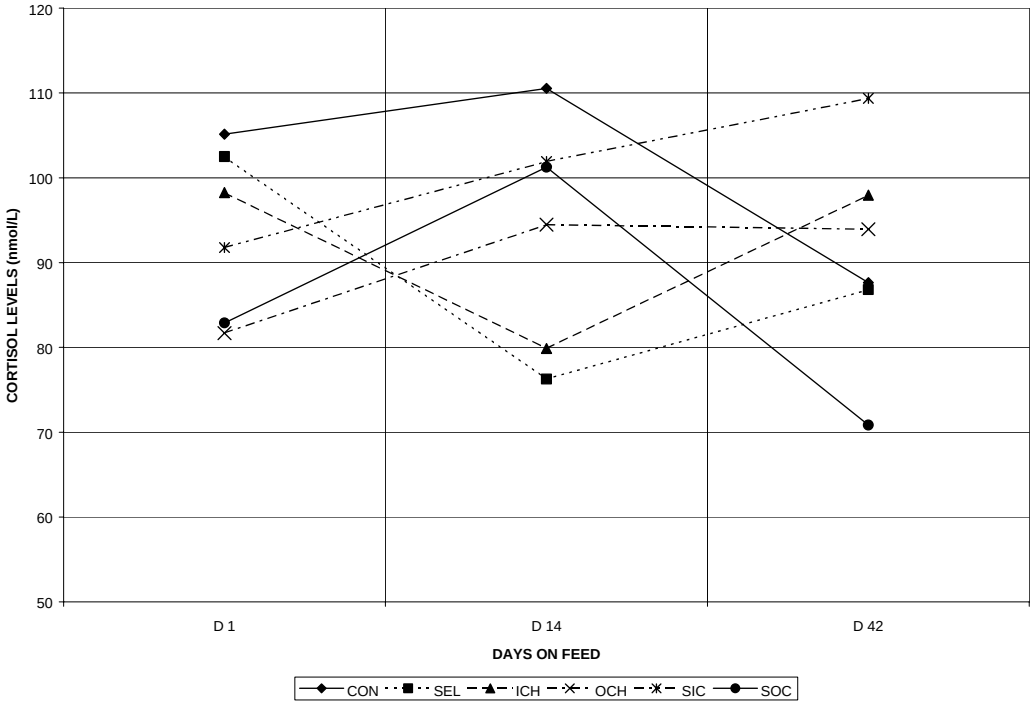
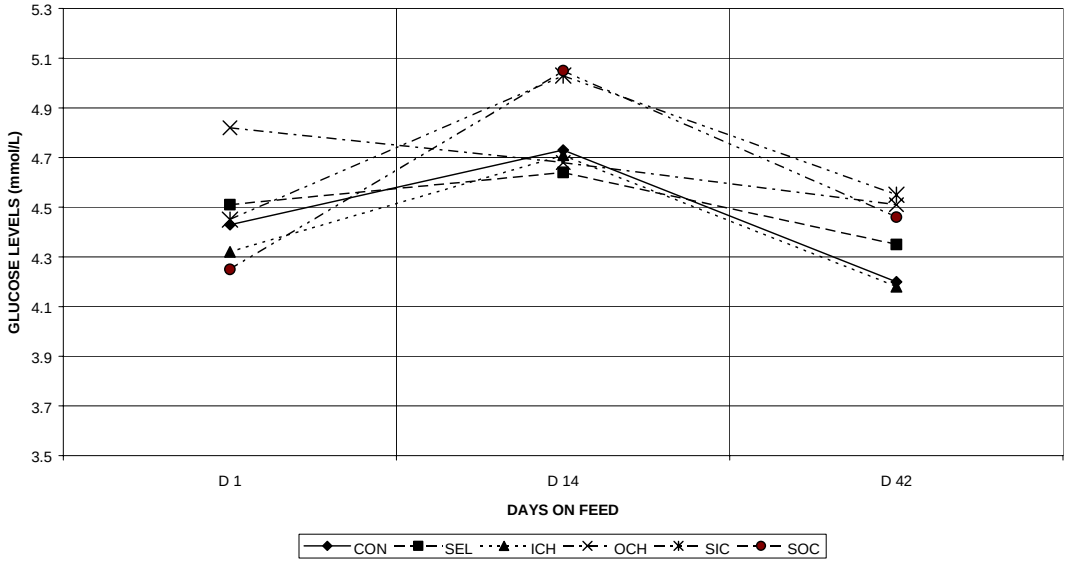


FIGURE 6.2: BLOOD GLUCOSE LEVELS OF FEEDLOT CATTLE FED A SUPPLEMENT OF SELENIUM AND CHROMIUM



6.5.2. PERFORMANCE

Results related to growth rate are presented in Table 6.5 and Fig. 6.3. The data recorded on d 04 were discarded because the values were high probably due to weight shrink on d 0. The overall live weight gain showed an exponential trend from d70 until d 012; the trial was terminated two weeks later (d 025) in order to obtain similar carcass maturity. Treatment SIC responded more promptly on d56 after the adjustment of the diet. Treatment SIC performed consistently better than all the other treatments ($P \leq 0.05$) except against treatment SOC. This again shows that the organic Cr is not necessarily more efficient than the inorganic form.

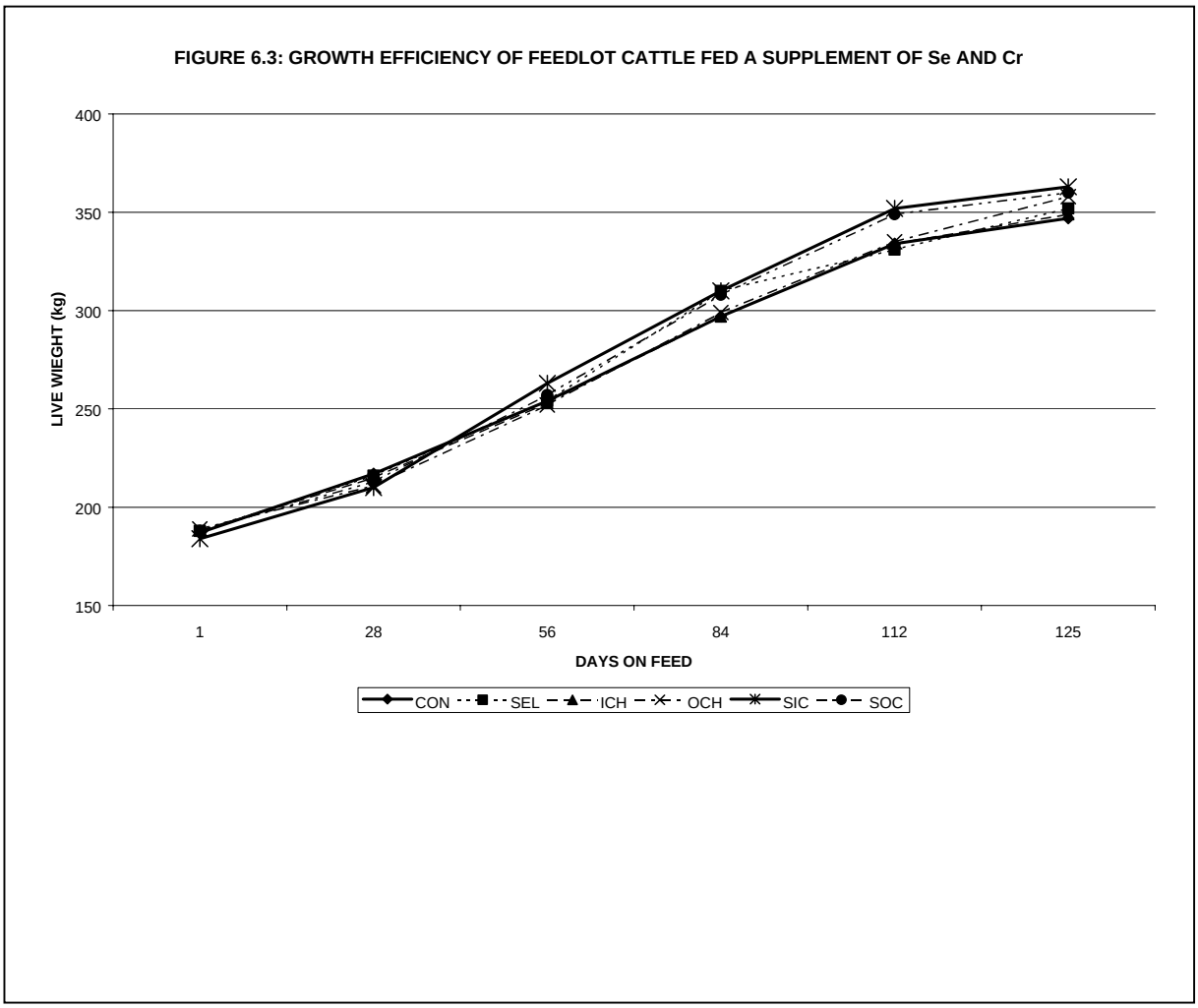
Study of regressions between ADG and P-FCR on the one hand and cortisol and glucose levels on the other hand from d 0 to d42 revealed no relationship between these parameters. This was seen in experiment-1, as it was expected because, among other reasons, such as the breed potential, the adaptation stressors, etc… the growth potential is low at this stage. However, some management strategies can be drawn from these experiments (1 and 3). It appears that Se or Cr supplementation alone is effective in the alleviation of stress and it is therefore recommended during the adaptation period. The combined elements (Se and Cr) might be recommended for the production and finishing phase in order to improve weight gain. According to Bunting *et al.* (1994), the beneficial effects of Cr supplementation can be attributed to its apparent influence on the distribution of energy between adipose and lean tissue. This is important because the management of the growth process in the feedlot consists basically of the control of the deposition of lean tissue (protein) (Slabbert, 1989).

TABLE 6.5: AVERAGE DAILY GAIN (Kg.D^{-1}) OF FEEDLOT CATTLE FED A SUPPLEMENT OF SE AND CR – EXPERIMENT 3

Day	Treatment					
	CON	**SEL**	**ICH**	**OCH**	**SIC**	**SOC**
28	1.071±0.12	0.997±0.12	0.952±0.12	0.795±0.12	0.908±0.12	0.909±0.12
42	0.923 ^{abc} ±0.09	0.913 ^{abc} ±0.09	1.002 ^{abc} ±0.09	0.844 ^{ac} ±0.10	1.151 ^{b} ±0.09	0.866 ^{c} ±0.10
56	1.183 ^{a} ±0.07	1.183 ^{a} ±0.07	1.153 ^{a} ±0.07	1.128 ^{a} ±0.07	1.414 ^{b} ±0.07	1.234 ^{ab} ±0.07
70	1.256 ^{a} ±0.06	1.357 ^{ab} ±0.06	1.238 ^{a} ±0.06	1.234 ^{a} ±0.06	1.488 ^{b} ±0.06	1.390 ^{ab} ±0.06
84	1.310 ^{a} ±0.07	1.458 ^{ab} ±0.07	1.290 ^{a} ±0.07	1.310 ^{a} ±0.07	1.503 ^{b} ±0.07	1.429 ^{ab} ±0.07
98	1.454 ^{ac} ±0.07	1.431 ^{ac} ±0.07	1.356 ^{c} ±0.07	1.404 ^{ac} ±0.07	1.667 ^{b} ±0.07	1.551 ^{ab} ±0.07
112	1.410 ^{a} ±0.06	1.378 ^{a} ±0.06	1.398 ^{a} ±0.06	1.403 ^{a} ±0.06	1.611 ^{b} ±0.06	1.552 ^{ab} ±0.06
125	1.364±0.06	1.403±0.06	1.371±0.06	1.445±0.06	1.531±0.06	1.472±0.06

NB. Values with different superscripts differ significantly (P≤0.05) within a row.

FIGURE 6.3: GROWTH EFFICIENCY OF FEEDLOT CATTLE FED A SUPPLEMENT OF Se AND Cr - EXPERIMENT 3



6.5.3. FEED CONVERSION RATIO

The data related to feed coversion ratio is presented in Appendix C2. The model used to analyse the generated data included P-FCR as a dependent variable and treatment as an independent variable. The means obtained (Table 6.6) were comparable to those in experiment-1.

Treatment SIC was the most efficient with lowest values from d42 as compared to most other treatments ($P \leq 0.05$), followed by treatment SOC which was the second lowest though not significantly different. Other studies (Chang & Mowat, 1992; Moonsie-Shageer & Mowat, 1993) have reported on the beneficial effects of Cr on feed efficiency as evident by lower feed conversion. However, these reports and the present results are not in consonance with those by Bunting *et al* (1994) who did not find positive effects with Cr picolinate in Holstein calves. Pollard and Richardson (1999) used the high-Cr yeast and found no effect on dry matter intake (DMI) at the level of 0.2 ppm dosage, whilst the 0.4 ppm dose reduced the DMI and increasing the feed: gain ratio.

Dietary supplement of Se did not affect the feed intake of the animals in this experiment. Se has been shown not to affect the digestibility of nutrients and feed intake (Nicholson *et al.*, 1991b) and Se supplementation does not affect the fermentation process of bovine fluid in vitro (Ortman and Pehrson, 1997a).

TABLE 6.6: PREDICTED FEED CONVERSION RATIO (+ S.E.M.) OF FEEDLOT CATTLE FED A SUPPLEMENT OF SE AND CR – EXPERIMENT 3

Day	Treatment					
	CON	**SEL**	**OCH**	**ICH**	**SIC**	**SOC**
28	7.869±0.554	8.069±0.554	8.289±0.554	9.149±0.578	8.518±0.554	8.541±0.578
42	8.394$^{a\,b}$ ±0.413	8.495$^{a\,b}$ ±0.413	8.056$^{a\,b}$ ±0.413	8.786^{a} ±0.431	7.379^{b} ±0.413	8.691$^{a\,b}$ ±0.431
56	7.253^{a} ±0.270	7.242^{a} ±0.270	7.346^{a} ±0.270	7.450^{a} ±0.282	6.324^{b} ±0.270	7.013$^{a\,b}$ ±0.282
70	6.944^{a} ±0.243	6.534$^{a\,b}$ ±0.243	7.001^{a} ±0.243	7.000^{a} ±0.254	6.036^{b} ±0.243	6.392$^{a\,b}$ ±0.254
84	6.733^{a} ±0.254	6.150$^{a\,b}$ ±0.254	6.806^{a} ±0.254	6.702^{a} ±0.266	5.979^{b} ±0.254	6.251$^{a\,b}$ ±0.266
98	6.168^{a} ±0.258	6.263^{a} ±0.258	6.573^{a} ±0.258	6.330^{a} ±0.270	5.403^{b} ±0.258	5.802$^{a\,b}$ ±0.270
112	6.319^{a} ±0.251^{a}	6.458^{a} ±0.250	6.406^{a} ±0.250	6.330^{a} ±0.262	5.597^{b} ±0.251	5.796$^{a\,b}$ ±0.262
125	6.480±0.244	6.360±0.244	6.506±0.244	6.170±0.255	5.870±0.244	6.100±0.255

NB. Values with different superscripts differ significantly (P≤0.05) within a row.

6.5.4. CARCASS PARAMETERS

The mean warm carcass mass (WCM) was 193.7 kg and cold carcass mass (CCM) was 189.6 kg. These values were higher than those recorded in experiment-1 probably because a better diet was used in this experiment and the suitability of the animals to feedloting. Weight shrink did not differ between treatments. Although the differences were not statistically significant (P=0.11), treatment SIC had a higher WCM, compared to treatments CON, SEL and ICH. Treatment OCH performed better than ICH in having a higher WCM, but the dressing percentage (DP) showed again the advantage (P≤0.05) of treatment SIC making it difficult to draw a definitive conclusion.

A descriptive study of carcass conformation (CC) and fat code (FC) is presented in Table 6.8. All the carcasses were within CC-3 and 4. Carcass fat codes were within FC-2, 3 and 4. Eighty-seven percent of carcasses were FC-2 and 10% were FC-3, making a total of ninety-seven percent carcasses within the preferential range. Animals treated with both chromium forms were 100% CF-2. This indicates that these treatments could delay the carcass maturity thereby allowing it to attain higher carcass weight within the recommended lean meat codes FC-2 and 3.

The mean dressing percentage (DP) was 54.51 and it showed a significant difference between treatments (P≤0.05). As shown in Table 6.7, treatment SIC had the highest DP (56.08%) as compared to other treatments. The mean meat pH was 5.65 and 5.71, respectively for pH1 and pH2. There was no significant difference between the two variables over time, but the two values were within the range of normal meat ultimate pH (Laurie, 1985). However, when all the variables related to carcass characteristics are considered, treatment SIC seems to have performed better.

TABLE 6.7: CARCASS CHARACTERISTICS OF FEEDLOT CATTLE FED A SUPPLEMENT OF SE AND CR – EXPERIMENT 3

	ITEM					
Treatment	**LWT125 (kg ±SEM)**	**WCM (kg ±SEM)**	**CCM (kg ±SEM)**	**DP (%)**	**pH 1**	**pH 2**
CON	347.5 ±21.1	189.6 [a] ±4.8	185.6 ±4.8	54.6[a] ±0.5	5.6 ±0.1	5.8 ±0.04
SEL	352.5 ±33.9	190.0 [a] ±4.8	186.1±4.8	53.9 [a] ±0.5	5.6 ±0.1	5.7 ±0.04
ICH	349.2 ±33.2	187.4 [a] ±4.8	183.7±4.8	53.6 [a] ±0.5	5.6 ±0.1	5.7 ±0.04
OCH	358.6 ±22.9	195.5 [a b] ±5.0	191.0±4.9	54.5 [a] ±0.5	5.5 ±0.1	5.7 ±0.04
SIC	363.8 ±27.8	204.0 [b] ±4.8	199.6±4.8	56.1[b] ±0.5	5.8 ±0.1	5.7 ±0.04
SOC	360.4 ±24.4	196.0 [a b] ±5.0	191.8±4.9	54.5 [a] ±0.5	5.7 ±0.1	5.8 ±0.04

NB. Values with different superscripts differ significantly (P≤0.05) within a column.

Abbreviations: LWT125: live weight on d 125; WCM: warm cold carcass mass; CCM: cold carcass mass; DP: dressing percentage; pH1:meat pH1 on slaughter day; pH2: meat pH 24 hours later.

TABLE 6.8: FREQUENCY AND PERCENTAGE OF CARCASS FAT CONFORMATION (CF) AND FAT CODES (FC) OF FEEDLOT CATTLE FED A SUPPLEMENT OF SE AND CR – EXPERIMENT 3

Treatment	Observation	Conformation				Fat Code					
		3	**%**	**4**	**%**	**2**	**%**	**3**	**%**	**4**	**%**
CON	12	10	83.33	2	16.67	9	75.00	2	16.67	1	8.33
SEL	12	10	83.33	2	16.67	10	83.33	2	16.67	0	0
ICH	12	8	66.67	4	33.33	12	100.00	0	0	0	0
OCH	11	10	90.91	1	9.09	11	100.00	0	0	0	0
SIC	12	10	83.33	2	16.67	10	83.33	1	8.33	1	8.33
SOC	11	9	81.82	2	18.18	9	81.82	2	18.18	0	0

6.5.5. MINERALS

6.5.5.1. MINERAL STATUS

Data related to liver mineral concentrations and correlations are presented in Table 6.9 and 6.10. It appears that all the liver mineral concentrations were normal. Calcium and Zn concentrations were statistically different between some treatments ($P \leq 0.05$), whilst Mg, Cu and Cr concentrations tended to differ ($P < 0.1$). Treatment SIC had the highest Zn ($P \leq 0.05$) and Cr ($P = 0.1$) concentrations in the liver. However, there were fewer differences and interactions between treatments in this experiment compared to experiment-1.

With regard to differences between chemical forms, there were no differences in mineral concentrations between ICH and OCH and between SIC and SOC. This, again, did not support the hypothesis of the superiority of the organic Cr forms over the inorganic ones, as suggested by other investigators (Mowat *et al.* 1993; Gadd, 1995; Lyons, 1997).

As seen in experiment 1, supplemental Se (treatment SEL) highly increased ($P \leq 0.001$) liver tissue retention of Ca. This phenomenon has been difficult to explain in the absence of interaction between the two minerals. However, Puls (1994) has indicated that chronic stress raises the level of serum Ca. Moreover, it has been shown in the two experiments (1 and 3) that Se is ineffective in lowering cortisol levels on d42. This may be an indication that Se has no effect on dietary stress. Given that this type of stress is considered chronic in the feedlot due to high-energy diet, it can be speculated that the high serum Ca causes high liver Ca.

The effect of supplemental Cr on tissue mineral retention e.g. liver, muscle etc., has been variable. Anderson *et al* (1997) reported that one diet with Cr concentration of more than 300 mg per kg resulted in non-detectable changes in tissue Cr in pigs. Nevertheless, even with lower doses, e.g. 200 mg of high-Cr yeast per kg of diet, Chang *et al* (1992) could not detect changes in tissue Zn, Fe, Mg, Ca and P concentrations. Changes were noted for Cu in steers fed urea-corn, but not in those fed the soybean meal. Results obtained by

Moonsie-Shageer and Mowat (1993) showed a positive effect of supplemental Cr on the increment of serum Ca and Mg.

Diets in this experiment provided high doses of Cr (Table 6.3). The dietary supplement of Cr did not affect the retention of Cr and most of the minerals in the liver tissue. This is in consonance with the suggestion that Cr absorption is inversely related to dietary intake (Anderson and Kozvloski, 1985 cited by Anderson *et al.* 1997). It also has been suggested that when the diet is adequate in protein requirements (such as in the present study), there is less dietary stress susceptible to mobilise the available Cr (Chang *et al.*, 1992) and to increase the tissue demand for other minerals.

According to Cloete *et al* (1994), the deficiencies in major nutrients such as energy and protein may impede on the responses to dietary supplement of Cu, Se and Co. This suggests that the poor response to supplemental Se and Cr with regard to tissue minerals retention, is due to the fact that the diets used in this experiment provided adequate levels of nutrients.

6.5.5.2. INTERACTION BETWEEN MINERALS

The correlation coefficients and statistical significance of the minerals are presented in Table 6.10. Contrary to experiment-1, there were lesser interactions between minerals in the present experiment. Selenium did not show any interaction whilst Cr interacted with Mn and Zn. Both relationships have been reported by Puls (1994).

The interactions between Cr and Mn or Zn are presented in the following regression formula:

$$Cr = -0.135^{a} + 0.297^{b}(Mn) + 0.019^{c}(Zn) \quad R^2=0.18$$

Where: ^{a} = intercept; ^{b} = coefficient of parameter Mn; ^{c} = coefficient of parameter Zn; (Mn) = mean of liver Mn concentration and (Zn) = mean of liver Zn concentration.

Liver Mn and Zn means were respectively, 4.12 ppm and 39.12 ppm. It is therefore estimated that for each Cr unit increase, liver Mn concentration increased by 1.1 units while liver Zn concentration increased by 0.6 units. These estimates are low and agree with those in experiment-1 and other findings by Chang *et al.* (1992) and Anderson *et al.* (1997) where the dietary Cr did not augment the concentrations of, among other minerals, that of Zn. It was suggested that, because the diet provided adequate levels of minerals in this trial, it was difficult to get dramatic response to Se and Cr supplementation.

6.5.5.3. INTERACTION BETWEEN MINERALS AND PERFORMANCE

There was no correlation between, on one hand the ADG on d 125, and on the other hand the liver concentrations of Se and Cr or their interaction in the present experiment. Minerals have not been shown to affect positively the performance of cattle in the previous experiment and in Chang *et al.* (1992) study. This does not exclude the fact that mineral supplementation is beneficial to cattle performance. It was stated that the prerequisite to a clinical or production response to supplementation is a state of mineral deficiency. It is believed that because both diets provided adequate levels of minerals, it was difficult to obtain a dramatic change.

TABLE 6.9: LIVER MINERAL CONTENT (PPM ± SEM) OF FEEDLOT CATTLE FED A SUPPLEMENT OF SE AND CR – EXPERIMENT 3 ON WET BASIS

Mineral	Treatment						Average
	CON	**SEL**	**ICH**	**OCH**	**SIC**	**SOC**	
Ca	58.85 [a] ± 7.81	133.40 ± 7.81 [b]	46.79 [a] ± 7.91	43.03 [a] ± 8.16	59.43 [a] ± 7.81	45.24 [a] ± 8.16	65.04
P	3260.0 ± 280.1	3358.5 ± 280.1	3657.8 ± 280.1	3059.0 ± 292.5	3430.8 ± 280.1	3253.7 ± 292.5	3341.8
Mg	63.19 ± 9.43	89.37 ± 9.43	66.90 ± 9.43	74.07 ± 9.85	86.72 ± 9.43	94.66 ± 9.85	79.00
Co	6.02 ± 0.71	5.84 ± 0.71	7.26 ± 0.71	5.72 ± 0.74	7.32 ± 0.71	7.46 ± 0.74	6.60
Cu	77.67 ± 7.02	81.94 ± 7.02	84.37 ± 7.02	88.00 ± 7.33	88.20 ± 7.02	60.44 ± 7.33	80.27
Fe	48.59 ± 3.37	46.38 ± 3.37	57.98 ± 3.37	47.26 ± 3.52	49.18 ± 3.37	50.73 3.52	50.05
Mn	3.85 ± 0.15	3.90 ± 0.15	4.26 ± 0.15	4.21 ± 0.16	4.29 ± 0.15	4.23 ± 0.16	4.12
Zn	32.52 [a] ± 2.99	38.01 [ab] ± 2.99	34.85 [a c] ± 2.99	44.54 [c b] ± 3.28	46.09 [b] ± 2.99	39.73 [ab] ± 3.12	39.12
Se	1.71 ± 0.35	1.63 ± 0.35	1.50 ± 0.35	1.63 ± 0.36	1.59 ± 0.35	1.74 ± 0.36	1.63
Cr	1.65 ± 0.22	1.44 ± 0.22	1.91 ± 0.23	1.80 ± 0.23	2.26 ± 0.22	2.01 ± 0.23	1.84

NB. Values with different superscripts differ significantly ($P \leq 0.05$) within a row.

TABLE 6.10: CORRELATION COEFFICIENT BETWEEN MINERALS IN LIVER OF FEEDLOT CATTLE FED DIFFERENT COMBINATIONS OF Se AND Cr

Item (R^2/P)[x]	**Se**	**Cr**	**Ca**	**P**	**Mg**	**Co**	**Cu**	**Fe**	**Mn**	**Zn**
Se										
Cr									0.27 0.02	0.32 0.01
Ca										
P								0.31 0.01		
Mg						0.26 0.03			0.23 0.05	
Co					0.26 0.03				0.38 0.001	
Fe				0.31 0.01						
Mn		0.27 0.02			0.23 0.05	0.38 0.001				
Zn		0.32 0.01								

[x] R^2 = correlation coefficient; P = probability value

CHAPTER 7: THE EFFECT OF DIFFERENT COMBINATIONS OF SELENIUM AND CHROMIUM ON FEEDLOT CATTLE – EXPERIMENT 4

7.1. INTRODUCTION AND AIM

Dietary supplements of Se and Cr have been shown to bring some changes in stress alleviation and improvement of growth performance, carcass characteristics and mineral status of feedlot cattle in previous experiments. Although there was no correlation between the two elements in these experiments, the results suggested that the best way of supplementing the two trace elements might be by combining them. Another issue was to find the best combination. For this purpose, two different forms – inorganic and organic - of each element were used in order to provide four different combinations (see Table 7.1).

The diets used in the previous experiments did not include any ionophore because there was a need for avoiding the confounding effects of many feed additives. However, no specific investigations were undertaken to explain the effect of this feed additive for the simple reason that the experiment was not designed for this purpose. In the last experiment, it was added for the simple reason of complying with the standard feed formulation in South Africa.

7.2. HYPOTHESIS

It was proposed that

- the effects of Se and Cr are more pronounced if an ionophore is added to the diet.
- Se and Cr combinations have better effects than the single elements on the alleviation of stress, feed conversion, growth performance and carcass characteristics.
- Se and Cr combinations improve the mineral status and interactions of feedlot cattle than Se and Cr alone.

7.3 MATERIALS AND METHODS

7.3.1. ANIMAL AND EXPERIMENTAL DESIGN

Thirty-six weaner calves having a mean body mass of 221kg of body mass were used in this trial. Contrary to the first three trials, these animals were heavier because they were of medium to big frame. They were Bovelder x Hereford crosses. They were shipped from Newcastle, a town situated in the Southern Region (Kwa-Zulu Natal) of South Africa at approximately 250 km from the experimental farm (Medunsa).

In this trial, the animals were processed at an interim farm. Upon arrival at Medunsa, the animals were allowed to rest overnight. Fresh hay and clean water were provided. The next morning (d 1), they were ranked according to initial body weight from the least to most heavy and allocated at random to six pens of six animals each corresponding to six treatments (Table 7.1). The weight distribution was similar in all six pens.

The animals were clinically assessed three times a day for illness and treated accordingly. One animal died of heartwater on d 29. A prospective outbreak of the disease was prevented by blocking all the animals with injectable (IM) Oxytetracycline (EngemycinND 10%, Intervet SA).

The animals were transported on d 120 to the abattoir of the Agricultural Research Council (ARC) – Irene station, situated about 40 km from the Medunsa Experimental Farm. They were slaughtered in two batches for two consecutive mornings. In order to minimise the day of slaughter effects, an equal number of animals from each treatment was slaughtered per day. The remaining animals were fed hay and provided with fresh water in order to minimise the loss of condition. Liver samples were also taken as usual and kept accordingly.

TABLE 7.1: EXPERIMENTAL DESIGN OF FEEDLOT CATTLE FED DIFFERENT COMBINATIONS OF SE AND CR – EXPERIENCE 4

ANIMALS		TREATMENT	
TOTAL	PER PEN	GROUP	ABBREVIATION
36 ANIMALS	6	Negative Control	NECO
	6	Monensin Control	MOCO
	6	Inorganic Se X Inorganic Cr	ISIC
	6	Inorganic Se X Organic Cr	ISOC
	6	Organic Se X Inorganic Cr	OSIC
	6	Organic Se X Organic Cr	OSOC

7.3.2. DIETS AND FEEDING PATTERNS

The animals were fed for 102 days on an appropriate feedlot ration as described in Table 7.2. The feed intake was recorded daily on a pen basis for feeding management purposes. This has been shown to be a limiting factor for more elaborate statistical analyses. Therefore, pooled feed samples were used for chemical analysis. The rations were mixed at the experimental farm. Feeding was *ad libitum.*

Three types of diets were provided, i.e.:

- (a) Negative Control diet: a basal diet providing required levels of energy, protein, crude fibre, calcium and phosphorus.
- (b) Monensin Control diet: consisting of basal diet (a) to which 33g of RumensinND (Elanco, AH) per tone of feed was added.
- (c) Specific treatment diets consisted of diet (b) to which 0.3 ppm of the trace element is added accordingly, e.g.: for treatment ISIC, the ration included 0.3 mg of sodium selenite and 0.3 mg of sodium sulphate per kg DM. Table 7.2 provides the details of diet composition.

7.3.3. ANALYTICAL PROCEDURES

Liver and feed samples for mineral analyses were prepared at the Nutritional Laboratory of the Department of Animal Science – University of Pretoria. These methods were similar to those previously used (experiments 1 and 3). A slightly different procedure was used for Se preparation. A programmable heating block was used for the digestion of the samples overnight.

Description of Se preparation:

The samples consisting of 1 g of liver tissue were carefully measured and placed in acid washed culture tubes. Four ml of the mixture 1:4 $HCLO_4$: HNO3 were added. The tubes were then placed on the digestion block overnight with the following programme:

- 16h:00 to 20h:00 at room temperature
- 20h:00 to 21h:00 up from romm temperature (25 degrees) to 100 degrees
- 21h:00 to 22h:00 at 100 degrees

- 22h:00 to 23h:00 up to 180 degrees
- 23h:00 to 05h:00 at 180 degrees
- 05h:00 to 07h:00 down to 130 degrees
- 07h:00 to 08h:00 at 130 degree
- 08h00 to 09h:00 down to 100 degrees

At 9H:00 the next morning, the tubes were removed from the block and cooled to room temperature for approximately ten minutes. One ml of 20% HCI was added and the tubes replaced in the block for 40 minutes. This is to reduce Se VI to Se IV. After 40 minutes, the tubes were removed and allowed to reach the room temperature. Hydrochloric Acid (HCI) 10% was added up to 20-ml mark.

7.3.4. STATISTICAL ANALYSIS

Statistical models used were those described in previous experiments. All the values were included in the analyses because the inclusion of outliers did not affect the results. Data related to feed intake were not treated by elaborate methods due to the small size of the samples, i.e., 6 values corresponding to six pens (treatments) of six animals.

7.4. PARAMETERS MONITORED

The following investigations were undertaken:

- Proximate analysis and mineral determinations as in previous experiments (1 and 3).
- Blood glucose and cortisol determinations on d 0, d 13 and d 47.
- Live weights; Predicted feed conversion ratios; Carcass parameters: Warm and Cold Carcass Masses, Dressing Percentages.
- Mineral levels: pooled feed and liver tissue samples.

TABLE 7.2: DIET COMPOSITION AND NUTRIENTS IN ½ TON OF FEED FOR FEEDLOT CATTLE - EXPERIMENT 3

INGREDIENTS	Inclusion	
	Kg	%
YELLOW MAIZE MEAL	200	40
Eragrostis hay	60	12
Defatted Germ (DFG)	125	25
Wheaten Bran	40	8
Molasses	30	6
Malt Dust	25	5
Limestone	5	1
Salt	5	1
Urea	5	1
Mono-Calcium-Phosphate	2.5	0.5
Premix[1]	2.5	0.5
Nutrients		
Dry Matter (DM)	90.06 %	
Ash	6.47 %	
Fibre	10.24 %	
Protein	13.54 %	
Calcium	0.58 %	
Phosphorus	0.44 %	
Magnesium	0.19 %	
Copper	12.6 mg/kg	
Iron	507.8 mg/kg	
Manganese	88.7 mg/kg	
Zinc	48.7 mg/kg	
Cobalt	3.3 mg/kg	
Selenium	1.32 mg/kg	
Chromium	2.7 mg/kg	

[1]Six different mineral-vitamin premixes for the six treatments as indicated in experimental design

7.5. RESULTS AND DISCUSSION

7.5.1. BLOOD CORTISOL AND GLUCOSE

Mean blood cortisol values were 88.85, 98.50 and 112.46 nmo/l respectively on d l, d 13 and d 47. It indicates an increase from d l3 to d 43. Though not statistically different, blood cortisol values for treatments ISIC and OSIC were the lowest. In general, the values recorded in this trial were similar to those observed in the previous ones (1996, 1997). They were all higher than the means quoted in the literature. Diurnal variation and various stressful situations such as handling might have altered the cortisol levels (Grandin, 1997).

The analysis of contrast of blood cortisol variables per day indicated no difference between days. But a tendency to differ (P=0.10) was noted for the contrast d 47 versus d 13. As illustrated in Figure 7.1, treatments ISIC and OSIC had lower values on d 47 than other treatments for which, the curves tended to increase with the control treatment being intermediary.

It has been difficult to attribute the high values of blood cortisol to breed effect as speculated in previous experiments because the animals used in the present trial were those recommendable for feedlot production. However, this experiment was conducted during the South African summer which might have been responsible for heat stress to which the animals would have been more susceptible compared to those used in Experiment-1 and 2. It also appeared that in this experiment, the cortisol levels continued to rise or were even higher towards the end of the adaptation period. This might also indicate that dietary stress was prominent in this experiment. It was therefore suggested that treatments ISIC and OSIC tended to be more efficient than others in lowering the dietary stress.

Mean glucose values were 4.76, 4.59 and 4.80 mmo1/L respectively on d 1, d 13 and d 47. These values are within the normal range of blood glucose in cattle. As presented in Figure 7.2, blood glucose levels decreased though not significantly on d 13 and increased again on d 47. Treatments NECO, MOCO, ISIC had low values compared to other

treatments. Repeated measures of analysis of variance showed no differences between days for glucose. Nevertheless, analysis of glucose levels for all the trials have not been a sound indicator for stress assessment compared to cortisol levels.

These results also reveal that organic forms of Cr combined to Se have no obvious advantage over the inorganic Cr combinations. The same with Se, no distinctive effect was noted which could be ascribed to the form of the trace element. Sodium selenite has been reported to be less biologically effective than Se-enriched yeast (Mahan and Parret, 1996). Ortman and Pehrson (1997b) reported that there is no difference in glutathione peroxidase even though there was a trend for the concentrations to be higher in the tissues of those supplemented with the yeast product. This combined with the pronounced effect of Cr sulphate due to its high solubility (Merck & Co, 1996) might explain why the organic forms are not necessarily more efficient than the inorganic ones.

7.5.2. CORRELATION BETWEEN CORTISOL AND GLUCOSE WITH ADG AND P- FCR

Blood cortisol and glucose levels were correlated on d 0 ($r_{xy=}$ 0.64; P=0.0046) and d 47 (r_{xy} =0.49; P=0.0046). This is in consonance with the hypothesis that Se and Cr can alleviate stress by lowering blood cortisol and allowing better utilisation of energy storage. Some studies showed this correlation (Anderson *et al*. 1997; Depew *et al*. 1998).

The ADG was negatively correlated to P-FCR (r_{xy} =0.99; P<0.0001) on d 13 and d 47. As shown previously, the growth potential of cattle is negatively affected by low feed intake and bad feed efficiency during the adaptation period (Wagner *et al*., No date). However, these results indicate that supplementation of Se and Cr for the whole growth period in feedlot cattle might bring some good results.

There was a positive correlation between blood cortisol and glucose on d 47 (r_{xy} = 0.49; P=0.005). This agrees with the hypothesis and it is an indication that a treatment that is efficient on lowering cortisol level might be beneficial on glucose utilisation. Positive

results on the carry-over effect of stress alleviation by Cr supplementation on cattle performance have been reported in the second trial and by Moonsie-Shageer and Mowat (1993). In contrast, Bunting *et al*. (1994) did not demonstrate that though the cortisol level was lowered by Cr supplementation.

7.5.3 PERFORMANCE

The animals attained on average 377.143 ± 7.3 kg live weight. The mean ADG was 1.510 $kg.d^{-1}$. It is closer to the national mean value reported by Henning *et al*. (1999). Selenium and Cr supplementation did not significantly affect the overall growth efficiency of the steers. However, during the adaptation period, ADG and P-FCR were significantly different ($P \leq 0.05$) on d 13 and d 27. Least square means of ADG and P- FCR are presented in Table 7.3. Treatments NECO, MOCO and OSIC had better ADG and P-FCR during this period.

It was suggested in previous experiments that the response to trace element supplementation is influenced by the presence of other factors such as energy or protein deficiencies, parasite infestations or management as pointed out by Van Ryssen *et al.* (1992). However, the feed nutrients reported in Table 7.2 are all within the normal range therefore eliminating the possibility of deficiencies in this experiment.

Supplementing Cr did not improve the animal performance (Arthington *et al*. 1997; Kegley and Spears, 1995). Johansson *et al*. (1990) did not find a significant difference in weight gain in lambs supplemented with either sodium selenite or high-Se yeast. Other researchers (Arthur and Boyne, 1983; Droke and Loerch, 1989) did not demonstrate the improvement of growth with Se supplementation. Once again, it is agreed with van Ryssen *et al.* (1992) that growth rate is not an accurate measure of the effect of Se supplementation.

The analysis of contrast of live weight between days showed a linear increase in weight until d 76. The growth curve is presented in Figure 7.3. It is clear that 102 days on feed were adequate for a study of growth since there was no noticeable difference in ADG between days after d76. Live weights of different combinations of Se and Cr were not statistically different (not reported). Consistently, it appears that the combined form of organic Se and organic Cr is not more efficient than the combination of inorganic Se and Cr forms on animal performance.

Figure 7.1 Blood cortisol levels (nmol/L) for feedlot cattle fed different combinations of Se and Cr

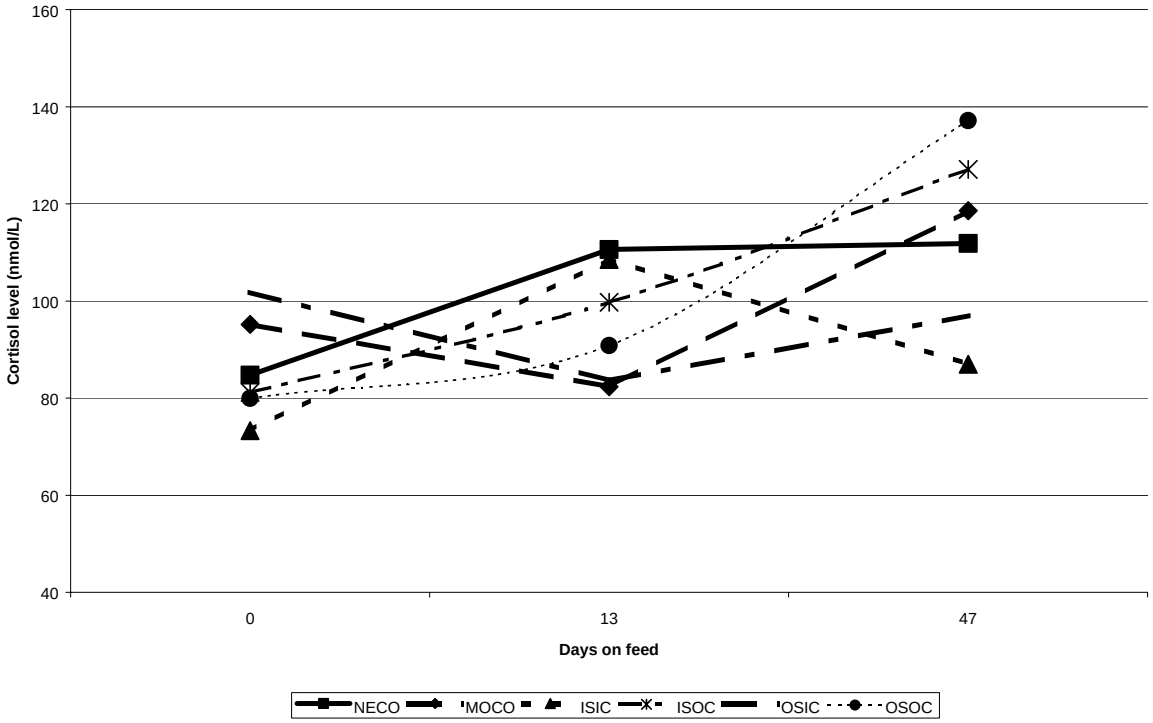


FIGURE 7.2: GLUCOSE LEVELS OF FEEDLOT CATTLE FED DIFFERENT COMBINATIONS OF Se AND Cr

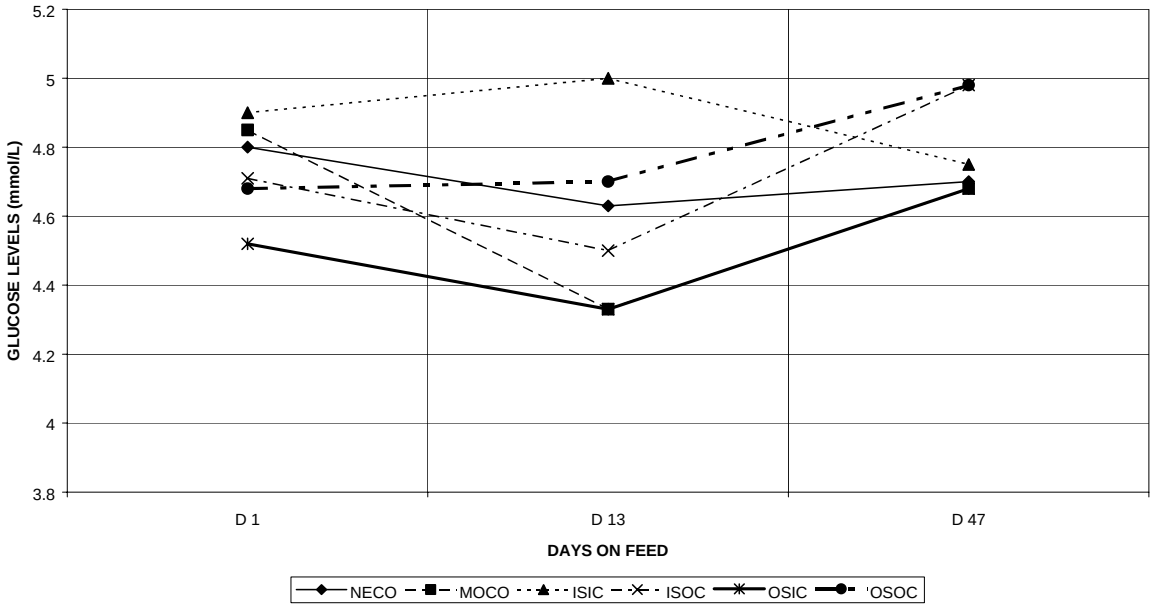
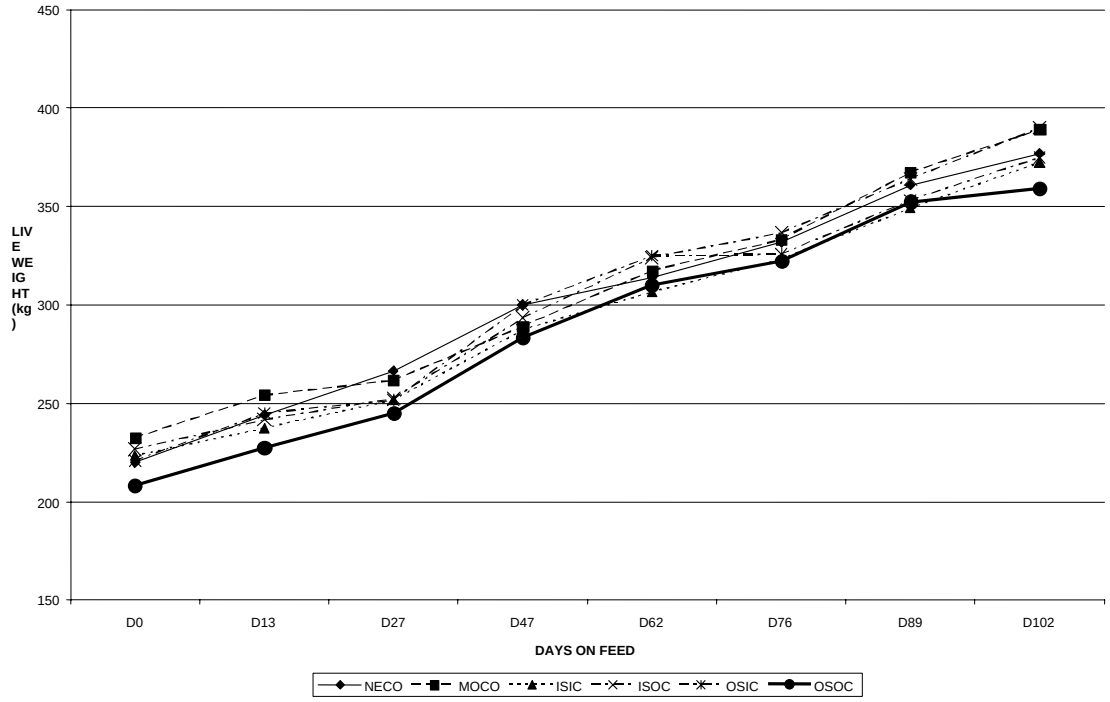


TABLE 7.3: AVERAGE DAILY GAIN AND PREDICTED FEED CONVERSION RATIOS OF FEEDLOT CATTLE FED DIFFERENT COMBINATIONS OF SE AND CR

Day	**Item**	**Treatment**							**P value**
		NECO	**MOCO**	**ISIC**	**OSIC**	**ISOC**	**OSOC**	SEM	
13	ADG	1.860^{ac}	1.667^{abc}	1.090^{bd}	1.859^{c}	1.154^{bd}	1.474^{abc}	0.0956	0.049
	P-FCR	5.030^{a}	5.653^{ac}	7.817^{bd}	4.861^{a}	7.441^{bc}	6.192^{acd}	0.348	0.048
27	ADG	1.728^{a}	1.080^{b}	1.049^{b}	1.142^{b}	0.957^{b}	1.358^{b}	0.074	0.019
	P-FCR	5.272^{a}	7.761^{b}	7.928^{b}	7.437^{b}	8.331^{b}	6.503$^{a\,b}$	0.308	0.033
47	ADG	1.617	1.206	1.365	1.684	1.418	1.596	0.060	0.159
	P-FCR	5.607	7.274	6.525	5.420	6.281	5.639	0.228	0.143

NB. Values with different superscripts differ significantly (P≤0.05) within a row

FIGURE 7.3: GROWTH EFFICIENCY OF FEEDLOT CATTLE FED DIFFERENT COMBINATIONS OF SELENIUM AND CHROMIUM



7.5.3. CARCASS CHARACTERISTICS

The carcass characteristics are illustrated in Table 7.4. The warm and cold carcass masses (CCM) of the steers across the six treatments were, respectively: 205.954 kg and 201.970 kg. The mean dressing percentage was 54.6%. These values were similar to the national average of 213 kg for CCM (Grobler, 1998) and 55% for DP (Ford, 1998). This is another sign that these steers were more appropriate for feedlot under South African conditions than those used in the previous experiments.

No statistical differences were observed between treatments for these parameters. Chang *et al.* (1992) and Mathison and Engstrom (1995) reported similar results with high-Cr yeast and chelated Cr. However, treatment ISIC had higher WCM and CCM than treatment ISOC; similarly, treatment OSIC performed better than treatment OSOC. It might be deduced that the combinations involving the inorganic Cr were more efficient than those of the organic form.

As shown in Table 7.5, the majority of the carcasses were classified in Carcass Conformation (CC) 3 (80%) and Carcass Fat (CF) code 2 (86%). This is an indication that the animals were not completely mature nor were they completely ready for the market. As pointed out in the previous experiments, monitoring of the live weight and visual assessment of fatness were conducted in order to compare the animals at the same degree of maturity. However, it seems that treatment ISIC, OSIC and OSOC were closer to maturity than other groups because more than a quarter of the carcasses in these groups was in CF 3. This, particularly for treatments ISIC and OSIC, is of utmost economic importance because these treatments also determined higher carcass masses. South African consumers are willing to pay more for the beef with lean to moderate fat average i.e. the CF 2 and CF 3 (Ford, 1998).

TABLE 7.4: CARCASS CHARACTERISTICS OF FEEDLOT CATTLE FED DIFFERENT COMBINATIONS OF Se and Cr – EXPERIMENT 4

Treatment	Live weight (kg + SEM)	WCM (kg ± SEM)	CCM (kg ± SEM)	WCM - CCM (kg ± SEM)	DP (%± SEM)
NECO	377.0 ± 48.94	205.9± 12.286	201.6± 12.445	4.2± 0.312	54.60± 0.94
MOCO	389.2 ± 35.13	208.0± 11.216	204.0± 11.060	4.2± 0.180	53.41± 0.86
ISIC	372.5 ± 34.02	208.5± 11.216	204.8± 11.060	3.6± 0.080	55.95± 0.86
ISOC	375.0 ± 43.01	201.7± 11.216	197.6± 11.060	4.1± 0.257	53.62± 0.86
OSIC	390.0 ± 59.33	213.7± 11.216	209.7± 11.060	4.0± 0.233	54.95± 0.86
OSOC	359.2 ± 35.13	197.8± 11.216	194.0± 11.060	3.8± 0.233	54.95± 0.86

Where: WCM is warm carcass mass; CCM is cold carcass mass; DP is dressing percentage.

TABLE 7.5: FREQUENCY AND PERCENT OF TREATMENTS BY CARCASS FAT CONFORMATION (CF) AND FAT CODES (FC) FOR FEEDLOT CATTLE FED DIFFERENT COMBINATIONS OF Se AND Cr – EXPERIMENT 4

		Conformation				**Fat Code**			
Treatment	**Observation**	**3**	**%**	**4**	**%**	**2**	**%**	**3**	**%**
NECO	5	4	80.00	1	20.00	5	100.00	0	
MOCO	6	4	66.67	2	33.33	6	100.00	0	
ISIC	6	5	83.33	1	16.67	4	66.67	2	33.33
ISOC	6	5	83.33	1	16.67	6	100.00	0	
OSIC	6	5	83.33	1	16.67	5	83.33	1	16.67
OSOC	6	5	83.33	1	16.67	4	66.67	2	33.33
TOTAL	35	28	80.00	7	20.00	30	85.71	5	14.29

7.5.4. MINERALS

7.5.4.1. MINERAL STATUS

As done in previous experiments (Experiment 1 and 3), the outliers were included in the analysis because there was no difference in the results when they were removed. The mineral values are presented in Table 7.6. Paired-T test was used to compare different treatments. Only Se and Cr values were statistically different ($P \leq 0.05$) between treatments. Liver Se concentrations were 2 to 4-fold higher than the normal values (Table 2.2) whilst Cr concentrations were normal. With regard to Se, it is probable that the animals responded favourably because they were initially Se deficient. Previous grazing history can have significant effects on liver mineral stores (Galyean *et al*. 1996). It has been reported that grazing herbivores in the sourveld regions of Kwazulu-Natal (South Africa) probably suffer from mild to serious Se deficiency (Van Ryssen, 2001).

Treatment ISIC had the highest liver Se levels ($P \leq 0.01$) in this experiment and in the previous experiment (3). If it is accepted that tissue uptake of Se is an estimate of Se bioavailability (Echevarria *et al*. 1989), then the combination of sodium selenite and Cr sulphate (treatment ISIC) makes Se more available to the animal based on significantly ($P < 0.0001$) higher concentrations in this treatment groups compared to all other groups (Table 7.6).

Treatment ISOC, OSIC and OSOC had higher liver tissue Cr concentration ($P \leq 0.01$) compared to NECO and MOCO. These concentrations were higher than the range recorded in the experimental laboratory (Onderstepoort, SA) and lower than the referral values (Puls, 1994). It seems that the dietary supplement of Cr has increased the liver tissue retention of this trace element. This has been shown by Anderson *et al* (1997) in pigs and Experiment-1 and might have a direct implication on the human diet which is known to be marginal in Cr content (NRC, 1997).

7.5.4.2. MINERAL INTERACTIONS

Selenium did not have any relationship with other minerals in this study. In contrast, Cr showed some interactions with Cu, Fe, Mn and Mg. Stepwise regressions were used to study these interactions. Copper value did not meet the 0.1500 significance level for entry into the model probably because it was highly correlated with other elements in the model, i.e. with Fe and Mn (Table 7.7). Also among other elements, Fe and Mn reduce the utilisation of Cu (Puls, 1994).

The interactions between Cr on one hand and Fe, Mn and Mg on the other are presented in the following regression formula:

$$\mathbf{Cr = 1.49^{a} - 0.009^{b}\,(Fe) - 0.23^{c}\,(Mn) + 0.038^{d}\,(Mg)}\quad R^2 = 0.70$$

Where: ^{a} = intercept; ^{b} = Fe coefficient; ^{c} = Mn coefficient and ^{d} = Mg coefficient.

If the mean value of each element is replaced in the formula, it is estimated that for each Cr unit increase, Fe and Mn will decrease by 0.4 unit while Mg concentration will increase by 6 units. With the exception of this noticeable effect on Mg, Cr has not been shown to affect positively the concentration of other minerals in the previous experiments. In the contrary, Cr was negatively correlated to Fe, Cu and Mn and positively to Mg. The tendency for Cr to be negatively correlated with other minerals has been demonstrated in Experiment-1 where it was negatively correlated with Co, Ca and Mg. This raises the need for special precaution to be taken when feeding Cr in excess. Furthermore, it is thought that because Cr does not improve the retention of other minerals such as Cu, Fe or Zn (Anderson *et al.*, 1997) or Zn, Fe, Mg, Ca and P (Chang *et al.*, 1992), only adequate Cr concentrations might be fed to the animals.

TABLE 7.6: LIVER MINERAL CONCENTRATIONS (ppm) OF FEEDLOT CATTLE FED DIFFERENT COMBINATIONS OF Se AND Cr - EXPERIMENT 4 ON WET BASIS

MINERAL	TREATMENT						MEAN	P-VALUE
	NECO	MOCO	ISIC	ISOC	OSIC	OSOC		
Fe	144.3± 34.9	166.1± 31.8	150.1± 31.8	60.5 ± 34.8	122.3± 31.8	103.6± 31.8	**125.77**	**NS**
Cu	102.3 ± 9.7	95.3 ± 8.8	107.5 ± 8.8	96.6 ± 9.7	72.6 ± 8.8	98.1 ± 8.8	**95.17**	**NS**
Mn	4.4 ± 0.7	5.3 ± 0.6	5.6 ± 0.6	3.7 ± 0.7	4.4 ± 0.6	4.3 ± 0.6	**4.67**	**NS**
Zn	37.3 ± 5.0	41.1 ± 4.5	42.6 ± 4.5	33.2 ± 5.0	31.9 ± 4.5	44.0 ± 4.5	**38.51**	**NS**
Co	2.9 ± 0.4	3.2 ± 0.3	2.9 ± 0.3	2.7 ± 0.4	2.8 ± 0.3	2.5 ± 0.3	**2.84**	**NS**
Cr	2.1^{a} ± 0.5	2.9^{a} ± 0.4	3.3^{a} ± 0.4	4.9^{bcd} ± 0.5	4.3^{cd} ± 0.4	4.7^{d} ± 0.4	**3.71**	**0.0009**
Ca	46.9 ± 4.1	54.7 ± 3.8	54.4 ± 3.8	49.2 ± 4.1	55.1 ± 3.8	52.8 ± 3.8	**52.4**	**NS**
Mg	108.3 ± 4.6	120.0 ± 4.2	117.9 ± 4.2	116.2 ± 4.6	122.2 ± 4.2	125.0 ± 4.2	**118.6**	**NS**
Se	0.8^{ac} ± 0.2	1.1^{ac} ± 0.1	1.7^{b} ± 0.1	1.0^{c} ± 0.2	0.4^{d} ± 0.1	0.3^{d} ± 0.1	**0.9**	**<0.0001**
P	3500.0±417.4	4133.3±381.1	4116.7±381.1	3120.0±417.4	3766.7±381.1	3866.7±381.1	**3776.5**	**NS**

NB. Values with different superscripts differ significantly (P≤0.05) within a row

Abbreviation NS = Not Statistically different

TABLE 7.7: CORRELATION COEFFICIENT BETWEEN MINERALS IN LIVER OF FEEDLOT CATTLE FED DIFFERENT COMBINATIONS OF Se AND Cr – EXPERIMENT 4 ON WET BASIS

Item $(R^2/P)^X$	**Fe**	**Cu**	**Mn**	**Zn**	**Co**	**Cr**	**Ca**	**Mg**	**Se**	**P**
Fe		0.42 0.01	0.77 <.0001			-0.77 <.0001	0.51 0.002			
Cu	0.42 0.01		0.39 0.02		0.31 0.08	-0.36 0.04				
Mn	0.77 <.0001				0.30 0.08	-0.69 <.0001	0.37 0.03		0.30 0.09	
Zn										0.33 0.05
Co			0.30 0.08	0.30 0.08						
Cr	-0.77 <0.0001	-0.36 0.04	-0.69 <0.0001					0.40 0.02	-0.29 0.10	
Ca	0.51 0.002		0.37 0.03					0.45 0.007		
Mg						0.40 0.02	0.45 0.007			
Se			0.30 0.09			-0.29 0.10				
P				0.33 0.05						

[X] R^2 = correlation coefficient ; P = probability value

CHAPTER 8: GENERAL DISCUSSION

Feeding feedlot cattle is increasingly becoming an expensive exercise because of the volatility of the feedstuffs prices. The feedlot industry must survive and still be able to provide not only abundant food but also safe and wholesome products. Many techniques and tools have been used to manipulate the growth rate. The increased pressure upon available resources and the resistance of the consumers to the use of odd means, such as the feedstuffs of animal origin in production have acerbated the crisis in the industry. There is a trend for the reuse of natural means among which minerals occupy a very important place.

The trace elements Se and Cr have been introduced into the animal feeding and the results of different research are not conclusive (NRC, 1980; NRC, 1997). However, these elements have been used in the management of the major problem in feedlot, i.e. the recurrent stress on the animals and its implications on the whole production process. Feedlot cattle are subjected to various stressors (Cole *et al.,* 1988). Alleviation of stress has been considered as the most important management task in the feedlot (Preston & Willis 1974).

The animals were supplemented with dietary Se and Cr in order to elucidate:

- The mode of action of Se and Cr on stress
- The subsequent performance, carcass characteristics and meat quality including meat colour and
- The animal mineral status and interactions.

The plasma concentration of cortisol has been used to reflect the effect of different stressors (Jenssen-Warren and Nyberg, 1993) and blood glucose levels were used to test the carry-over effect of Se and Cr on the general metabolism and utilisation of energy. The results of this study were less inconsistent than in the literature and it emerged that Se was more efficient on decreasing cortisol levels during the initial days on feed while Cr and Se-Cr combination were more efficient in the later stage. It was speculated that Se

acted directly on blood cortisol by affecting the free radical - antioxidant capacity balance of the stressed animals while Cr might have acted indirectly on glucose metabolism.

The carry-over effects on the animal performance and carcass characteristics were reported by, among other researchers: Arthur & Boyne 1983; Droke & Loerch 1989; Mowat & Chang 1992; Mowat *et al.,* 1993; Moonsie-Shageer & Mowat 1993; Mowat *et al.,* 1994 . The results were conflicting in the literature as well as in different trials of this study. It has always been difficult to ascribe the improvement of growth rate to a particular factor because it is a multifactorial phenomenon that involves the genetic make up of the animal and the external factors (Preston & Willis 1974; Slabbert 1989). It was also agreed with van Ryssen *et al.,* (1992) that growth rate is not an accurate measure of Se supplementation. However, supplemental Cr and its combinations with Se more positively affected the dressing percentage (DP) and meat pH.

The appearance of meat is an important attribute (Laurie, 1985). It influences the customer decision to purchase or reject the product (Liu *et al.,* 1996a; Sheehy *et al.,* 1997). The process of lipid peroxidation leads to the denaturation of meat colour components (Liu *et al.,* 1996b) and limits the acceptability of meat (Sheehy *et al.,* 1997). It was thought that Se might affect the meat colour through its antioxidant capacity and Cr would act through the change in meat pH. The results from this research showed that Cr might be more effective than Se on meat colour.

Chen and Huang (1989) and Smith *et al.,* (1996) demonstrated that meat pH values had significant correlations with meat colour score in pork. Oster and Fewson (1990) established that colour meter values provided little information compared to that given by meat pH. The theory drawn form this experiment was that a dietary supplement of Cr improves the glucose incorporation in muscle as glycogen. This maintains an adequate drop in meat pH that lowers the lipid peroxidation and prevents the accumulation of metmyoglobin responsible for meat discolouration.

The improvement of mineral status of the animal has been also studied. However, from the results of the present study and many reports in the literature review, many aspects are still not clear. The mineral concentrations in feed were generally normal. Selenium was exceptionally high in feed but this was not translated to high liver tissue Se. Although it is accepted that tissue uptake of Se is an estimate of Se bioavailability (Echevarria *et al.*, 1989), there is a limit to body absorption of Se. It seems that not all Se consumed is utilised (Van Ryssen, 1996) and an inverse relationship exists between Se uptake and levels of dietary Se (Jelinek, 1985). Selenium was shown to interact with other minerals but it was consistently correlated positively with Ca.

Supplementing Cr increased liver retention of this element in the present study and that of Anderson *et al.*, (1997). Others (Anderson and Kozlowski, 1985 cited by Chang *et al.*, 1992) in contrast reported that Cr absorption is inversely related to dietary intake and that excessive Cr is not absorbed efficiently. However, Cr supplement might have a negative impact on the retention of other minerals. Chromium was negatively correlated with other minerals i.e. Co in Experiment-1 and Fe and Mn in Experiment-2. Precautions must be taken not to feed higher doses of Cr.

Another important aspect dealt with was the efficiency of different chemical forms of Se and Cr. There are numerous reports of the superiority of organic forms over the inorganic ones (Gadd, 1995; Hemken, 1997; Close, 1998). Others also reported inconsistent results (Arthington *et al.*, 1997). But this study has shown that both the organic Se and Cr and their combinations were not more efficient that the inorganic forms.

Supplemental chromium sulphate particularly determined better ADG, P-FCR and DP than the high-Cr yeast (Experiment-3). Its combination with the two different forms of Se gave better results on performance and DP (Experiment-4). It seems that the rate of absorption (solubility) of an element determines its availability to the animal. This explained why Cr sulphate which is as soluble as the organic form (Merck & Co 1996), has been more efficient than the lesser insoluble Cr chloride on which studies advocating the superiority of organic forms were based.

This study has revealed that:

- Selenium is likely to be effective on the physical stress relief while Cr appears to be more effective on the alleviation of dietary stress.
- The interaction effects of Se and Cr are more prominent on alleviation of stress as measured by blood cortisol and glucose concentrations compared to separate supplement of Se and Cr.
- Blood cortisol levels are better indicators of stress levels than blood glucose levels.
- Chromium sulphate supplemented at a concentration of 0.3 mg per kg of DM is a potent source of Cr for feedlot cattle.
- Organic forms of Se or Cr are not necessarily more efficient than the inorganic forms on different aspects of feedlot cattle production including performance, carcass characteristics and mineral liver tissue retention.
- High intake of Cr causes a decrease in the retention of other minerals such as Co, Fe and Mn.
- There is a limit to body absorption of Se and this might make Se poisoning a rare occurrence.
- Dietary supplement of Se increases the concentration of liver tissue Ca.
- Solubility of an element affects its bioavailability and efficiency more than its chemical form.
- Dietary supplements of Cr might affect the colour of meat through its intervention on meat pH.

It appears that part of the concerns of this study has been clarified. Although Se and Cr supplementation could decrease stress levels, the carry-over effect on animal growth performance and carcass characteristics could not be shown clearly. There was an indication that when these elements are combined it may affect these criteria. A tendency to affect the meat colour and consequently the shelf life of meat was also shown.

Mineral status including liver retention of Se and Cr were in contrast positively affected making the wish to provide food rich in these nutrients fulfilled. It was also demonstrated

that organic forms are not necessarily superior to the inorganic forms. In order to survive under the difficult economical conditions stated earlier, it will be advisable to not only attend to the market wishes but also to consider the prices of the feedstuffs together with the premixes. This study has shown that using the cheaper inorganic forms can attain that. However, more studies are needed in order to understand some of the properties of Se and Cr.

Future studies that may enhance this understanding would be:

- The investigations into the free radicals and anti-oxidant capacity of the animals in order to understand their effects on stress
- The lung histopathology because it is related to stress and it reveals all the lesions including the non clinical cases of the Respiratory Disease
- The effects of dietary supplements of Se and Cr on lipid peroxidation of packed meat for more details on its intervention on meat colour and extension of meat shelf life.

In the light of the present findings, it is possible to overcome the problem related to the use of odd products by using appropriate means such as trace elements Se and Cr. It was shown that Se and Cr could decrease stress in animals and lead to the improvement of the animal performance and carcass characteristics including meat colour. Dietary supplement of Se and Cr also affect positively the retention of these elements in the liver, but precautions must be taken when feeding excessive Cr because it might affect negatively the retention of other minerals. It is also wise to consider the price of the premix because there is no difference in the effects of different chemical forms be it organic or inorganic. This study has shown that feeding inorganic forms of Se and Cr and their combinations give good results in feedlot cattle production.

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APPENDICES

APPENDIX A.1: BLOOD CORTISOL (nmol) AND GLUCOSE (mmol) OF FEEDLOT CATTLE FED A SUPPLEMENT OF SELENIUM AND CHROMIUM – EXPERIMENT 1

DAY	TTT	PEN	VACC	TAG	WEIGHT	ADG	FCR	GLUCO	CORTI
0	**1**	**1**	**1**	**A1Y**	220.000	0.000	0.000	5.7	60
0	**1**	**1**	**1**	**A2Y**	195.000	0.000	0.000	4.9	92
0	**1**	**1**	**1**	**A3Y**	205.000	0.000	0.000	4.3	67
0	**1**	**1**	**1**	**A4Y**	170.000	0.000	0.000	3.9	61
0	**1**	**1**	**1**	**A5Y**	190.000	0.000	0.000	4.6	64
0	**1**	**1**	**1**	**A6Y**	145.000	0.000	0.000	5.4	90
0	**1**	**2**	**2**	**B1Y**	220.000	0.000	0.000	4.1	53
0	**1**	**2**	**2**	**B2Y**	200.000	0.000	0.000	4.2	51
0	**1**	**2**	**2**	**B3Y**	190.000	0.000	0.000	4.9	42
0	**1**	**2**	**2**	**B4Y**	175.000	0.000	0.000	5.3	80
0	**1**	**2**	**2**	**B5Y**	170.000	0.000	0.000	3.8	56
0	**1**	**2**	**2**	**B6Y**	165.000	0.000	0.000	5.5	54
0	**1**	**3**	**3**	**C1Y**	200.000	0.000	0.000	5.4	67
0	**1**	**3**	**3**	**C2Y**	180.000	0.000	0.000	5.1	58
0	**1**	**3**	**3**	**C3Y**	190.000	0.000	0.000	5.3	107
0	**1**	**3**	**3**	**C4Y**	185.000	0.000	0.000	5.9	96
0	**1**	**3**	**3**	**C5Y**	170.000	0.000	0.000	5.5	58
0	**1**	**3**	**3**	**C6Y**	165.000	0.000	0.000	4.1	75
0	**2**	**4**	**1**	**A1G**	210.000	0.000	0.000	4.8	108
0	**2**	**4**	**1**	**A2G**	200.000	0.000	0.000	4.7	106
0	**2**	**4**	**1**	**A4G**	170.000	0.000	0.000	4.7	75
0	**2**	**4**	**1**	**A5G**	175.000	0.000	0.000	4.7	102
0	**2**	**4**	**1**	**A6G**	160.000	0.000	0.000	5.2	73
0	**2**	**5**	**2**	**B1G**	220.000	0.000	0.000	4.9	94
0	**2**	**5**	**2**	**B2G**	220.000	0.000	0.000	5.1	28
0	**2**	**5**	**2**	**B3G**	185.000	0.000	0.000	4.9	34
0	**2**	**5**	**2**	**B4G**	190.000	0.000	0.000	4.7	100
0	**2**	**5**	**2**	**B5G**	175.000	0.000	0.000	4.4	79
0	**2**	**5**	**2**	**B6G**	160.000	0.000	0.000	5.0	63
0	**2**	**6**	**3**	**C1G**	215.000	0.000	0.000	4.9	106
0	**2**	**6**	**3**	**C2G**	205.000	0.000	0.000	4.1	28
0	**2**	**6**	**3**	**C3G**	195.000	0.000	0.000	6.3	43
0	**2**	**6**	**3**	**C4G**	160.000	0.000	0.000	4.6	95
0	**2**	**6**	**3**	**C5G**	175.000	0.000	0.000	6.1	117
0	**2**	**6**	**3**	**C6G**	170.000	0.000	0.000	4.5	139
0	**3**	**7**	**1**	**A1R**	190.000	0.000	0.000	4.9	91
0	**3**	**7**	**1**	**A2R**	220.000	0.000	0.000	5.0	49
0	**3**	**7**	**1**	**A3R**	190.000	0.000	0.000	5.0	53
0	**3**	**7**	**1**	**A4R**	175.000	0.000	0.000	4.7	137
0	**3**	**7**	**1**	**A5R**	150.000	0.000	0.000	4.6	77
0	**3**	**7**	**1**	**A6R**	175.000	0.000	0.000	6.0	71
0	**3**	**8**	**2**	**B1R**	215.000	0.000	0.000	5.5	105
0	**3**	**8**	**2**	**B2R**	200.000	0.000	0.000	5.1	81
0	**3**	**8**	**2**	**B3R**	200.000	0.000	0.000	5.0	60

APPENDIX A.1: BLOOD CORTISOL (nmol) AND GLUCOSE (mmol) OF FEEDLOT CATTLE FED A SUPPLEMENT OF SELENIUM AND CHROMIUM – EXPERIMENT 1 (CONTINUED)

DAY	TTT	PEN	VACC	TAG	WEIGHT	ADG	FCR	GLUCO	CORTI
0	**3**	**8**	**2**	**B4R**	165.000	0.000	0.000	4.5	80
0	**3**	**8**	**2**	**B5R**	155.000	0.000	0.000	5.3	61
0	**3**	**8**	**2**	**B6R**	155.000	0.000	0.000	5.7	54
0	**3**	**9**	**3**	**C1R**	200.000	0.000	0.000	5.3	64
0	**3**	**9**	**3**	**C2R**	210.000	0.000	0.000	4.9	33
0	**3**	**9**	**3**	**C4R**	195.000	0.000	0.000	5.0	63
0	**3**	**9**	**3**	**C5R**	180.000	0.000	0.000	5.6	92
0	**3**	**9**	**3**	**C6R**	170.000	0.000	0.000	5.0	45
0	**4**	**10**	**1**	**A1B**	200.000	0.000	0.000	4.6	44
0	**4**	**10**	**1**	**A2B**	205.000	0.000	0.000	4.3	39
0	**4**	**10**	**1**	**A3B**	185.000	0.000	0.000	5.0	82
0	**4**	**10**	**1**	**A4B**	190.000	0.000	0.000	4.0	100
0	**4**	**10**	**1**	**A5B**	165.000	0.000	0.000	5.2	74
0	**4**	**10**	**1**	**A6B**	165.000	0.000	0.000	6.3	67
0	**4**	**11**	**2**	**B1B**	210.000	0.000	0.000	5.0	90
0	**4**	**11**	**2**	**B2B**	185.000	0.000	0.000	4.9	76
0	**4**	**11**	**2**	**B3B**	190.000	0.000	0.000	4.9	73
0	**4**	**11**	**2**	**B4B**	185.000	0.000	0.000	3.7	58
0	**4**	**11**	**2**	**B5B**	190.000	0.000	0.000	4.8	87
0	**4**	**11**	**2**	**B6B**	145.000	0.000	0.000	3.9	28
0	**4**	**12**	**3**	**C1B**	215.000	0.000	0.000	4.7	59
0	**4**	**12**	**3**	**C2B**	210.000	0.000	0.000	7.2	75
0	**4**	**12**	**3**	**C3B**	180.000	0.000	0.000	5.8	86
0	**4**	**12**	**3**	**C4B**	145.000	0.000	0.000	5.9	95
0	**4**	**12**	**3**	**C5B**	155.000	0.000	0.000	4.9	61
0	**4**	**12**	**3**	**C6B**	165.000	0.000	0.000	5.6	101
14	**1**	**1**	**1**	**A1Y**	245.000	1.786	4.985	5	39
14	**1**	**1**	**1**	**A2Y**	220.000	1.786	4.985	4.6	28
14	**1**	**1**	**1**	**A3Y**	215.000	0.714	9.338	4.5	70
14	**1**	**1**	**1**	**A4Y**	190.000	1.429	6.218	4.8	60
14	**1**	**1**	**1**	**A5Y**	205.000	1.071	7.669	4.9	89
14	**1**	**1**	**1**	**A6Y**	175.000	2.143	3.970	4.3	85
14	**1**	**2**	**2**	**B1Y**	240.000	1.429	6.218	4.4	63
14	**1**	**2**	**2**	**B2Y**	230.000	2.143	3.970	4.8	72
14	**1**	**2**	**2**	**B3Y**	205.000	1.071	7.669	5.1	54
14	**1**	**2**	**2**	**B4Y**	205.000	2.143	3.970	5.1	39
14	**1**	**2**	**2**	**B5Y**	190.000	1.429	6.218	4.6	51
14	**1**	**2**	**2**	**B6Y**	185.000	1.429	6.218	5.2	89
14	**1**	**3**	**3**	**C1Y**	240.000	2.857	2.595	4.8	36
14	**1**	**3**	**3**	**C2Y**	215.000	2.500	3.174	5.8	39
14	**1**	**3**	**3**	**C3Y**	210.000	1.429	6.218	4.8	38
14	**1**	**3**	**3**	**C4Y**	195.000	0.714	9.338	4.7	28
14	**1**	**3**	**3**	**C5Y**	195.000	1.786	4.985	4.6	56
14	**1**	**3**	**3**	**C6Y**	190.000	1.786	4.985	4.7	37
14	**2**	**4**	**1**	**A1G**	230.000	1.429	6.218	5.6	50

APPENDIX A.1: BLOOD CORTISOL (nmol) AND GLUCOSE (mmol) OF FEEDLOT CATTLE FED A SUPPLEMENT OF SELENIUM AND CHROMIUM – EXPERIMENT 1 (CONTINUED)

DAY	TTT	PEN	VACC	TAG	WEIGHT	ADG	FCR	GLUCO	CORTI
14	**2**	**4**	**1**	**A2G**	220.000	1.429	6.218	8.4	100
14	**2**	**4**	**1**	**A4G**	195.000	1.786	4.985	5.5	81
14	**2**	**4**	**1**	**A5G**	190.000	1.071	7.669	6.3	109
14	**2**	**4**	**1**	**A6G**	190.000	2.143	3.970	6.3	50
14	**2**	**5**	**2**	**B1G**	240.000	1.429	6.218	4.7	28
14	**2**	**5**	**2**	**B2G**	245.000	1.786	4.985	4.8	74
14	**2**	**5**	**2**	**B3G**	220.000	2.500	3.174	5.5	37
14	**2**	**5**	**2**	**B4G**	210.000	1.429	6.218	5.1	87
14	**2**	**5**	**2**	**B5G**	200.000	1.786	4.985	5.7	36
14	**2**	**5**	**2**	**B6G**	190.000	2.143	3.970	4.4	82
14	**2**	**6**	**3**	**C1G**	255.000	2.857	2.595	5	73
14	**2**	**6**	**3**	**C2G**	230.000	1.786	4.985	4.2	28
14	**2**	**6**	**3**	**C3G**	210.000	1.071	7.669	5.6	55
14	**2**	**6**	**3**	**C4G**	190.000	2.143	3.970	4.4	135
14	**2**	**6**	**3**	**C5G**	200.000	1.786	4.985	5.4	99
14	**2**	**6**	**3**	**C6G**	185.000	1.071	7.669	4.6	65
14	**3**	**7**	**1**	**A1R**	220.000	2.143	3.970	5.4	49
14	**3**	**7**	**1**	**A2R**	240.000	1.429	6.218	4.9	82
14	**3**	**7**	**1**	**A3R**	215.000	1.786	4.985	5.1	84
14	**3**	**7**	**1**	**A4R**	200.000	1.786	4.985	4.5	28
14	**3**	**7**	**1**	**A5R**	190.000	2.857	2.595	4.6	33
14	**3**	**7**	**1**	**A6R**	190.000	1.071	7.669	4.5	28
14	**3**	**8**	**2**	**B1R**	240.000	1.786	4.985	4.9	42
14	**3**	**8**	**2**	**B2R**	230.000	2.143	3.970	5.2	28
14	**3**	**8**	**2**	**B3R**	210.000	0.714	9.338	4.8	98
14	**3**	**8**	**2**	**B4R**	200.000	2.500	3.174	5.3	63
14	**3**	**8**	**2**	**B5R**	180.000	1.786	4.985	5.1	28
14	**3**	**8**	**2**	**B6R**	175.000	1.429	6.218	4.8	70
14	**3**	**9**	**3**	**C1R**	235.000	2.500	3.174	5.2	98
14	**3**	**9**	**3**	**C2R**	240.000	2.143	3.970	5	95
14	**3**	**9**	**3**	**C4R**	210.000	1.071	7.669	5.1	97
14	**3**	**9**	**3**	**C5R**	200.000	1.429	6.218	4.5	67
14	**3**	**9**	**3**	**C6R**	180.000	0.714	9.338	5	28
14	**4**	**10**	**1**	**A1B**	240.000	2.857	2.595	4.6	28
14	**4**	**10**	**1**	**A2B**	245.000	2.857	2.595	4.2	76
14	**4**	**10**	**1**	**A3B**	215.000	2.143	3.970	5	95
14	**4**	**10**	**1**	**A4B**	205.000	1.071	7.669	4.7	70
14	**4**	**10**	**1**	**A5B**	180.000	1.071	7.669	4.7	104
14	**4**	**10**	**1**	**A6B**	180.000	1.071	7.669	5.1	35
14	**4**	**11**	**2**	**B1B**	245.000	2.500	3.174	5	68
14	**4**	**11**	**2**	**B2B**	235.000	3.571	2.093	4.7	58

APPENDIX A.1: BLOOD CORTISOL (nmol) AND GLUCOSE (mmol) OF FEEDLOT CATTLE FED A SUPPLEMENT OF SELENIUM AND CHROMIUM – EXPERIMENT 1 (CONTINUED**)**

DAY	TTT	PEN	VACC	TAG	WEIGHT	ADG	FCR	GLUCO	CORTI
14	**4**	**11**	**2**	**B3B**	240.000	3.571	2.093	5.1	105
14	**4**	**11**	**2**	**B4B**	200.000	1.071	7.669	4.2	31
14	**4**	**11**	**2**	**B5B**	215.000	1.786	4.985	4.6	65
14	**4**	**11**	**2**	**B6B**	165.000	1.429	6.218	4.5	100
14	**4**	**12**	**3**	**C1B**	250.000	2.500	3.174	4.7	102
14	**4**	**12**	**3**	**C2B**	230.000	1.429	6.218	5.8	141
14	**4**	**12**	**3**	**C3B**	200.000	1.429	6.218	5	58
14	**4**	**12**	**3**	**C4B**	185.000	2.857	2.595	5.4	71
14	**4**	**12**	**3**	**C5B**	170.000	1.071	7.669	5.6	145
14	**4**	**12**	**3**	**C6B**	195.000	2.143	3.970	4.8	73
42	**1**	**1**	**1**	**A1Y**	270.000	1.190	7.161	5.9	133
42	**1**	**1**	**1**	**A2Y**	260.000	1.548	5.783	5.1	145
42	**1**	**1**	**1**	**A3Y**	240.000	0.833	8.757	5.2	77
42	**1**	**1**	**1**	**A4Y**	230.000	1.429	6.218	6.1	54
42	**1**	**1**	**1**	**A5Y**	245.000	1.310	6.677	5.5	57
42	**1**	**1**	**1**	**A6Y**	210.000	1.548	5.783	4.8	67
42	**1**	**2**	**2**	**B1Y**	270.000	1.190	7.161	5	44
42	**1**	**2**	**2**	**B2Y**	250.000	1.190	7.161	5	75
42	**1**	**2**	**2**	**B3Y**	255.000	1.548	5.783	4.9	109
42	**1**	**2**	**2**	**B4Y**	255.000	1.905	4.623	5.4	99
42	**1**	**2**	**2**	**B5Y**	220.000	1.190	7.161	5.1	83
42	**1**	**2**	**2**	**B6Y**	205.000	0.952	8.201	5.3	148
42	**1**	**3**	**3**	**C1Y**	260.000	1.429	6.218	5.7	85
42	**1**	**3**	**3**	**C2Y**	250.000	1.667	5.372	5.7	102
42	**1**	**3**	**3**	**C3Y**	230.000	0.952	8.201	5.2	39
42	**1**	**3**	**3**	**C4Y**	215.000	0.714	9.338	5.1	126
42	**1**	**3**	**3**	**C5Y**	230.000	1.429	6.218	5.8	59
42	**1**	**3**	**3**	**C6Y**	215.000	1.190	7.161	4.8	95
42	**2**	**4**	**1**	**A1G**	245.000	0.833	8.757	4.9	129
42	**2**	**4**	**1**	**A2G**	240.000	0.952	8.201	5	48
42	**2**	**4**	**1**	**A4G**	210.000	0.952	8.201	5.9	47
42	**2**	**4**	**1**	**A5G**	220.000	1.071	7.669	5	103
42	**2**	**4**	**1**	**A6G**	225.000	1.548	5.783	5.2	65
42	**2**	**5**	**2**	**B1G**	280.000	1.429	6.218	5.2	54
42	**2**	**5**	**2**	**B2G**	290.000	1.667	5.372	5	65
42	**2**	**5**	**2**	**B3G**	235.000	1.190	7.161	5.1	120
42	**2**	**5**	**2**	**B4G**	255.000	1.548	5.783	5.2	145
42	**2**	**5**	**2**	**B5G**	230.000	1.310	6.677	5.4	66
42	**2**	**5**	**2**	**B6G**	210.000	1.190	7.161	4.9	45
42	**2**	**6**	**3**	**C1G**	280.000	1.548	5.783	4.4	90
42	**2**	**6**	**3**	**C2G**	255.000	1.190	7.161	4.6	158
42	**2**	**6**	**3**	**C3G**	260.000	1.548	5.783	5	118
42	**2**	**6**	**3**	**C4G**	205.000	1.071	7.669	4.2	49
42	**2**	**6**	**3**	**C5G**	220.000	1.071	7.669	5.1	48
42	**2**	**6**	**3**	**C6G**	205.000	0.833	8.757	4.7	50
42	**3**	**7**	**1**	**A1R**	250.000	1.429	6.218	4.7	61

APPENDIX A.1: BLOOD CORTISOL (nmol) AND GLUCOSE (mmol) OF FEEDLOT CATTLE FED A SUPPLEMENT OF SELENIUM AND CHROMIUM – EXPERIMENT 1 (CONTINUED)

DAY	TTT	PEN	VACC	TAG	WEIGHT	ADG	FCR	GLUCO	CORTI
42	**3**	**7**	**1**	**A2R**	280.000	1.429	6.218	4.5	64
42	**3**	**7**	**1**	**A3R**	250.000	1.429	6.218	5.2	94
42	**3**	**7**	**1**	**A4R**	235.000	1.429	6.218	5.3	123
42	**3**	**7**	**1**	**A5R**	220.000	1.667	5.372	5.5	117
42	**3**	**7**	**1**	**A6R**	230.000	1.310	6.677	5.2	47
42	**3**	**8**	**2**	**B1R**	260.000	1.071	7.669	4.6	69
42	**3**	**8**	**2**	**B2R**	260.000	1.429	6.218	5.5	106
42	**3**	**8**	**2**	**B3R**	240.000	0.952	8.201	5.1	59
42	**3**	**8**	**2**	**B4R**	230.000	1.548	5.783	5.1	56
42	**3**	**8**	**2**	**B5R**	205.000	1.190	7.161	5.5	57
42	**3**	**8**	**2**	**B6R**	215.000	1.429	6.218	5.2	94
42	**3**	**9**	**3**	**C1R**	270.000	1.667	5.372	5.6	87
42	**3**	**9**	**3**	**C2R**	260.000	1.190	7.161	5.2	133
42	**3**	**9**	**3**	**C4R**	225.000	0.714	9.338	4.6	78
42	**3**	**9**	**3**	**C5R**	240.000	1.429	6.218	4.9	80
42	**3**	**9**	**3**	**C6R**	205.000	0.833	8.757	6.4	77
42	**4**	**10**	**1**	**A1B**	265.000	1.548	5.783	5.4	64
42	**4**	**10**	**1**	**A2B**	285.000	1.905	4.623	5.8	48
42	**4**	**10**	**1**	**A3B**	250.000	1.548	5.783	5.1	45
42	**4**	**10**	**1**	**A4B**	230.000	0.952	8.201	5.1	45
42	**4**	**10**	**1**	**A5B**	200.000	0.833	8.757	4.7	56
42	**4**	**10**	**1**	**A6B**	220.000	1.310	6.677	5.2	42
42	**4**	**11**	**2**	**B1B**	285.000	1.786	4.985	4.8	79
42	**4**	**11**	**2**	**B2B**	265.000	1.905	4.623	4.7	76
42	**4**	**11**	**2**	**B3B**	260.000	1.667	5.372	5.4	50
42	**4**	**11**	**2**	**B4B**	230.000	1.071	7.669	5	66
42	**4**	**11**	**2**	**B5B**	240.000	1.190	7.161	4.5	87
42	**4**	**11**	**2**	**B6B**	195.000	1.190	7.161	4.2	59
42	**4**	**12**	**3**	**C1B**	270.000	1.310	6.677	4.5	99
42	**4**	**12**	**3**	**C2B**	285.000	1.786	4.985	6	64
42	**4**	**12**	**3**	**C3B**	230.000	1.190	7.161	4.8	72
42	**4**	**12**	**3**	**C4B**	210.000	1.548	5.783	5.1	45
42	**4**	**12**	**3**	**C5B**	200.000	1.071	7.669	5	57
42	**4**	**12**	**3**	**C6B**	220.000	1.310	6.677	4.4	49

APPENDIX A.2: LIVE WEIGHT, AVERAGE DAILY GAIN AND PREDICTED FEED CONVERSION OF FEEDLOT CATTLE FED A SUPPLEMENT OF SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 1

TTT	PEN	VACC	TAG	M9	D 0	D 04	ADG14	PFCR14	D28	ADG28	PFCR28
1	1	1	A1Y	215.000	220.000	245.000	1.786	4.985	260.000	1.429	6.218
1	1	1	A2Y	180.000	195.000	220.000	1.786	4.985	250.000	1.964	4.450
1	1	1	A3Y	180.000	205.000	215.000	0.714	9.338	235.000	1.071	7.669
1	1	1	A4Y	160.000	170.000	190.000	1.429	6.218	215.000	1.607	5.574
1	1	1	A5Y	160.000	190.000	205.000	1.071	7.669	220.000	1.071	7.669
1	1	1	A6Y	130.000	145.000	175.000	2.143	3.970	190.000	1.607	5.574
1	2	2	B1Y	200.000	220.000	240.000	1.429	6.218	250.000	1.071	7.669
1	2	2	B2Y	195.000	200.000	230.000	2.143	3.970	240.000	1.429	6.218
1	2	2	B3Y	175.000	190.000	205.000	1.071	7.669	240.000	1.786	4.985
1	2	2	B4Y	160.000	175.000	205.000	2.143	3.970	235.000	2.143	3.970
1	2	2	B5Y	150.000	170.000	190.000	1.429	6.218	210.000	1.429	6.218
1	2	2	B6Y	145.000	165.000	185.000	1.429	6.218	195.000	1.071	7.669
1	3	3	C1Y	210.000	200.000	240.000	2.857	2.595	250.000	1.786	4.985
1	3	3	C2Y	185.000	180.000	215.000	2.500	3.174	240.000	2.143	3.970
1	3	3	C3Y	180.000	190.000	210.000	1.429	6.218	215.000	0.893	8.476
1	3	3	C4Y	160.000	185.000	195.000	0.714	9.338	200.000	0.536	10.254
1	3	3	C5Y	155.000	170.000	195.000	1.786	4.985	200.000	1.071	7.669
1	3	3	C6Y	150.000	165.000	190.000	1.786	4.985	195.000	1.071	7.669
2	4	1	A1G	200.000	210.000	230.000	1.429	6.218	235.000	0.893	8.476
2	4	1	A2G	190.000	200.000	220.000	1.429	6.218	225.000	0.893	8.476
2	4	1	A4G	160.000	170.000	195.000	1.786	4.985	195.000	0.893	8.476
2	4	1	A5G	150.000	175.000	190.000	1.071	7.669	200.000	0.893	8.476
2	4	1	A6G	145.000	160.000	190.000	2.143	3.970	200.000	1.429	6.218
2	5	2	B1G	200.000	220.000	240.000	1.429	6.218	250.000	1.071	7.669
2	5	2	B2G	200.000	220.000	245.000	1.786	4.985	270.000	1.786	4.985
2	5	2	B3G	170.000	185.000	220.000	2.500	3.174	220.000	1.250	6.916
2	5	2	B4G	170.000	190.000	210.000	1.429	6.218	220.000	1.071	7.669
2	5	2	B5G	150.000	175.000	200.000	1.786	4.985	200.000	0.893	8.476
2	5	2	B6G	145.000	160.000	190.000	2.143	3.970	195.000	1.250	6.916
2	6	3	C1G	205.000	215.000	255.000	2.857	2.595	255.000	1.429	6.218
2	6	3	C2G	190.000	205.000	230.000	1.786	4.985	240.000	1.250	6.916
2	6	3	C3G	180.000	195.000	210.000	1.071	7.669	245.000	1.786	4.985
2	6	3	C4G	160.000	160.000	190.000	2.143	3.970	195.000	1.250	6.916
2	6	3	C5G	150.000	175.000	200.000	1.786	4.985	200.000	0.893	8.476
2	6	3	C6G	135.000	170.000	185.000	1.071	7.669	190.000	0.714	9.338
3	7	1	A1R	200.000	190.000	220.000	2.143	3.970	230.000	1.429	6.218
3	7	1	A2R	200.000	220.000	240.000	1.429	6.218	260.000	1.429	6.218
3	7	1	A3R	175.000	190.000	215.000	1.786	4.985	225.000	1.250	6.916
3	7	1	A4R	165.000	175.000	200.000	1.786	4.985	210.000	1.250	6.916
3	7	1	A5R	150.000	150.000	190.000	2.857	2.595	210.000	2.143	3.970
3	7	1	A6R	140.000	175.000	190.000	1.071	7.669	200.000	0.893	8.476
3	8	2	B1R	205.000	215.000	240.000	1.786	4.985	250.000	1.250	6.916
3	8	2	B2R	190.000	200.000	230.000	2.143	3.970	240.000	1.429	6.218
3	8	2	B3R	180.000	200.000	210.000	0.714	9.338	230.000	1.071	7.669

APPENDIX A.2: LIVE WEIGHT, AVERAGE DAILY GAIN AND PREDICTED FEED CONVERSION OF FEEDLOT CATTLE FED A SUPPLEMENT OF SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 1 (CONTINUED)

TTT	PEN	VACC	TAG	D42	ADG42	PFCR42	D56	ADG56	PFCR56	D70	ADG70	PFCR70
1	1	1	A1Y	270.000	1.190	7.161	280.000	1.111	7.497	300.000	1.143	7.361
1	1	1	A2Y	260.000	1.548	5.783	265.000	1.296	6.730	300.000	1.500	5.954
1	1	1	A3Y	240.000	0.833	8.757	260.000	1.019	7.902	295.000	1.286	6.772
1	1	1	A4Y	230.000	1.429	6.218	245.000	1.389	6.368	270.000	1.429	6.218
1	1	1	A5Y	245.000	1.310	6.677	260.000	1.296	6.730	280.000	1.286	6.772
1	1	1	A6Y	210.000	1.548	5.783	215.000	1.296	6.730	250.000	1.500	5.954
1	2	2	B1Y	270.000	1.190	7.161	275.000	1.019	7.902	305.000	1.214	7.062
1	2	2	B2Y	250.000	1.190	7.161	260.000	1.111	7.497	295.000	1.357	6.490
1	2	2	B3Y	255.000	1.548	5.783	260.000	1.296	6.730	270.000	1.143	7.361
1	2	2	B4Y	255.000	1.905	4.623	260.000	1.574	5.689	295.000	1.714	5.214
1	2	2	B5Y	220.000	1.190	7.161	235.000	1.204	7.106	265.000	1.357	6.490
1	2	2	B6Y	205.000	0.952	8.201	215.000	0.926	8.322	205.000	0.571	10.066
1	3	3	C1Y	260.000	1.429	6.218	280.000	1.481	6.021	320.000	1.714	5.214
1	3	3	C2Y	250.000	1.667	5.372	260.000	1.481	6.021	300.000	1.714	5.214
1	3	3	C3Y	230.000	0.952	8.201	250.000	1.111	7.497	280.000	1.286	6.772
1	3	3	C4Y	215.000	0.714	9.338	235.000	0.926	8.322	260.000	1.071	7.669
1	3	3	C5Y	230.000	1.429	6.218	240.000	1.296	6.730	270.000	1.429	6.218
1	3	3	C6Y	215.000	1.190	7.161	220.000	1.019	7.902	250.000	1.214	7.062
2	4	1	A1G	245.000	0.833	8.757	260.000	0.926	8.322	285.000	1.071	7.669
2	4	1	A2G	240.000	0.952	8.201	260.000	1.111	7.497	285.000	1.214	7.062
2	4	1	A4G	210.000	0.952	8.201	230.000	1.111	7.497	255.000	1.214	7.062
2	4	1	A5G	220.000	1.071	7.669	230.000	1.019	7.902	250.000	1.071	7.669
2	4	1	A6G	225.000	1.548	5.783	250.000	1.667	5.372	285.000	1.786	4.985
2	5	2	B1G	280.000	1.429	6.218	295.000	1.389	6.368	330.000	1.571	5.698
2	5	2	B2G	290.000	1.667	5.372	315.000	1.759	5.069	340.000	1.714	5.214
2	5	2	B3G	235.000	1.190	7.161	260.000	1.389	6.368	280.000	1.357	6.490
2	5	2	B4G	255.000	1.548	5.783	270.000	1.481	6.021	290.000	1.429	6.218
2	5	2	B5G	230.000	1.310	6.677	255.000	1.481	6.021	280.000	1.500	5.954
2	5	2	B6G	210.000	1.190	7.161	240.000	1.481	6.021	275.000	1.643	5.452
2	6	3	C1G	280.000	1.548	5.783	300.000	1.574	5.689	310.000	1.357	6.490
2	6	3	C2G	255.000	1.190	7.161	270.000	1.204	7.106	295.000	1.286	6.772
2	6	3	C3G	260.000	1.548	5.783	290.000	1.759	5.069	320.000	1.786	4.985
2	6	3	C4G	205.000	1.071	7.669	220.000	1.111	7.497	250.000	1.286	6.772
2	6	3	C5G	220.000	1.071	7.669	240.000	1.204	7.106	270.000	1.357	6.490
2	6	3	C6G	205.000	0.833	8.757	220.000	0.926	8.322	245.000	1.071	7.669
3	7	1	A1R	250.000	1.429	6.218	255.000	1.204	7.106	275.000	1.214	7.062
3	7	1	A2R	280.000	1.429	6.218	290.000	1.296	6.730	325.000	1.500	5.954
3	7	1	A3R	250.000	1.429	6.218	260.000	1.296	6.730	290.000	1.429	6.218
3	7	1	A4R	235.000	1.429	6.218	245.000	1.296	6.730	260.000	1.214	7.062
3	7	1	A5R	220.000	1.667	5.372	225.000	1.389	6.368	260.000	1.571	5.698
3	7	1	A6R	230.000	1.310	6.677	235.000	1.111	7.497	255.000	1.143	7.361
3	8	2	B1R	260.000	1.071	7.669	260.000	0.833	8.757	290.000	1.071	7.669
3	8	2	B2R	260.000	1.429	6.218	270.000	1.296	6.730	305.000	1.500	5.954
3	8	2	B3R	240.000	0.952	8.201	245.000	0.833	8.757	270.000	1.000	7.985

APPENDIX A.2: LIVE WEIGHT, AVERAGE DAILY GAIN AND PREDICTED FEED CONVERSION OF FEEDLOT CATTLE FED A SUPPLEMENT OF SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 1 (CONTINUED)

TTT	PEN	VACC	TAG	D84	ADG84	PFCR84	D98	ADG98	PFCR98	D 012	ADG112	PFCR112
1	1	1	A1Y	325.000	1.250	6.916	350.000	1.327	6.610	365.000	1.295	6.736
1	1	1	A2Y	310.000	1.369	6.444	330.000	1.378	6.412	365.000	1.518	5.889
1	1	1	A3Y	315.000	1.310	6.677	340.000	1.378	6.412	380.000	1.563	5.730
1	1	1	A4Y	295.000	1.488	5.997	320.000	1.531	5.843	335.000	1.473	6.052
1	1	1	A5Y	290.000	1.190	7.161	325.000	1.378	6.412	345.000	1.384	6.387
1	1	1	A6Y	265.000	1.429	6.218	275.000	1.327	6.610	300.000	1.384	6.387
1	2	2	B1Y	320.000	1.190	7.161	350.000	1.327	6.610	360.000	1.250	6.916
1	2	2	B2Y	320.000	1.429	6.218	345.000	1.480	6.028	365.000	1.473	6.052
1	2	2	B3Y	280.000	1.071	7.669	315.000	1.276	6.813	325.000	1.205	7.099
1	2	2	B4Y	310.000	1.607	5.574	340.000	1.684	5.315	360.000	1.652	5.422
1	2	2	B5Y	285.000	1.369	6.444	315.000	1.480	6.028	340.000	1.518	5.889
1	2	2	B6Y	210.000	0.536	10.254	240.000	0.765	9.086	250.000	0.759	9.117
1	3	3	C1Y	340.000	1.667	5.372	365.000	1.684	5.315	380.000	1.607	5.574
1	3	3	C2Y	305.000	1.488	5.997	325.000	1.480	6.028	335.000	1.384	6.387
1	3	3	C3Y	290.000	1.190	7.161	310.000	1.224	7.020	320.000	1.161	7.285
1	3	3	C4Y	275.000	1.071	7.669	290.000	1.071	7.669	295.000	0.982	8.065
1	3	3	C5Y	280.000	1.310	6.677	310.000	1.429	6.218	320.000	1.339	6.560
1	3	3	C6Y	270.000	1.250	6.916	300.000	1.378	6.412	325.000	1.429	6.218
2	4	1	A1G	295.000	1.012	7.932	310.000	1.020	7.894	325.000	1.027	7.865
2	4	1	A2G	290.000	1.071	7.669	305.000	1.071	7.669	325.000	1.116	7.475
2	4	1	A4G	285.000	1.369	6.444	300.000	1.327	6.610	305.000	1.205	7.099
2	4	1	A5G	265.000	1.071	7.669	295.000	1.224	7.020	300.000	1.116	7.475
2	4	1	A6G	295.000	1.607	5.574	315.000	1.582	5.663	330.000	1.518	5.889
2	5	2	B1G	350.000	1.548	5.783	380.000	1.633	5.487	390.000	1.518	5.889
2	5	2	B2G	365.000	1.726	5.175	385.000	1.684	5.315	390.000	1.518	5.889
2	5	2	B3G	295.000	1.310	6.677	315.000	1.327	6.610	330.000	1.295	6.736
2	5	2	B4G	315.000	1.488	5.997	340.000	1.531	5.843	350.000	1.429	6.218
2	5	2	B5G	300.000	1.488	5.997	325.000	1.531	5.843	335.000	1.429	6.218
2	5	2	B6G	280.000	1.429	6.218	300.000	1.429	6.218	315.000	1.384	6.387
2	6	3	C1G	315.000	1.190	7.161	340.000	1.276	6.813	355.000	1.250	6.916
2	6	3	C2G	330.000	1.488	5.997	340.000	1.378	6.412	350.000	1.295	6.736
2	6	3	C3G	345.000	1.786	4.985	365.000	1.735	5.148	375.000	1.607	5.574
2	6	3	C4G	265.000	1.250	6.916	285.000	1.276	6.813	290.000	1.161	7.285
2	6	3	C5G	290.000	1.369	6.444	305.000	1.327	6.610	325.000	1.339	6.560
2	6	3	C6G	260.000	1.071	7.669	280.000	1.122	7.448	295.000	1.116	7.475
3	7	1	A1R	300.000	1.310	6.677	330.000	1.429	6.218	350.000	1.429	6.218
3	7	1	A2R	340.000	1.429	6.218	355.000	1.378	6.412	365.000	1.295	6.736
3	7	1	A3R	310.000	1.429	6.218	315.000	1.276	6.813	340.000	1.339	6.560
3	7	1	A4R	275.000	1.190	7.161	300.000	1.276	6.813	320.000	1.295	6.736
3	7	1	A5R	270.000	1.429	6.218	290.000	1.429	6.218	310.000	1.429	6.218
3	7	1	A6R	280.000	1.250	6.916	300.000	1.276	6.813	315.000	1.250	6.916
3	8	2	B1R	300.000	1.012	7.932	320.000	1.071	7.669	335.000	1.071	7.669
3	8	2	B2R	320.000	1.429	6.218	335.000	1.378	6.412	375.000	1.563	5.730
3	8	2	B3R	285.000	1.012	7.932	290.000	0.918	8.357	320.000	1.071	7.669

APPENDIX A.2: LIVE WEIGHT, AVERAGE DAILY GAIN AND PREDICTED FEED CONVERSION OF FEEDLOT CATTLE FED A SUPPLEMENT OF SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 1 (CONTINUED)

TTT	PEN	VACC	TAG	D 020	ADG	PFCR120
1	1	1	A1Y	380.000	1.333	6.583
1	1	1	A2Y	365.000	1.417	6.263
1	1	1	A3Y	390.000	1.542	5.804
1	1	1	A4Y	350.000	1.500	5.954
1	1	1	A5Y	365.000	1.458	6.107
1	1	1	A6Y	305.000	1.333	6.583
1	2	2	B1Y	360.000	1.167	7.260
1	2	2	B2Y	370.000	1.417	6.263
1	2	2	B3Y	325.000	1.125	7.437
1	2	2	B4Y	360.000	1.542	5.804
1	2	2	B5Y	340.000	1.417	6.263
1	2	2	B6Y	255.000	0.750	9.161
1	3	3	C1Y	390.000	1.583	5.657
1	3	3	C2Y	340.000	1.333	6.583
1	3	3	C3Y	325.000	1.125	7.437
1	3	3	C4Y	325.000	1.167	7.260
1	3	3	C5Y	330.000	1.333	6.583
1	3	3	C6Y	315.000	1.250	6.916
2	4	1	A1G	355.000	1.208	7.087
2	4	1	A2G	340.000	1.167	7.260
2	4	1	A4G	320.000	1.250	6.916
2	4	1	A5G	315.000	1.167	7.260
2	4	1	A6G	340.000	1.500	5.954
2	5	2	B1G	395.000	1.458	6.107
2	5	2	B2G	390.000	1.417	6.263
2	5	2	B3G	340.000	1.292	6.748
2	5	2	B4G	355.000	1.375	6.421
2	5	2	B5G	340.000	1.375	6.421
2	5	2	B6G	320.000	1.333	6.583
2	6	3	C1G	360.000	1.208	7.087
2	6	3	C2G	355.000	1.250	6.916
2	6	3	C3G	385.000	1.583	5.657
2	6	3	C4G	305.000	1.208	7.087
2	6	3	C5G	335.000	1.333	6.583
2	6	3	C6G	310.000	1.167	7.260
3	7	1	A1R	360.000	1.417	6.263
3	7	1	A2R	375.000	1.292	6.748
3	7	1	A3R	340.000	1.250	6.916
3	7	1	A4R	330.000	1.292	6.748
3	7	1	A5R	320.000	1.417	6.263
3	7	1	A6R	330.000	1.292	6.748
3	8	2	B1R	340.000	1.042	7.799
3	8	2	B2R	385.000	1.542	5.804
3	8	2	B3R	325.000	1.042	7.799

APPENDIX A.2: LIVE WEIGHT, AVERAGE DAILY GAIN AND PREDICTED FEED CONVERSION OF FEEDLOT CATTLE FED A SUPPLEMENT OF SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 1 (CONTINUED)

TTT	PEN	VACC	TAG	M9	D 0	D 04	ADG14	PFCR14	D28	ADG28	PFCR28
3	**8**	**2**	**B4R**	160.000	165.000	200.000	2.500	3.174	205.000	1.429	6.218
3	**8**	**2**	**B5R**	150.000	155.000	180.000	1.786	4.985	190.000	1.250	6.916
3	**8**	**2**	**B6R**	140.000	155.000	175.000	1.429	6.218	190.000	1.250	6.916
3	**9**	**3**	**C1R**	200.000	200.000	235.000	2.500	3.174	255.000	1.964	4.450
3	**9**	**3**	**C2R**	200.000	210.000	240.000	2.143	3.970	245.000	1.250	6.916
3	**9**	**3**	**C4R**	170.000	195.000	210.000	1.071	7.669	220.000	0.893	8.476
3	**9**	**3**	**C5R**	150.000	180.000	200.000	1.429	6.218	220.000	1.429	6.218
3	**9**	**3**	**C6R**	150.000	170.000	180.000	0.714	9.338	190.000	0.714	9.338
4	**10**	**1**	**A1B**	200.000	200.000	240.000	2.857	2.595	255.000	1.964	4.450
4	**10**	**1**	**A2B**	195.000	205.000	245.000	2.857	2.595	275.000	2.500	3.174
4	**10**	**1**	**A3B**	175.000	185.000	215.000	2.143	3.970	240.000	1.964	4.450
4	**10**	**1**	**A4B**	160.000	190.000	205.000	1.071	7.669	215.000	0.893	8.476
4	**10**	**1**	**A5B**	150.000	165.000	180.000	1.071	7.669	200.000	1.250	6.916
4	**10**	**1**	**A6B**	140.000	165.000	180.000	1.071	7.669	200.000	1.250	6.916
4	**11**	**2**	**B1B**	210.000	210.000	245.000	2.500	3.174	265.000	1.964	4.450
4	**11**	**2**	**B2B**	180.000	185.000	235.000	3.571	2.093	250.000	2.321	3.545
4	**11**	**2**	**B3B**	180.000	190.000	240.000	3.571	2.093	250.000	2.143	3.970
4	**11**	**2**	**B4B**	160.000	185.000	200.000	1.071	7.669	210.000	0.893	8.476
4	**11**	**2**	**B5B**	160.000	190.000	215.000	1.786	4.985	220.000	1.071	7.669
4	**11**	**2**	**B6B**	130.000	145.000	165.000	1.429	6.218	190.000	1.607	5.574
4	**12**	**3**	**C1B**	200.000	215.000	250.000	2.500	3.174	260.000	1.607	5.574
4	**12**	**3**	**C2B**	195.000	210.000	230.000	1.429	6.218	265.000	1.964	4.450
4	**12**	**3**	**C3B**	175.000	180.000	200.000	1.429	6.218	210.000	1.071	7.669
4	**12**	**3**	**C4B**	150.000	145.000	185.000	2.857	2.595	190.000	1.607	5.574
4	**12**	**3**	**C5B**	140.000	155.000	170.000	1.071	7.669	190.000	1.250	6.916
4	**12**	**3**	**C6B**	160.000	165.000	195.000	2.143	3.970	210.000	1.607	5.574

APPENDIX A.2: LIVE WEIGHT, AVERAGE DAILY GAIN AND PREDICTED FEED CONVERSION OF FEEDLOT CATTLE FED A SUPPLEMENT OF SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 1 (CONTINUED)

TTT	PEN	VAC C	TAG	D42	ADG42	PFCR42	D56	ADG56	PFCR56	D70	ADG70
3	**8**	**2**	**B4R**	230.000	1.548	5.783	240.000	1.389	6.368	255.000	1.286
3	**8**	**2**	**B5R**	205.000	1.190	7.161	210.000	1.019	7.902	235.000	1.143
3	**8**	**2**	**B6R**	215.000	1.429	6.218	220.000	1.204	7.106	240.000	1.214
3	**9**	**3**	**C1R**	270.000	1.667	5.372	275.000	1.389	6.368	310.000	1.571
3	**9**	**3**	**C2R**	260.000	1.190	7.161	280.000	1.296	6.730	315.000	1.500
3	**9**	**3**	**C4R**	225.000	0.714	9.338	230.000	0.648	9.671	265.000	1.000
3	**9**	**3**	**C5R**	240.000	1.429	6.218	250.000	1.296	6.730	275.000	1.357
3	**9**	**3**	**C6R**	205.000	0.833	8.757	230.000	1.111	7.497	255.000	1.214
4	**10**	**1**	**A1B**	265.000	1.548	5.783	275.000	1.389	6.368	290.000	1.286
4	**10**	**1**	**A2B**	285.000	1.905	4.623	295.000	1.667	5.372	320.000	1.643
4	**10**	**1**	**A3B**	250.000	1.548	5.783	255.000	1.296	6.730	280.000	1.357
4	**10**	**1**	**A4B**	230.000	0.952	8.201	235.000	0.833	8.757	260.000	1.000
4	**10**	**1**	**A5B**	200.000	0.833	8.757	205.000	0.741	9.207	240.000	1.071
4	**10**	**1**	**A6B**	220.000	1.310	6.677	225.000	1.111	7.497	235.000	1.000
4	**11**	**2**	**B1B**	285.000	1.786	4.985	300.000	1.667	5.372	335.000	1.786
4	**11**	**2**	**B2B**	265.000	1.905	4.623	275.000	1.667	5.372	310.000	1.786
4	**11**	**2**	**B3B**	260.000	1.667	5.372	270.000	1.481	6.021	300.000	1.571
4	**11**	**2**	**B4B**	230.000	1.071	7.669	245.000	1.111	7.497	260.000	1.071
4	**11**	**2**	**B5B**	240.000	1.190	7.161	255.000	1.204	7.106	280.000	1.286
4	**11**	**2**	**B6B**	195.000	1.190	7.161	200.000	1.019	7.902	215.000	1.000
4	**12**	**3**	**C1B**	270.000	1.310	6.677	290.000	1.389	6.368	315.000	1.429
4	**12**	**3**	**C2B**	285.000	1.786	4.985	300.000	1.667	5.372	320.000	1.571
4	**12**	**3**	**C3B**	230.000	1.190	7.161	245.000	1.204	7.106	285.000	1.500
4	**12**	**3**	**C4B**	210.000	1.548	5.783	230.000	1.574	5.689	255.000	1.571
4	**12**	**3**	**C5B**	200.000	1.071	7.669	205.000	0.926	8.322	230.000	1.071
4	**12**	**3**	**C6B**	220.000	1.310	6.677	240.000	1.389	6.368	255.000	1.286

APPENDIX A.2: LIVE WEIGHT, AVERAGE DAILY GAIN AND PREDICTED FEED CONVERSION OF FEEDLOT CATTLE FED A SUPPLEMENT OF SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 1 (CONTINUED)

TTT	PEN	VACC	TAG	D84	ADG 84	PFCR 84	D98	ADG 98	PFCR 98	D 012	ADG 112	PFCR 112	D 020	ADG	PFCR 120
3	**8**	**2**	**B4R**	285.000	1.429	6.218	300.000	1.378	6.412	335.000	1.518	5.889	335.000	1.417	6.263
3	**8**	**2**	**B5R**	265.000	1.310	6.677	285.000	1.327	6.610	300.000	1.295	6.736	310.000	1.292	6.748
3	**8**	**2**	**B6R**	260.000	1.250	6.916	285.000	1.327	6.610	310.000	1.384	6.387	315.000	1.333	6.583
3	**9**	**3**	**C1R**	335.000	1.607	5.574	345.000	1.480	6.028	365.000	1.473	6.052	375.000	1.458	6.107
3	**9**	**3**	**C2R**	325.000	1.369	6.444	330.000	1.224	7.020	365.000	1.384	6.387	370.000	1.333	6.583
3	**9**	**3**	**C4R**	300.000	1.250	6.916	305.000	1.122	7.448	330.000	1.205	7.099	340.000	1.208	7.087
3	**9**	**3**	**C5R**	310.000	1.548	5.783	320.000	1.429	6.218	350.000	1.518	5.889	365.000	1.542	5.804
3	**9**	**3**	**C6R**	285.000	1.369	6.444	295.000	1.276	6.813	320.000	1.339	6.560	325.000	1.292	6.748
4	**10**	**1**	**A1B**	330.000	1.548	5.783	335.000	1.378	6.412	350.000	1.339	6.560	365.000	1.375	6.421
4	**10**	**1**	**A2B**	340.000	1.607	5.574	365.000	1.633	5.487	380.000	1.563	5.730	385.000	1.500	5.954
4	**10**	**1**	**A3B**	300.000	1.369	6.444	310.000	1.276	6.813	320.000	1.205	7.099	325.000	1.167	7.260
4	**10**	**1**	**A4B**	290.000	1.190	7.161	300.000	1.122	7.448	325.000	1.205	7.099	335.000	1.208	7.087
4	**10**	**1**	**A5B**	260.000	1.131	7.412	280.000	1.173	7.232	290.000	1.116	7.475	305.000	1.167	7.260
4	**10**	**1**	**A6B**	260.000	1.131	7.412	295.000	1.327	6.610	315.000	1.339	6.560	320.000	1.292	6.748
4	**11**	**2**	**B1B**	370.000	1.905	4.623	395.000	1.888	4.673	420.000	1.875	4.711	425.000	1.792	4.966
4	**11**	**2**	**B2B**	335.000	1.786	4.985	360.000	1.786	4.985	380.000	1.741	5.127	385.000	1.667	5.372
4	**11**	**2**	**B3B**	335.000	1.726	5.175	345.000	1.582	5.663	370.000	1.607	5.574	370.000	1.500	5.954
4	**11**	**2**	**B4B**	295.000	1.310	6.677	300.000	1.173	7.232	330.000	1.295	6.736	335.000	1.250	6.916
4	**11**	**2**	**B5B**	310.000	1.429	6.218	335.000	1.480	6.028	350.000	1.429	6.218	360.000	1.417	6.263
4	**11**	**2**	**B6B**	245.000	1.190	7.161	250.000	1.071	7.669	270.000	1.116	7.475	275.000	1.083	7.617
4	**12**	**3**	**C1B**	350.000	1.607	5.574	370.000	1.582	5.663	390.000	1.563	5.730	390.000	1.458	6.107
4	**12**	**3**	**C2B**	340.000	1.548	5.783	365.000	1.582	5.663	380.000	1.518	5.889	385.000	1.458	6.107
4	**12**	**3**	**C3B**	305.000	1.488	5.997	320.000	1.429	6.218	355.000	1.563	5.730	360.000	1.500	5.954
4	**12**	**3**	**C4B**	295.000	1.786	4.985	310.000	1.684	5.315	330.000	1.652	5.422	335.000	1.583	5.657
4	**12**	**3**	**C5B**	265.000	1.310	6.677	290.000	1.378	6.412	320.000	1.473	6.052	320.000	1.375	6.421
4	**12**	**3**	**C6B**	285.000	1.429	6.218	300.000	1.378	6.412	320.000	1.384	6.387	320.000	1.292	6.748

APPENDIX A.3: FEED CONSUMPTION OF FEEDLOT CATTLE FED A SUPPLEMENT OF SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 1

TTT	PEN	VACC	M9	D 0	D 04	ADG14	FEED 04	ADMI14	D28	ADG28	FEED28	TOTF28	ADMI28
1	1	1	170.833	187.500	208.333	1.488	411.450	4.898	228.333	1.458	506.420	917.870	5.464
1	2	2	170.833	186.667	209.167	1.607	443.100	5.275	228.333	1.488	506.420	949.520	5.652
1	3	3	173.333	181.667	207.500	1.845	390.350	4.647	216.667	1.250	495.850	886.200	5.275
2	4	1	169.000	179.167	201.667	1.607	443.100	5.275	207.500	1.012	390.350	833.450	4.961
2	5	2	172.500	191.667	217.500	1.845	443.100	5.275	225.833	1.220	538.050	981.150	5.840
2	6	3	170.000	186.667	211.667	1.786	506.400	6.029	220.833	1.220	506.400	1012.800	6.029
3	7	1	171.667	183.333	209.167	1.845	379.810	4.522	222.500	1.399	474.750	854.560	5.087
3	8	2	170.833	181.667	205.833	1.726	390.360	4.647	217.500	1.280	495.850	886.210	5.275
3	9	3	174.000	184.167	205.833	1.548	379.800	4.521	220.000	1.280	482.670	862.470	5.134
4	10	1	170.000	185.000	210.833	1.845	411.450	4.898	230.833	1.637	506.400	917.850	5.463
4	11	2	170.000	184.167	216.667	2.321	379.810	4.522	230.833	1.667	506.400	886.210	5.275
4	12	3	170.000	178.333	205.000	1.905	411.460	4.898	220.833	1.518	569.700	981.160	5.840

APPENDIX A.3: FEED CONSUMPTION OF FEEDLOT CATTLE FED A SUPPLEMENT OF SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 1 (CONTINUED)

TTT	PEN	VACC	D42	ADG42	FEED42	TOTFE42	ADMI42	D56	ADG56	FEED56	TOTFE56	ADMI56
1	1	1	242.500	1.310	506.420	1424.290	5.652	254.167	1.190	601.700	2025.990	6.030
1	2	2	242.500	1.329	506.420	1455.940	5.778	250.833	1.146	538.070	1994.010	5.935
1	3	3	233.333	1.230	538.080	1424.280	5.652	247.500	1.176	664.690	2088.970	6.217
2	4	1	224.167	1.071	464.220	1297.670	5.149	242.500	1.131	538.080	1835.750	5.464
2	5	2	250.000	1.389	538.080	1519.230	6.029	272.500	1.443	633.050	2152.280	6.406
2	6	3	237.500	1.210	538.070	1550.870	6.154	256.667	1.250	538.080	2088.950	6.217
3	7	1	244.167	1.448	569.730	1424.290	5.652	251.667	1.220	538.080	1962.370	5.840
3	8	2	235.000	1.270	538.070	1424.280	5.652	240.833	1.057	601.360	2025.640	6.029
3	9	3	234.167	1.190	593.470	1455.940	5.778	245.833	1.101	601.360	2057.300	6.123
4	10	1	241.667	1.349	538.070	1455.920	5.777	248.333	1.131	664.670	2120.590	6.311
4	11	2	245.833	1.468	443.100	1329.310	5.275	257.500	1.310	633.020	1962.330	5.840
4	12	3	235.833	1.369	633.040	1614.200	6.406	251.667	1.310	633.010	2247.210	6.688

APPENDIX A.3: FEED CONSUMPTION OF FEEDLOT CATTLE FED A SUPPLEMENT OF SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 1 (CONTINUED)

TTT	PEN	VACC	D70	ADG70	FEED70	TOTFE70	ADMI70	D84	ADG84	FEED84	TOTFE84	ADMI84
1	1	1	282.500	1.357	664.650	2690.640	6.406	300.000	1.339	791.250	3481.890	6.909
1	2	2	272.500	1.226	696.300	2690.310	6.406	287.500	1.200	791.250	3481.560	6.908
1	3	3	280.000	1.405	727.950	2816.920	6.707	293.333	1.329	791.250	3608.170	7.159
2	4	1	268.333	1.274	633.000	2468.750	5.878	282.500	1.230	791.250	3260.000	6.468
2	5	2	299.167	1.536	727.950	2880.230	6.858	317.500	1.498	791.250	3671.480	7.285
2	6	3	281.667	1.357	664.650	2753.600	6.556	300.833	1.359	759.600	3513.200	6.971
3	7	1	277.500	1.345	664.650	2627.020	6.255	295.833	1.339	727.950	3354.970	6.657
3	8	2	265.833	1.202	633.000	2658.640	6.330	285.833	1.240	759.600	3418.240	6.782
3	9	3	276.667	1.321	664.650	2721.950	6.481	304.167	1.429	759.600	3481.550	6.908
4	10	1	270.833	1.226	727.950	2848.540	6.782	296.667	1.329	822.900	3671.440	7.285
4	11	2	283.333	1.417	727.950	2690.280	6.405	315.000	1.558	854.550	3544.830	7.033
4	12	3	276.667	1.405	696.300	2943.510	7.008	306.667	1.528	886.200	3829.710	7.599

APPENDIX A.3: FEED CONSUMPTION OF FEEDLOT CATTLE FED A SUPPLEMENT OF SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 1 (CONTINUED)

TTT	PEN	**VACC**	**D98**	**ADG98**	**FEED98**	**TOTFE98**	**ADMI98**	**D 020**	**ADG120**	**TOTFEED**	**ADMI120**	**FCR**
1	**1**	**1**	323.333	1.386	822.900	4304.790	7.321	359.167	1.431	5862.624	7.944	5.553
1	**2**	**2**	317.500	1.335	822.900	4304.460	7.321	335.000	1.236	5862.973	7.944	6.427
1	**3**	**3**	316.667	1.378	917.850	4526.020	7.697	337.500	1.299	6084.517	8.245	6.349
2	**4**	**1**	300.833	1.241	886.200	4146.200	7.051	328.333	1.243	5641.142	7.644	6.149
2	**5**	**2**	340.833	1.522	854.550	4526.030	7.697	356.667	1.375	6084.251	8.244	5.996
2	**6**	**3**	319.167	1.352	791.250	4304.450	7.320	341.667	1.292	5736.009	7.772	6.017
3	**7**	**1**	315.000	1.344	822.900	4177.870	7.105	342.500	1.326	5640.859	7.643	5.763
3	**8**	**2**	302.500	1.233	791.250	4209.490	7.159	335.000	1.278	5672.683	7.687	6.016
3	**9**	**3**	312.500	1.310	822.900	4304.450	7.320	347.500	1.361	5799.134	7.858	5.773
4	**10**	**1**	314.167	1.318	854.550	4525.990	7.697	339.167	1.285	6052.859	8.202	6.384
4	**11**	**2**	330.833	1.497	917.850	4462.680	7.590	358.333	1.451	6052.282	8.201	5.650
4	**12**	**3**	325.833	1.505	917.850	4747.560	8.074	351.667	1.444	6369.129	8.630	5.975

APPENDIX A.4: CARCASS CHARACTERISTICS OF FEEDLOT CATTLE FED SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 1

TTT	PEN	VACC	TAG	WM	CCM	SHRP	CF	FC	LWT120	DPP	PH1	PH2
1	**1**	**1**	**A1Y**	196	191.1	2.50	3	2	380	50.29	5.9	5.9
1	**1**	**1**	**A2Y**	200	195	2.50	3	2	365	53.42	5.9	5.7
1	**1**	**1**	**A3Y**	200	195	2.50	3	1	390	50.00	5.9	5.8
1	**1**	**1**	**A4Y**	176	171.6	2.50	3	2	350	49.03	6.1	5.8
1	**1**	**1**	**A5Y**	178	173.6	2.47	3	2	365	47.56	6.1	5.7
1	**1**	**1**	**A6Y**	155	151.1	2.50	3	2	305	49.54	5.5	5.7
1	**2**	**2**	**B1Y**	186	181.4	2.47	3	2	360	50.39	6	5.7
1	**2**	**2**	**B2Y**	193	188.2	2.49	3	2	370	50.86	5.4	5.7
1	**2**	**2**	**B3Y**	185	180.2	2.49	3	2	325	55.45	5.8	5.7
1	**2**	**2**	**B4Y**	208	202.8	2.50	3	2	360	56.33	5.6	5.7
1	**2**	**2**	**B5Y**	191	185.3	2.98	3	2	340	54.50	5.7	5.8
1	**2**	**2**	**B6Y**	132	128.7	2.50	3	2	255	50.47		
1	**3**	**3**	**C1Y**	214	208.7	2.48	3	2	390	53.51	6.6	5.8
1	**3**	**3**	**C2Y**	178	173.6	2.47	3	2	340	51.06	5.8	5.6
1	**3**	**3**	**C3Y**	175	170.6	2.48	3	2	325	52.49	5.5	5.6
1	**3**	**3**	**C4Y**	174	169.7	2.47	3	2	325	52.22	5.6	5.9
1	**3**	**3**	**C5Y**	169	164.8	2.49	3	2	330	49.94	6	5.7
1	**3**	**3**	**C6Y**	180	175.5	2.50	3	1	315	55.71	5.6	5.8
2	**4**	**1**	**A1G**	187	182.3	2.51	3	1	355	51.35	6.4	5.8
2	**4**	**1**	**A2G**	173	168.7	2.49	3	2	340	49.62	6.4	6.2
2	**4**	**1**	**A4G**	178	173.6	2.47	3	2	320	54.25	5.4	5.7
2	**4**	**1**	**A5G**	162	158	2.47	3	2	315	50.16	5.8	6.3
2	**4**	**1**	**A6G**	173	168.7	2.49	3	2	340	49.62	5.7	6
2	**5**	**2**	**B1G**	219	213.5	2.51	3	2	395	54.05	6.6	5.6
2	**5**	**2**	**B2G**	218	212.6	2.48	3	2	390	54.51	5.9	5.8
2	**5**	**2**	**B3G**	170	165.8	2.47	3	2	340	48.76	5.4	5.8
2	**5**	**2**	**B4G**	182	177.5	2.47	3	2	355	50.00	5.4	5.7
2	**5**	**2**	**B5G**	195	190.1	2.51	3	2	340	55.91	6.6	5.8
2	**5**	**2**	**B6G**	183	178.4	2.48	3	2	320	55.75	6.1	5.8
2	**6**	**3**	**C1G**	197	192.1	2.49	3	2	360	53.36	5.8	5.8
2	**6**	**3**	**C2G**	179	174.5	2.51	4	2	355	49.15	5.7	5.8
2	**6**	**3**	**C3G**	196	191.1	2.50	3	2	385	49.64	5.9	5.8
2	**6**	**3**	**C4G**	160	156	2.50	3	2	305	51.15	5.8	5.8
2	**6**	**3**	**C5G**	193	188.2	2.49	3	2	335	56.18	5.8	5.7
2	**6**	**3**	**C6G**	160	156	2.50	3	2	310	50.32	5.7	5.8
3	**7**	**1**	**A1R**	201	196	2.44	3	2	360	54.44	6.1	5.6
3	**7**	**1**	**A2R**	212	206.7	2.50	3	3	375	55.12	6.2	5.6
3	**7**	**1**	**A3R**	181	176.5	2.49	3	2	340	51.91	6.2	5.7
3	**7**	**1**	**A4R**	174	169.7	2.47	3	2	330	51.42	6.4	5.8
3	**7**	**1**	**A5R**	182	177.5	2.47	3	2	320	55.47	6.8	5.7
3	**7**	**1**	**A6R**	186	181.4	2.47	3	1	330	54.97	6.3	5.8
3	**8**	**2**	**B1R**	185	180.4	2.49	3	2	340	53.06	6	5.8
3	**8**	**2**	**B2R**	200	195	2.50	3	2	385	50.65	6	5.7
3	**8**	**2**	**B3R**	175	170.7	2.46	3	2	325	52.52	6	

APPENDIX A.4: CARCASS CHARACTERISTICS OF FEEDLOT CATTLE FED SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 1

TTT	PEN	VACC	TAG	WM	CCM	SHRP	CF	FC	LWT120	DPP	PH1	PH2
3	**8**	**2**	**B4R**	172	167.7	2.50	3	2	335	50.06	5.4	5.7
3	**8**	**2**	**B5R**	166	161.9	2.47	3	2	310	52.23	5.9	5.7
3	**8**	**2**	**B6R**	164	159.9	2.50	3	1	315	50.76	6.1	5.7
3	**9**	**3**	**C1R**	204	198.9	2.50	3	2	375	53.04	5.4	5.7
3	**9**	**3**	**C2R**	193	188.2	2.49	3	2	370	50.86	6.1	5.6
3	**9**	**3**	**C4R**	188	183.3	2.50	3	2	340	53.91	5.4	5.7
3	**9**	**3**	**C5R**	199	193	3.02	4	2	365	52.88	5.5	
3	**9**	**3**	**C6R**	172	167.7	2.50	3	2	325	51.60	6.2	5.6
4	**10**	**1**	**A1B**	202	197	2.48	3	3	365	53.97	5.7	5.9
4	**10**	**1**	**A2B**	206	200.9	2.48	3	2	385	52.18	6.3	5.9
4	**10**	**1**	**A3B**	169	164.8	2.49	3	2	325	50.71	6.7	5.7
4	**10**	**1**	**A4B**	176	171.6	2.50	3	2	335	51.22	6.7	5.8
4	**10**	**1**	**A5B**	165	160.9	2.48	3	2	305	52.75	6.1	5.8
4	**10**	**1**	**A6B**	180	175.6	2.44	3	2	320	54.88	6.6	5.9
4	**11**	**2**	**B1B**	231	225.2	2.51	4	3	425	52.99	6.3	5.8
4	**11**	**2**	**B2B**	209	203.8	2.49	4	2	385	52.94	6.3	5.8
4	**11**	**2**	**B3B**	209	203.8	2.49	3	2	370	55.08	6.3	5.7
4	**11**	**2**	**B4B**	185	180.4	2.49	3	2	335	53.85	6.6	5.9
4	**11**	**2**	**B5B**	185	180.4	2.49	4	2	360	50.11	6.1	
4	**11**	**2**	**B6B**	168	163.8	2.50	3	2	275	59.56	6.1	5.7
4	**12**	**3**	**C1B**	202	197	2.48	3	3	390	50.51	6.3	6.2
4	**12**	**3**	**C2B**	203	197.9	2.51	3	3	385	51.40	6.3	6
4	**12**	**3**	**C3B**	193	188.2	2.49	3	2	360	52.28	6.2	5.8
4	**12**	**3**	**C4B**	177	172.6	2.49	3	2	335	51.52	6.6	5.9
4	**12**	**3**	**C5B**	174	169.7	2.47	3	2	320	53.03	6.1	5.8
4	**12**	**3**	**C6B**	171	166.7	2.51	3	2	320	52.09	6	5.8

APPENDIX A.5: MEASUREMENTS OF SUB-CUTANEOUS FAT, FAT CODE AND PERCENT OF MEAT YIELD FOR CARCASSES OF FEEDLOT CATTLE FED A SUPPLEMENT OF SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 1

PEN	VACC	TAG	SFAT1	SFAT2	SFAT3	FCODE	PMYIELD	SCUTFAT
1	**1**	**A1Y**	5.8	4.1	0.8	2	79.70	4.05
1	**1**	**A2Y**	4.9	3.3	0.7	2	79.87	3.89
1	**1**	**A3Y**	6.8	5.1	0.7	2	79.52	4.23
1	**1**	**A4Y**	4	3.8	1	2	79.89	3.85
1	**1**	**A5Y**	4	3.6	1.6	2	79.88	3.87
1	**1**	**A6Y**	3.5	4.3	1.5	2	79.87	3.86
2	**2**	**B1Y**	1.6	1	0.8	2	80.40	3.38
2	**2**	**B2Y**	8.7	4.3	4.3	3	79.41	4.98
2	**2**	**B3Y**	3.8	0.9	0.5	1	80.01	3.23
2	**2**	**B4Y**	5.6	4.5	2.4	2	79.60	4.16
2	**2**	**B5Y**	4.3	3.6	1.2	2	79.87	3.88
2	**2**	**B6Y**	6	5	0.8	2	79.60	4.14
3	**3**	**C1Y**	3.7	0.9	0.5	1	80.02	3.22
3	**3**	**C2Y**	5.1	3.5	1.1	2	79.81	3.96
3	**3**	**C3Y**	2.7	2	0.5	2	80.21	3.55
3	**3**	**C4Y**	5.9	5.5	1.3	3	79.73	4.56
3	**3**	**C5Y**	1.3	1.8	0.2	1	80.19	2.99
3	**3**	**C6Y**	5.8	4.8	0.6	2	79.65	4.09
4	**1**	**A1G**	3.7	2.8	0.5	2	80.04	3.71
4	**1**	**A2G**	3.2	0.4	0.4	1	80.12	3.12
4	**1**	**A4G**	2.2	1.3	1.3	2	80.29	3.50
4	**1**	**A5G**	4.4	2.5	1.1	2	79.97	3.81
4	**1**	**A6G**	2.7	1.9	0.1	2	80.24	3.52
5	**2**	**B2G**	4.2	3.5	2.7	2	79.81	3.96
5	**2**	**B3G**	6.6	4.1	2.2	2	79.55	4.23
5	**2**	**B4G**	4.6	3.9	1.8	2	79.78	3.97
5	**2**	**B5G**	3.1	2.2	0.4	2	80.16	3.60
5	**2**	**B6G**	3.7	1.3	1.5	2	80.13	3.68
6	**3**	**C1G**	5.6	2.6	0.2	2	79.89	3.89
6	**3**	**C2G**	5.2	7.2	1.7	2	79.43	4.26
6	**3**	**C4G**	6.6	5.1	0.8	2	79.53	4.21
6	**3**	**C5G**	1.3	1.2	0.2	1	80.25	2.95
6	**3**	**C6G**	2.8	3.2	1.4	2	80.05	3.70
7	**1**	**A1R**	3.9	2	1	2	80.07	3.71
7	**1**	**A2R**	3.7	2.4	1.4	2	80.03	3.74
7	**1**	**A3R**	1.3	1.2	0.2	1	80.25	2.95
7	**1**	**A4R**	7.6	6.6	0.6	2	79.30	4.41
7	**1**	**A5R**	3.1	2.2	0.4	2	80.16	3.60
7	**1**	**A6R**	10.1	4.1	3.7	3	79.32	5.08

APPENDIX A.5: MEASUREMENTS OF SUB-CUTANEOUS FAT, FAT CODE AND PERCENT OF MEAT YIELD FOR CARCASSES OF FEEDLOT CATTLE FED A SUPPLEMENT OF SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 1 (CONTINUED)

PEN	VACC	TAG	SFAT1	SFAT2	SFAT3	FCODE	PMYIELD	SCUTFAT
8	**2**	**B2R**	4.5	4.1	0.8	2	79.83	3.91
8	**2**	**B3R**	3.5	6	2.2	3	79.87	4.38
8	**2**	**B4R**	3.9	2.8	0.9	2	80.00	3.76
8	**2**	**B5R**	2	2.4	1.4	2	80.20	3.56
8	**2**	**B6R**	4.7	2.4	0.9	2	79.96	3.82
9	**3**	**C1R**	6.2	4.2	1.6	2	79.61	4.16
9	**3**	**C2R**	3.7	2.3	1.3	2	80.05	3.73
9	**3**	**C4R**	1.8	0.6	1.4	2	80.38	3.41
9	**3**	**C5R**	4.1	4.2	0.8	2	79.86	3.87
9	**3**	**C6R**	3.3	3.3	0.5	2	80.04	3.70
10	**1**	**A1B**	8.8	4.8	3.2	2	79.22	4.59
10	**1**	**A2B**	5.2	4.1	1.7	2	79.71	4.05
10	**1**	**A4B**	2	1	0.8	2	80.36	3.42
10	**1**	**A5B**	3.3	3.3	1.6	2	79.98	3.77
10	**1**	**A6B**	4	3.4	0.3	1	79.77	3.41
11	**2**	**B1B**	2.2	1.3	1.3	2	80.29	3.50
11	**2**	**B2B**	2.8	2.3	1.3	2	80.13	3.63
11	**2**	**B3B**	3.5	2.2	0.7	2	80.11	3.66
11	**2**	**B4B**	3.4	2.7	0.5	2	80.08	3.67
11	**2**	**B5B**	6	4.6	0.7	2	79.64	4.10
11	**2**	**B6B**	0.8	0.7	2	2	80.44	3.35
12	**3**	**C1B**	2.7	3.3	0.9	2	80.07	3.66
12	**3**	**C2B**	7.4	1.9	2.4	3	79.86	4.55
12	**3**	**C3B**	2.2	4	3.1	2	79.94	3.80
12	**3**	**C4B**	1.7	1.8	1.2	2	80.29	3.47
12	**3**	**C5B**	6.7	7.6	1.4	2	79.26	4.43
12	**3**	**C6B**	9.2	5.1	1.1	2	79.26	4.52

APPENDIX A.6: CONCENTRATIONS (ppm) ON WET BASIS OF MINERAL ELEMENTS IN THE LIVER TISSUES OF FEEDLOT CATTLE FED SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 1

TTT	PEN	VACC	TAG	CA	P	MG	CO	CU	FE	MN	SE	ZN	CR
1	**1**	**1**	**A1Y**	97.2	6541	252.1	1.5	69.8	94.9	5.2	3.3	71.8	1.9
1	**1**	**1**	**A2Y**	23.1	3095	110.8	1.65	43.2	89.6	3.7	0.6	38.8	1.41
1	**1**	**1**	**A3Y**	89.5	4541	126.1	1.7	71.3	100	3.9	1.5	43.9	2.75
1	**1**	**1**	**A4Y**	61	3701	77.3	1.52	69.3	76.1	3	2.7	43.8	1.01
1	**1**	**1**	**A5Y**	60.7	2965	90.6	1.45	67	72.7	3.2	3	41	1.9
1	**1**	**1**	**A6Y**	64.9	5353	210	1.4	120.8	85.8	5.5	2.5	58.3	2
1	**2**	**2**	**B1Y**	11.3	2299	135.9	1.12	90	77.2	5.7	0.8	40.6	2.8
1	**2**	**2**	**B2Y**	149	2785	193.7	0.95	91.6	71	5.1	0.8	52.5	0.6
1	**2**	**2**	**B3Y**	49.6	3975	134.4	1.15	49.9	68.3	3.6	0.7	37	2.3
1	**2**	**2**	**B4Y**	41.1	2561	110	1.1	56.9	71	3.7	0.9	34	2.41
1	**2**	**2**	**B5Y**	12.5	2160	98.6	1.25	57.1	65.4	3.7	0.9	34.7	2.04
1	**2**	**2**	**B6Y**	63.8	2758	158	0.81	93.6	89.2	4.4	0.3	47.6	1.71
1	**3**	**3**	**C1Y**	99.9	5076	154.1	0.95	102.9	91	3.8	3.7	46.3	1.71
1	**3**	**3**	**C2Y**	178	3159	167.3	0.9	71.1	95.7	4.1	0.8	91.3	0.9
1	**3**	**3**	**C3Y**	155	3249	201.25	11.9	83.8	74.4	5.2	0.6	48	1.32
1	**3**	**3**	**C4Y**	128	3975	150	0.8	128.9	104	5.4	3.9	83.9	1.54
1	**3**	**3**	**C5Y**	87.8	3098	147.3	1.1	232.4	68.6	4.8	3.6	41.7	1.72
1	**3**	**3**	**C6Y**	159	3159	174.2	0.95	100.7	78	4.6	0.7	47	0.55
2	**4**	**1**	**A1G**	142	3160	260	8.45	109.7	55.8	4.6	0.9	37.9	1.48
2	**4**	**1**	**A2G**	135	2804	196.25	9.48	78.8	151	8.3	0.4	93.7	1.25
2	**4**	**1**	**A4G**	165	1317	321.25	9.98	18.7	72	4.8	1.1	38	0.9
2	**4**	**1**	**A5G**	144	3327	158.75	4.62	58.7	58.1	4.5	0.9	36	1.08
2	**4**	**1**	**A6G**	156	1183	208.75	6.26	65.6	58	4.7	0.5	41.1	1.65
2	**5**	**2**	**B1G**	165	1720	191.25	5.6	41.8	45.6	4.7	1.1	44	1.35
2	**5**	**2**	**B2G**	164	3475	201.25	7.54	66	51.4	6	2.2	42.1	1.44
2	**5**	**2**	**B3G**	176	3860	186.25	9.82	41.5	59.6	5.3	1.1	40.6	1
2	**5**	**2**	**B4G**	167	4168	193.12	8.1	39.4	50.5	5.4	3.2	39.1	1
2	**5**	**2**	**B5G**	163	4376	215.62	8.75	60.4	47.2	5.4	1.7	38.7	0.8
2	**5**	**2**	**B6G**	175	1441	232.5	8.75	42.5	61.3	5.2	2.3	40.9	0.8
2	**6**	**3**	**C1G**	132	3627	235	7.98	144.8	80.2	6.4	1.7	72.6	1.61
2	**6**	**3**	**C2G**	133	4150	255	9.81	81.5	133	6.9	1.2	45.3	1.55
2	**6**	**3**	**C3G**	140	3999	196.25	9.18	83.7	123	6.2	1.6	67.2	1.35
2	**6**	**3**	**C4G**	133	3194	303.12	9.46	122.8	158	7.1	2	71.5	1.75
2	**6**	**3**	**C5G**	159	3837	211.25	9.86	40.1	59.7	5.4	2.1	42.7	1.81
2	**6**	**3**	**C6G**	158	2669	181.9	9.48	45	59.3	5.6	1.9	35.5	1.4
3	**7**	**1**	**A1R**	70	3590	95	0.5	69.3	84.1	3.5	1.1	41.7	2.1
3	**7**	**1**	**A2R**	29	2356	80	0.7	84.9	57.1	3.7	1.2	31.5	3.1
3	**7**	**1**	**A3R**	67	2389	80	0.7	46.35	71.3	3.4	0.8	29	2.5
3	**7**	**1**	**A4R**	93	2742	80	0.4	80.7	85.4	8	1.7	47.1	2.4
3	**7**	**1**	**A5R**	71	2837	115	0.5	69.3	75.8	5.5	1	57.2	2.3
3	**7**	**1**	**A6R**	50.5	2386	95	0.6	96.3	68	4.2	0.9	30.9	1.5
3	**8**	**2**	**B1R**	35.5	2266	87.5	0.9	95.2	91.7	3.8	1.1	32.1	1.7
3	**8**	**2**	**B2R**	36.3	1883	85.9	1.25	36.9	75	3.5	1	36	3.8

APPENDIX A.6: CONCENTRATIONS (ppm) ON WET BASIS OF MINERAL ELEMENTS IN THE LIVER TISSUES OF FEEDLOT CATTLE FED SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 1 (CONTINUED)

TTT	PEN	VACC	TAG	CA	P	MG	CO	CU	FE	MN	SE	ZN	CR
3	**8**	**2**	**B3R**	36.3	2280	103.1	1.71	44	70.2	3.4	1.5	34.8	2.3
3	**8**	**2**	**B4R**	30	2068	115	125	81.4	78.5	3.6	1.6	41.6	2
3	**8**	**2**	**B5R**	25	4384	92.2	1.48	67.1	56.1	3.3	1.2	45.1	4.92
3	**8**	**2**	**B6R**	58	3579	107.5	1.55	70	124	3.7	2	36.8	2.54
3	**9**	**3**	**C1R**	35	4119	131	1.22	86.2	91.6	4.5	2.3	49.3	3.81
3	**9**	**3**	**C2R**	36.3	4253	182	1.2	114.7	123	6	1.8	53.6	3.1
3	**9**	**3**	**C4R**	69.4	2861	125	1.21	113.6	67.2	4.1	1.1	48	3.34
3	**9**	**3**	**C5R**	36.3	4253	182	1.2	114.7	123	6	1.8	53.6	3.25
3	**9**	**3**	**C6R**	58	3579	107.5	1.55	70	124	3.7	2	36.8	2.32
4	**10**	**1**	**A1B**	58	3457	137.5	1.2	138	147	6.3	1.8	37.2	2.7
4	**10**	**1**	**A2B**	27.5	2734	87.5	1.2	106.9	92.8	5.2	0.9	42.4	1.9
4	**10**	**1**	**A3B**	40	2310	115	0.9	54.8	72.3	5.4	1.5	37.8	2.1
4	**10**	**1**	**A4B**	40	3793	120	1	87.4	102	4.8	1	49	2.5
4	**10**	**1**	**A5B**	38.8	2255	95	0.9	124.9	67	5.3	1.9	32	1.4
4	**10**	**1**	**A6B**	34	2215	90	0.9	82.8	89.6	4.4	1.3	34	1.1
4	**11**	**2**	**B1B**	33	3299	90	1	78.1	85.8	6.4	2.3	68.5	1.4
4	**11**	**2**	**B2B**	40	3383	100	1.1	130.7	113	3.6	1.6	59	1.7
4	**11**	**2**	**B3B**	55	3832	112.5	1.2	144.1	84.3	6.5	1.9	42.3	1.6
4	**11**	**2**	**B4B**	35.5	2666	97.5	1.1	75.3	65.9	5	1.4	28.9	1.3
4	**11**	**2**	**B5B**	44	2188	55	0.9	66.9	56.9	5	1.5	38.2	0.9
4	**11**	**2**	**B6B**	59	2481	60	0.8	67	51.6	2	1.4	28.3	0.9
4	**12**	**3**	**C1B**	57.5	2103	127.5	0.7	86.4	83.4	7	2.1	73.4	2.1
4	**12**	**3**	**C2B**	77.5	4222	150	0.7	83.4	75.9	5.7	1.7	46.5	1.3
4	**12**	**3**	**C3B**	37.5	2636	112.5	0.7	96.5	71.5	7.1	1.6	41.2	3.2
4	**12**	**3**	**C4B**	35	2834	90	0.9	130.5	49	6	2	38.1	1.6
4	**12**	**3**	**C5B**	17.5	3038	80	0.9	71.8	77.2	6.4	2.5	82.9	1.8
4	**12**	**3**	**C6B**	48	3133	85	0.7	93.5	84.4	4.2	2	29.2	1.6

APPENDIX B.1: MEAT COLOUR COMPONENTS OF FEEDLOT CATTLE FED SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 2

DAY	TTT	TAG	SLAUG	METM	MYOGL	OXYMYOG
0	**1**	**A4Y**	**40**	12	14	74
0	**1**	**B2Y**	**48**	0	0	100
0	**1**	**B4Y**	**45**	0	20	80
0	**1**	**B5Y**	**44**	0	33	77
0	**1**	**C4Y**	**53**	0	36	64
0	**2**	**A2G**	**56**	11	17	72
0	**2**	**A6G**	**59**	6	34	60
0	**2**	**B2G**	**66**	7	49	44
0	**2**	**B5G**	**64**	10	19	71
0	**2**	**C3G**	**70**	15	16	69
0	**3**	**A2R**	**4**	4	36	60
0	**3**	**A4R**	**1**	0	75	25
0	**3**	**B1R**	**25**	0	0	100
0	**3**	**B3R**	**29**	6	34	60
0	**3**	**C1R**	**36**	5	33	62
0	**3**	**C3R**	**31**	0	30	70
0	**3**	**C6R**	**33**	4	28	68
0	**4**	**A2B**	**7**	2	33	65
0	**4**	**A3B**	**10**	4	36	61
0	**4**	**B2B**	**17**	7	25	69
0	**4**	**B5B**	**14**	0	16	84
0	**4**	**C2B**	**19**	1	57	41
0	**4**	**C5B**	**23**	10	22	69
7	**1**	**A4Y**	**40**	8	35	57
7	**1**	**A4Y**	**40**	22	24	54
7	**1**	**B2Y**	**48**	0	0	100
7	**1**	**B2Y**	**48**	9	55	36
7	**1**	**B4Y**	**45**	2	39	59
7	**1**	**B4Y**	**45**	0	50	50
7	**1**	**B5Y**	**44**	0	21	79
7	**1**	**B5Y**	**44**	1	16	83
7	**1**	**C4Y**	**53**	10	7	83
7	**1**	**C4Y**	**53**	10	5	86
7	**2**	**A2G**	**56**	16	57	28
7	**2**	**A2G**	**56**	25	52	24
7	**2**	**A6G**	**59**	0	50	50
7	**2**	**A6G**	**59**	0	66	34
7	**2**	**B2G**	**66**	0	75	25
7	**2**	**B2G**	**66**	0	50	50
7	**2**	**B5G**	**64**	6	17	77
7	**2**	**B5G**	**64**	4	20	76
7	**2**	**C3G**	**70**	7	18	75
7	**2**	**C3G**	**70**	7	13	81
7	**3**	**A2R**	**4**	3	25	72

APPENDIX B.1: MEAT COLOUR COMPONENTS OF FEEDLOT CATTLE FED SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 2 (CONTINUED)

DAY	TTT	TAG	SLAUG	METM	MYOGL	OXYMYOG
7	**3**	**A2R**	**4**	8	14	78
7	**3**	**A4R**	**1**	2	19	79
7	**3**	**A4R**	**1**	2	17	81
7	**3**	**B1R**	**25**	8	19	73
7	**3**	**B1R**	**25**	9	21	70
7	**3**	**B3R**	**29**	6	5	89
7	**3**	**B3R**	**29**	9	22	69
7	**3**	**C1R**	**36**	0	50	50
7	**3**	**C1R**	**36**	6	11	82
7	**3**	**C3R**	**31**	1	15	83
7	**3**	**C3R**	**31**	7	18	75
7	**3**	**C6R**	**33**	2	21	77
7	**3**	**C6R**	**33**	3	23	74
7	**4**	**A2B**	**7**	1	19	79
7	**4**	**A2B**	**7**	0	29	71
7	**4**	**A3B**	**10**	11	7	83
7	**4**	**A3B**	**10**	8	16	76
7	**4**	**B2B**	**17**	11	0	89
7	**4**	**B2B**	**17**	13	6	82
7	**4**	**B5B**	**14**	4	7	89
7	**4**	**B5B**	**14**	9	13	78
7	**4**	**C2B**	**19**	2	10	88
7	**4**	**C2B**	**19**	0	11	89
7	**4**	**C2B**	**19**	0	22	78
7	**4**	**C2B**	**19**	6	11	83
7	**4**	**C5B**	**23**	2	11	87
7	**4**	**C5B**	**23**	5	16	79
21	**1**	**A4Y**	**40**	2	55	43
21	**1**	**A4Y**	**40**	0	17	83
21	**1**	**B2Y**	**48**	2	25	73
21	**1**	**B2Y**	**48**	0	28	72
21	**1**	**B4Y**	**45**	0	38	62
21	**1**	**B4Y**	**45**	10	32	59
21	**1**	**B5Y**	**44**	2	19	80
21	**1**	**B5Y**	**44**	0	25	75
21	**1**	**C4Y**	**53**	11	11	78
21	**1**	**C4Y**	**53**	11	20	68
21	**2**	**A2G**	**56**	12	8	80
21	**2**	**A2G**	**56**	15	14	71
21	**2**	**A6G**	**59**	0	43	57
21	**2**	**A6G**	**59**	4	41	55
21	**2**	**B2G**	**66**	4	38	58
21	**2**	**B2G**	**66**	0	49	51
21	**2**	**B5G**	**64**	5	21	74

APPENDIX B.1: MEAT COLOUR COMPONENTS OF FEEDLOT CATTLE FED SODIUM SELENITE AND ORGANIC CHROMIUM – EXPERIMENT 2 (CONTINUED)

DAY	TTT	TAG	SLAUG	METM	MYOGL	OXYMYOG
21	**2**	**B5G**	**64**	9	15	76
21	**2**	**C3G**	**70**	2	17	81
21	**2**	**C3G**	**70**	3	42	55
21	**3**	**A2R**	**4**	1	27	72
21	**3**	**A2R**	**4**	11	8	81
21	**3**	**A4R**	**1**	0	32	68
21	**3**	**A4R**	**1**	0	16	84
21	**3**	**B1R**	**25**	0	18	82
21	**3**	**B1R**	**25**	0	21	80
21	**3**	**B3R**	**29**	1	19	81
21	**3**	**B3R**	**29**	0	23	77
21	**3**	**C1R**	**36**	0	38	72
21	**3**	**C1R**	**36**	0	33	67
21	**3**	**C3R**	**31**	0	28	72
21	**3**	**C3R**	**31**	0	41	65
21	**3**	**C6R**	**33**	4	9	86
21	**3**	**C6R**	**33**	9	13	78
21	**4**	**A2B**	**7**	5	11	83
21	**4**	**A2B**	**7**	0	30	70
21	**4**	**A3B**	**10**	13	24	63
21	**4**	**A3B**	**10**	7	15	77
21	**4**	**B2B**	**17**	4	18	78
21	**4**	**B2B**	**17**	13	20	67
21	**4**	**B5B**	**14**	21	22	57
21	**4**	**B5B**	**14**	26	34	40
21	**4**	**C2B**	**19**	0	41	59
21	**4**	**C2B**	**19**	2	5	93
21	**4**	**C2B**	**19**	50	0	50
21	**4**	**C2B**	**19**	0	18	82
21	**4**	**C5B**	**23**	0	30	70
21	**4**	**C5B**	**23**	0	21	79

APPENDIX C.1: BLOOD CORTISOL (nmol) AND GLUCOSE (mmol) OF FEEDLOT CATTLE FED SODIUM SELENITE AND DIFFERENT CHEMICAL FORMS OF CHROMIUM

TTT	PEN	NO	TAG	CORT1	GLUC1	CORT14	GLUC14	ADG14	EFCR 14	CORT42	GLUC42	ADG42	EFCR 42
1	**3**	**1**	**1261**	111.36	4.1	72.5	4.9	1.786	4.985	63.2	4.5	0.952	8.201
1	**3**	**2**	**1295**	109.15	4.5	170	4.8	2.500	3.174	50.44	4.7	1.429	6.218
1	**3**	**3**	**0**	101.63	4.6	117.91	4.3	1.071	7.669	62.11	4.7	0.952	8.201
1	**3**	**4**	**1024**	63.4	3.7	116.96	4.7	1.071	7.669	125.15	4	0.952	8.201
1	**3**	**5**	**747**	122.63	4.1	23.6	4.6	3.214	2.235	101.04	4.5	1.190	7.161
1	**3**	**6**	**714**	89.96	5.5	89.59	4.8	1.786	4.985	26.69	3.9	0.952	8.201
1	**3**	**7**	**1032**	63.38	4.4	82.4	5.2	2.500	3.174	74.6	3.7	0.952	8.201
1	**3**	**8**	**912**	115.05	4.2	108.6	4.7	1.786	4.985	186.86	4.4	0.714	9.338
1	**3**	**9**	**720**	122.1	4.5	112.48	5.1	1.786	4.985	117.64	4.2	1.190	7.161
1	**3**	**10**	**603**	48.03	3.7	82.88	4.7	1.786	4.985	34.47	4.2	0.476	10.571
1	**3**	**11**	**600**	192.2	5.3	177.27	4.1	1.071	7.669	96.65	3.6	0.595	9.942
1	**3**	**12**	**632**	122.81	4.6	172.21	4.9	1.429	6.218	112.68	4	0.714	9.338
2	**5**	**1**	**1316**	147.48	4.5	81.5	4.6	2.500	3.174	141.14	4.3	1.071	7.669
2	**5**	**2**	**1283**	68.81	3.9	54.69	4.4	2.500	3.174	50.14	3.8	1.071	7.669
2	**5**	**3**	**568**	88.39	4	32.54	4	1.786	4.985	10.56	3.7	0.952	8.201
2	**5**	**4**	**595**	135.88	5.7	39.56	4.1	1.429	6.218	51.32	4.1	0.714	9.338
2	**5**	**5**	**722**	139.14	4.2	75.61	4.6	2.500	3.174	42.86	4.9	1.548	5.783
2	**5**	**6**	**546**	84.94	4.4	88.33	4.9	1.071	7.669	183.54	4.1	0.714	9.338
2	**5**	**7**	**707**	92.65	5	48.93	4.1	1.786	4.985	134.89	4.4	0.357	11.225
2	**5**	**8**	**529**	87.73	4.3	45.8	4.7	1.786	4.985	28.8	4.4	0.714	9.338
2	**5**	**9**	**872**	89.69	4	86.81	5.2	2.143	3.970	50.24	4.8	1.667	5.372
2	**5**	**10**	**839**	92.2	4	167.66	4.8	2.143	3.970	147.54	4.7	0.714	9.338
2	**5**	**11**	**588**	104.1	5.2	116.61	5.3	1.786	4.985	111.12	4.3	0.714	9.338
2	**5**	**12**	**868**	98.94	4.9	77.12	5	1.071	7.669	89.54	4.4	0.714	9.338
3	**4**	**1**	**662**	74.6	4.1	20.37	3.7	1.786	4.985	108.44	3.5	0.595	9.942
3	**4**	**2**	**573**	143.17	4	100.81	4.5	1.429	6.218	56.89	4	0.952	8.201
3	**4**	**3**	**535**	91.76	4.4	145.92	4.1	2.143	3.970	121.82	4	0.595	9.942
3	**4**	**4**	**719**	75.84	4.9	102.34	5	1.786	4.985	129.44	4.6	0.833	8.757
3	**4**	**5**	**652**	69.04	4.4	23.76	5	1.786	4.985	121.87	4.2	1.429	6.218
3	**4**	**6**	**611**	116.82	4.8	54.06	4.4	1.071	7.669	35.01	4.2	0.952	8.201
3	**4**	**7**	**1027**	66.58	4.6	76.98	5.5	1.786	4.985	138.35	4.3	1.429	6.218
3	**4**	**8**	**620**	158.48	5.2	73.09	5	2.143	3.970	103.69	4.1	1.429	6.218
3	**4**	**9**	**549**	124.19	3.7	92.5	4.5	1.071	7.669	120.3	4.4	0.952	8.201
3	**4**	**10**	**741**	63.29	2.8	115.32	4.7	2.143	3.970	128.22	4.1	1.310	6.677
3	**4**	**11**	**1274**	54.51	4.4	98.61	5.4	0.714	9.338	82.63	4.6	0.833	8.757
3	**4**	**12**	**628**	140.83	4.5	54.53	4.8	0.714	9.338	28.89	4.2	0.714	9.338
4	**6**	**1**	**756**	75.03	4.4	93.31	5.3	2.143	3.970	145.99	4.8	0.952	8.201
4	**6**	**2**	**763**	101.83	4.4	76.89	3.7	1.429	6.218	49.57	3.8	1.310	6.677
4	**6**	**3**	**867**	102.5	6.3	120.85	4.7	2.143	3.970	34.07	4.5	0.714	9.338
4	**6**	**4**	**764**	106.1	4.6	112.4	4.4	1.786	4.985	114.2	4.3	0.595	9.942
4	**6**	**5**	**635**	78.18	3.9	145.11	5.1	-0.357	15.653	62.64	5.1	0.357	11.225
4	**6**	**7**	**718**	66.49	4.1	89.43	4.1	1.429	6.218	92.69	4.7	0.952	8.201
4	**6**	**8**	**555**	81.61	5.2	81.86	4.9	0.714	9.338	165.04	4.5	0.833	8.757

APPENDIX C.1: BLOOD CORTISOL (nmol) AND GLUCOSE (mmol) OF FEEDLOT CATTLE FED SODIUM SELENITE AND DIFFERENT CHEMICAL FORMS OF CHROMIUM (CONTINUED)

TTT	PEN	NO	TAG	CORT1	GLUC1	CORT14	GLUC14	ADG14	EFCR 14	CORT42	GLUC42	ADG42	EFCR 42
4	**6**	**9**	**1020**	50.47	4.2	74.04	4.7	1.071	7.669	120.31	4.7	0.952	8.201
4	**6**	**10**	**1028**	75.52	7	115.57	5.5	2.500	3.174	98.94	4.5	1.429	6.218
4	**6**	**11**	**1298**	79.36	3.8	64.8	4.2	1.786	4.985	72.24	3.9	0.595	9.942
4	**6**	**12**	**842**	81.44	5.1	64.89	4.9	1.071	7.669	77.68	4.8	0.595	9.942
5	**1**	**1**	**669**	59.73	4.1	33.19	4.9	1.786	4.985	66.52	4.7	1.071	7.669
5	**1**	**2**	**866**	94.45	4	88.79	4.6	2.857	2.595	75.84	4.2	1.310	6.677
5	**1**	**3**	**6707**	76.59	5.2	131.07	5.1	3.214	2.235	127.8	4.9	1.548	5.783
5	**1**	**4**	**1031**	123.9	0.6	89.56	5.1	2.500	3.174	51.35	4.1	1.310	6.677
5	**1**	**5**	**710**	108.6	5.9	170.1	4.6	1.071	7.669	50.44	4.8	0.714	9.338
5	**1**	**6**	**821**	93.83	5.3	135.25	4.5	1.429	6.218	168.39	4.5	1.071	7.669
5	**1**	**7**	**1317**	86.52	4.9	110.35	5.1	2.500	3.174	42.47	4.3	1.071	7.669
5	**1**	**8**	**1012**	69.99	4.5	95.14	4.7	2.500	3.174	28	4.7	1.190	7.161
5	**1**	**9**	**1034**	67.57	4.5	99.29	5	2.143	3.970	28	3.9	1.429	6.218
5	**1**	**10**	**524**	146.73	4.9	123.56	5.7	1.429	6.218	263.02	5.3	0.714	9.338
5	**1**	**11**	**636**	93.2	4.5	89.33	5.1	1.786	4.985	213.9	4.6	1.071	7.669
5	**1**	**12**	**735**	80.29	5	57.45	6	2.143	3.970	184.45	4.6	1.310	6.677
6	**2**	**1**	**527**	94.5	4.2	84.6	5	1.429	6.218	61.91	4.2	0.952	8.201
6	**2**	**3**	**526**	140.18	3.9	141.86	4.8	0.714	9.338	68.76	4.2	0.595	9.942
6	**2**	**4**	**670**	83.67	4.1	134.51	5	-0.357	15.653	34.33	5.3	0.238	11.902
6	**2**	**5**	**1022**	43.65	3.7	58.55	4.9	1.071	7.669	86.92	3.8	0.476	10.571
6	**2**	**6**	**566**	124.7	4	138.15	4.2	2.500	3.174	49.81	4	0.952	8.201
6	**2**	**7**	**748**	38.05	5.1	95.72	4.9	2.143	3.970	28	4.8	0.714	9.338
6	**2**	**8**	**586**	85.32	3.9	128.09	4.7	1.786	4.985	28	4.7	0.952	8.201
6	**2**	**9**	**561**	63.44	4.2	57.18	5.1	1.429	6.218	83.76	3.9	0.952	8.201
6	**2**	**10**	**1258**	104.45	4.6	76.92	5.9	2.500	3.174	152.63	5	1.429	6.218
6	**2**	**11**	**1046**	45.25	4.4	69.17	5.5	2.143	3.970	157.7	4.9	1.071	7.669
6	**2**	**12**	**547**	88.6	4.7	129.16	5.6	2.857	2.595	27.48	4.3	1.190	7.161

APPENDIX C.2: LIVE WEIGHT, AVERAGE DAILY GAIN AND PREDICTED FEED CONVERSION RATIO OF FEEDLOT CATTLE FED SODIUM SELENITE AND DIFFERENT CHEMICAL FORMS OF CHROMIUM – EXPERIMENT 3

TTT	PEN	TAG	D-4	D 0	SHR	D 04	ADG14	PFCR	D28	ADG28	PFCR	D42	ADG42	PFCR	D56	ADG56	PFCR
1	3	912	220	210	10	235	1.786	4.985	240	1.071	7.669	250	0.952	8.201	250	0.714	9.338
1	3	1295	210	200	10	235	2.500	3.174	250	1.786	4.985	260	1.429	6.218	290	1.607	5.574
1	3	1032	210	200	10	215	1.071	7.669	240	1.429	6.218	240	0.952	8.201	260	1.071	7.669
1	3	720	210	180	30	195	1.071	7.669	205	0.893	8.476	220	0.952	8.201	250	1.250	6.916
1	3	714	200	180	20	225	3.214	2.235	230	1.786	4.985	230	1.190	7.161	270	1.607	5.574
1	3	1024	195	190	5	215	1.786	4.985	220	1.071	7.669	230	0.952	8.201	260	1.250	6.916
1	3	632	195	180	15	215	2.500	3.174	210	1.071	7.669	220	0.952	8.201	260	1.429	6.218
1	3	747	190	190	0	215	1.786	4.985	215	0.893	8.476	220	0.714	9.338	250	1.071	7.669
1	3	1261	185	185	0	210	1.786	4.985	225	1.429	6.218	235	1.190	7.161	260	1.339	6.560
1	3	600	190	190	0	215	1.786	4.985	190	0.000	13.330	210	0.476	10.571	240	0.893	8.476
1	3	603	185	175	10	190	1.071	7.669	190	0.536	10.254	200	0.595	9.942	230	0.982	8.065
1	3	O	180	175	5	195	1.429	6.218	200	0.893	8.476	205	0.714	9.338	230	0.982	8.065
2	5	707	215	195	20	230	2.500	3.174	225	1.071	7.669	240	1.071	7.669	260	1.161	7.285
2	5	1283	215	205	10	240	2.500	3.174	235	1.071	7.669	250	1.071	7.669	270	1.161	7.285
2	5	588	210	210	0	235	1.786	4.985	235	0.893	8.476	250	0.952	8.201	270	1.071	7.669
2	5	546	205	200	5	220	1.429	6.218	230	1.071	7.669	230	0.714	9.338	260	1.071	7.669
2	5	839	200	185	15	220	2.500	3.174	225	1.429	6.218	250	1.548	5.783	270	1.518	5.889
2	5	872	200	190	10	205	1.071	7.669	210	0.714	9.338	220	0.714	9.338	245	0.982	8.065
2	5	568	195	195	0	220	1.786	4.985	210	0.536	10.254	210	0.357	11.225	240	0.804	8.900
2	5	1316	195	190	5	215	1.786	4.985	225	1.250	6.916	220	0.714	9.338	260	1.250	6.916
2	5	529	185	180	5	210	2.143	3.970	220	1.429	6.218	250	1.667	5.372	275	1.696	5.273
2	5	595	180	170	10	200	2.143	3.970	195	0.893	8.476	200	0.714	9.338	225	0.982	8.065
2	5	722	180	170	10	195	1.786	4.985	200	1.071	7.669	200	0.714	9.338	250	1.429	6.218
2	5	868	175	170	5	185	1.071	7.669	185	0.536	10.254	200	0.714	9.338	230	1.071	7.669
3	4	628	215	200	15	225	1.786	4.985	215	0.536	10.254	225	0.595	9.942	250	0.893	8.476
3	4	741	215	200	15	220	1.429	6.218	225	0.893	8.476	240	0.952	8.201	265	1.161	7.285
3	4	549	210	195	15	225	2.143	3.970	220	0.893	8.476	220	0.595	9.942	250	0.982	8.065
3	4	1027	200	200	0	225	1.786	4.985	235	1.250	6.916	235	0.833	8.757	250	0.893	8.476
3	4	1274	200	190	10	215	1.786	4.985	220	1.071	7.669	250	1.429	6.218	265	1.339	6.560
3	4	620	200	190	10	205	1.071	7.669	210	0.714	9.338	230	0.952	8.201	260	1.250	6.916
3	4	611	195	185	10	210	1.786	4.985	230	1.607	5.574	245	1.429	6.218	250	1.161	7.285
3	4	719	195	180	15	210	2.143	3.970	205	0.893	8.476	240	1.429	6.218	260	1.429	6.218
3	4	662	190	190	0	205	1.071	7.669	225	1.250	6.916	230	0.952	8.201	260	1.250	6.916
3	4	652	185	180	5	210	2.143	3.970	210	1.071	7.669	235	1.310	6.677	250	1.250	6.916
3	4	535	180	175	5	185	0.714	9.338	200	0.893	8.476	210	0.833	8.757	250	1.339	6.560
3	4	573	180	180	0	190	0.714	9.338	190	0.357	11.225	210	0.714	9.338	230	0.893	8.476

APPENDIX C.2: LIVE WEIGHT, AVERAGE DAILY GAIN AND PREDICTED FEED CONVERSION OF FEEDLOT CATTLE FED SODIUM SELENITE AND DIFFERENT CHEMICAL FORMS OF CHROMIUM – EXPERIMENT 3 (CONTINUED)

TTT	PEN	D70	ADG 70	PFCR	D84	ADG 84	PFCR	D98	ADG 98	PFCR	D 012	ADG 112	PFCR	D 025	ADG 125	PFCR
1	**3**	**275**	0.929	8.310	295	1.012	7.932	315	1.167	7.260	340	1.250	6.916	365	1.325	6.617
1	**3**	**315**	1.643	5.452	340	1.667	5.372	360	1.778	5.010	370	1.635	5.480	370	1.453	6.127
1	**3**	**285**	1.214	7.062	310	1.310	6.677	330	1.444	6.158	345	1.394	6.348	360	1.368	6.450
1	**3**	**270**	1.286	6.772	295	1.369	6.444	315	1.500	5.954	340	1.538	5.815	355	1.496	5.969
1	**3**	**290**	1.571	5.698	315	1.607	5.574	335	1.722	5.188	345	1.587	5.646	350	1.453	6.127
1	**3**	**280**	1.286	6.772	300	1.310	6.677	330	1.556	5.754	350	1.538	5.815	360	1.453	6.127
1	**3**	**290**	1.571	5.698	320	1.667	5.372	340	1.778	5.010	350	1.635	5.480	360	1.538	5.815
1	**3**	**270**	1.143	7.361	290	1.190	7.161	305	1.278	6.804	315	1.202	7.113	330	1.197	7.135
1	**3**	**285**	1.429	6.218	310	1.488	5.997	330	1.611	5.560	350	1.587	5.646	355	1.453	6.127
1	**3**	**270**	1.143	7.361	295	1.250	6.916	300	1.222	7.029	330	1.346	6.533	350	1.368	6.450
1	**3**	**240**	0.929	8.310	255	0.952	8.201	285	1.222	7.029	290	1.106	7.520	305	1.111	7.497
1	**3**	**240**	0.929	8.310	250	0.893	8.476	280	1.167	7.260	290	1.106	7.520	310	1.154	7.314
2	**5**	**295**	1.429	6.218	330	1.607	5.574	335	1.556	5.754	360	1.587	5.646	380	1.581	5.664
2	**5**	**305**	1.429	6.218	340	1.607	5.574	350	1.611	5.560	375	1.635	5.480	400	1.667	5.372
2	**5**	**300**	1.286	6.772	325	1.369	6.444	330	1.333	6.583	345	1.298	6.723	365	1.325	6.617
2	**5**	**290**	1.286	6.772	315	1.369	6.444	320	1.333	6.583	335	1.298	6.723	355	1.325	6.617
2	**5**	**300**	1.643	5.452	335	1.786	4.985	350	1.833	4.837	355	1.635	5.480	390	1.752	5.092
2	**5**	**275**	1.214	7.062	305	1.369	6.444	310	1.333	6.583	330	1.346	6.533	350	1.368	6.450
2	**5**	**265**	1.000	7.985	290	1.131	7.412	290	1.056	7.738	295	0.962	8.159	320	1.068	7.682
2	**5**	**290**	1.429	6.218	315	1.488	5.997	320	1.444	6.158	330	1.346	6.533	355	1.410	6.287
2	**5**	**310**	1.857	4.765	340	1.905	4.623	350	1.889	4.669	360	1.731	5.160	380	1.709	5.230
2	**5**	**245**	1.071	7.669	265	1.131	7.412	270	1.111	7.497	270	0.962	8.159	285	0.983	8.062
2	**5**	**270**	1.429	6.218	290	1.429	6.218	300	1.444	6.158	325	1.490	5.989	335	1.410	6.287
2	**5**	**255**	1.214	7.062	280	1.310	6.677	280	1.222	7.029	300	1.250	6.916	315	1.239	6.959
3	**4**	**270**	1.000	7.985	290	1.071	7.669	300	1.111	7.497	320	1.154	7.314	335	1.154	7.314
3	**4**	**290**	1.286	6.772	310	1.310	6.677	325	1.389	6.368	340	1.346	6.533	350	1.282	6.787
3	**4**	**270**	1.071	7.669	285	1.071	7.669	300	1.167	7.260	330	1.298	6.723	350	1.325	6.617
3	**4**	**270**	1.000	7.985	295	1.131	7.412	305	1.167	7.260	335	1.298	6.723	365	1.410	6.287
3	**4**	**290**	1.429	6.218	320	1.548	5.783	320	1.444	6.158	350	1.538	5.815	365	1.496	5.969
3	**4**	**285**	1.357	6.490	310	1.429	6.218	330	1.556	5.754	355	1.587	5.646	385	1.667	5.372
3	**4**	**290**	1.500	5.954	325	1.667	5.372	335	1.667	5.372	370	1.779	5.007	380	1.667	5.372
3	**4**	**285**	1.500	5.954	310	1.548	5.783	330	1.667	5.372	360	1.731	5.160	380	1.709	5.230
3	**4**	**260**	1.000	7.985	265	0.893	8.476	245	0.611	9.860	255	0.625	9.789	265	0.641	9.707
3	**4**	**265**	1.214	7.062	280	1.190	7.161	290	1.222	7.029	320	1.346	6.533	335	1.325	6.617
3	**4**	**280**	1.500	5.954	305	1.548	5.783	315	1.556	5.754	340	1.587	5.646	360	1.581	5.664
3	**4**	**250**	1.000	7.985	270	1.071	7.669	335	1.722	5.188	335	1.490	5.989	320	1.197	7.135

APPENDIX C.2: LIVE WEIGHT, AVERAGE DAILY GAIN AND PREDICTED FEED CONVERSION OF FEEDLOT CATTLE FED SODIUM SELENITE AND DIFFERENT CHEMICAL FORMS OF CHROMIUM – EXPERIMENT 3 (CONTINUED)

TTT	PEN	TAG	D-4	D 0	SHR	D 04	ADG 14	PFCR	D28	ADG 28	PFCR	D42	ADG 42	PFCR	D56	ADG 56	PFCR
4	**6**	**842**	215	210	5	240	2.143	3.970	235	0.893	8.476	250	0.952	8.201	275	1.161	7.285
4	**6**	**867**	215	205	10	225	1.429	6.218	240	1.250	6.916	260	1.310	6.677	285	1.429	6.218
4	**6**	**635**	205	195	10	225	2.143	3.970	215	0.714	9.338	225	0.714	9.338	250	0.982	8.065
4	**6**	**763**	205	195	10	220	1.786	4.985	220	0.893	8.476	220	0.595	9.942	260	1.161	7.285
4	**6**	**756**	200	200	0	195	-0.357	15.653	200	0.000	13.330	215	0.357	11.225	250	0.893	8.476
4	**6**	**555**	195	195	0	215	1.429	6.218	210	0.536	10.254	235	0.952	8.201	250	0.982	8.065
4	**6**	**764**	195	175	20	185	0.714	9.338	180	0.179	12.250	210	0.833	8.757	240	1.161	7.285
4	**6**	**1028**	185	190	-5	205	1.071	7.669	215	0.893	8.476	230	0.952	8.201	260	1.250	6.916
4	**6**	**718**	180	170	10	205	2.500	3.174	225	1.964	4.450	230	1.429	6.218	250	1.429	6.218
4	**6**	**1020**	180	170	10	195	1.786	4.985	190	0.714	9.338	195	0.595	9.942	220	0.893	8.476
4	**6**	**1298**	175	180	-5	195	1.071	7.669	200	0.714	9.338	205	0.595	9.942	240	1.071	7.669
5	**1**	**6707**	220	220	0	245	1.786	4.985	230	0.357	11.225	265	1.071	7.669	290	1.250	6.916
5	**1**	**1317**	210	200	10	240	2.857	2.595	225	0.893	8.476	255	1.310	6.677	270	1.250	6.916
5	**1**	**1034**	210	195	15	240	3.214	2.235	240	1.607	5.574	260	1.548	5.783	300	1.875	4.711
5	**1**	**821**	200	190	10	225	2.500	3.174	225	1.250	6.916	245	1.310	6.677	290	1.786	4.985
5	**1**	**524**	200	180	20	195	1.071	7.669	200	0.714	9.338	210	0.714	9.338	240	1.071	7.669
5	**1**	**735**	195	180	15	200	1.429	6.218	200	0.714	9.338	225	1.071	7.669	245	1.161	7.285
5	**1**	**1012**	195	190	5	225	2.500	3.174	205	0.536	10.254	235	1.071	7.669	270	1.429	6.218
5	**1**	**1031**	190	170	20	205	2.500	3.174	205	1.250	6.916	220	1.190	7.161	250	1.429	6.218
5	**1**	**866**	190	165	25	195	2.143	3.970	200	1.250	6.916	225	1.429	6.218	260	1.696	5.273
5	**1**	**669**	185	180	5	200	1.429	6.218	195	0.536	10.254	210	0.714	9.338	250	1.250	6.916
5	**1**	**710**	185	180	5	205	1.786	4.985	200	0.714	9.338	225	1.071	7.669	260	1.429	6.218
5	**1**	**636**	175	165	10	195	2.143	3.970	195	1.071	7.669	220	1.310	6.677	240	1.339	6.560
6	**2**	**586**	220	210	10	230	1.429	6.218	235	0.893	8.476	250	0.952	8.201	270	1.071	7.669
6	**2**	**1258**	210	200	10	210	0.714	9.338	210	0.357	11.225	225	0.595	9.942	260	1.071	7.669
6	**2**	**1046**	200	195	5	190	-0.357	15.653	200	0.179	12.250	205	0.238	11.902	250	0.982	8.065
6	**2**	**561**	200	200	0	215	1.071	7.669	215	0.536	10.254	220	0.476	10.571	260	1.071	7.669
6	**2**	**1022**	200	190	10	225	2.500	3.174	225	1.250	6.916	230	0.952	8.201	250	1.071	7.669
6	**2**	**526**	195	190	5	220	2.143	3.970	215	0.893	8.476	220	0.714	9.338	270	1.429	6.218
6	**2**	**748**	195	180	15	205	1.786	4.985	215	1.250	6.916	220	0.952	8.201	250	1.250	6.916
6	**2**	**670**	190	180	10	200	1.429	6.218	200	0.714	9.338	220	0.952	8.201	250	1.250	6.916
6	**2**	**547**	185	180	5	215	2.500	3.174	220	1.429	6.218	240	1.429	6.218	270	1.607	5.574
6	**2**	**566**	180	175	5	205	2.143	3.970	205	1.071	7.669	220	1.071	7.669	250	1.339	6.560
6	**2**	**527**	180	170	10	210	2.857	2.595	210	1.429	6.218	220	1.190	7.161	250	1.429	6.218

APPENDIX C.2: LIVE WEIGHT, AVERAGE DAILY GAIN AND PREDICTED FEED CONVERSION OF FEEDLOT CATTLE FED SODIUM SELENITE AND DIFFERENT CHEMICAL FORMS OF CHROMIUM – EXPERIMENT 3 (CONTINUED)

TTT	PEN	D70	ADG 70	PFCR	D84	ADG 84	PFCR	D98	ADG 98	PFCR	D 012	ADG 112	PFCR	D 025	ADG 125	PFCR
4	6	295	1.214	7.062	315	1.250	6.916	340	1.444	6.158	380	1.635	5.480	400	1.624	5.516
4	6	300	1.357	6.490	315	1.310	6.677	350	1.611	5.560	350	1.394	6.348	380	1.496	5.969
4	6	270	1.071	7.669	295	1.190	7.161	320	1.389	6.368	340	1.394	6.348	360	1.410	6.287
4	6	285	1.286	6.772	310	1.369	6.444	310	1.278	6.804	330	1.298	6.723	345	1.282	6.787
4	6	275	1.071	7.669	300	1.190	7.161	330	1.444	6.158	340	1.346	6.533	365	1.410	6.287
4	6	290	1.357	6.490	330	1.607	5.574	325	1.444	6.158	340	1.394	6.348	380	1.581	5.664
4	6	265	1.286	6.772	290	1.369	6.444	300	1.389	6.368	335	1.538	5.815	350	1.496	5.969
4	6	280	1.286	6.772	305	1.369	6.444	320	1.444	6.158	335	1.394	6.348	355	1.410	6.287
4	6	275	1.500	5.954	300	1.548	5.783	320	1.667	5.372	335	1.587	5.646	360	1.624	5.516
4	6	250	1.143	7.361	275	1.250	6.916	280	1.222	7.029	305	1.298	6.723	330	1.368	6.450
4	6	250	1.000	7.985	260	0.952	8.201	280	1.111	7.497	300	1.154	7.314	320	1.197	7.135
5	1	310	1.286	6.772	330	1.310	6.677	355	1.500	5.954	375	1.490	5.989	385	1.410	6.287
5	1	305	1.500	5.954	340	1.667	5.372	365	1.833	4.837	390	1.827	4.857	405	1.752	5.092
5	1	315	1.714	5.214	340	1.726	5.175	365	1.889	4.669	375	1.731	5.160	400	1.752	5.092
5	1	315	1.786	4.985	325	1.607	5.574	350	1.778	5.010	370	1.731	5.160	370	1.538	5.815
5	1	255	1.071	7.669	270	1.071	7.669	300	1.333	6.583	300	1.154	7.314	320	1.197	7.135
5	1	270	1.286	6.772	300	1.429	6.218	345	1.833	4.837	350	1.635	5.480	330	1.282	6.787
5	1	305	1.643	5.452	330	1.667	5.372	340	1.667	5.372	370	1.731	5.160	390	1.709	5.230
5	1	280	1.571	5.698	300	1.548	5.783	325	1.722	5.188	345	1.683	5.318	360	1.624	5.516
5	1	280	1.643	5.452	300	1.607	5.574	330	1.833	4.837	350	1.779	5.007	360	1.667	5.372
5	1	265	1.214	7.062	280	1.190	7.161	295	1.278	6.804	310	1.250	6.916	330	1.282	6.787
5	1	295	1.643	5.452	325	1.726	5.175	330	1.667	5.372	350	1.635	5.480	360	1.538	5.815
5	1	270	1.500	5.954	290	1.488	5.997	315	1.667	5.372	340	1.683	5.318	355	1.624	5.516
6	2	295	1.214	7.062	310	1.190	7.161	340	1.444	6.158	355	1.394	6.348	370	1.368	6.450
6	2	285	1.214	7.062	315	1.369	6.444	330	1.444	6.158	355	1.490	5.989	370	1.453	6.127
6	2	280	1.214	7.062	300	1.250	6.916	315	1.333	6.583	340	1.394	6.348	315	1.026	7.870
6	2	285	1.214	7.062	300	1.190	7.161	315	1.278	6.804	340	1.346	6.533	350	1.282	6.787
6	2	285	1.357	6.490	310	1.429	6.218	330	1.556	5.754	350	1.538	5.815	370	1.538	5.815
6	2	300	1.571	5.698	320	1.548	5.783	325	1.500	5.954	365	1.683	5.318	380	1.624	5.516
6	2	280	1.429	6.218	295	1.369	6.444	325	1.611	5.560	325	1.394	6.348	330	1.282	6.787
6	2	270	1.286	6.772	295	1.369	6.444	320	1.556	5.754	340	1.538	5.815	345	1.410	6.287
6	2	300	1.714	5.214	335	1.845	4.801	350	1.889	4.669	360	1.731	5.160	400	1.880	4.695
6	2	275	1.429	6.218	295	1.429	6.218	315	1.556	5.754	340	1.587	5.646	355	1.538	5.815
6	2	285	1.643	5.452	315	1.726	5.175	340	1.889	4.669	375	1.971	4.431	380	1.795	4.956

APPENDIX C.3: CARCASS CHARACTERISTICS OF FEEDLOT CATTLE FED SODIUM SELENITE AND DIFFERENT FORMS OF CHROMIUM – EXPERIMENT 3

TTT	PEN	TAG	WCM	CCM	SHR	SHRP	CF	FC	LW117	DPP	PH1	PH2
1	**3**	**1261**	196.2	191.6	4.6	2.34	3	2	365	53.75	5.66	5.61
1	**3**	**1295**	201.4	197.8	3.6	1.79	3	2	370	54.43	5.9	5.81
1	**3**	**O**	195.2	191.6	3.6	1.84	3	2	360	54.22	5.38	5.72
1	**3**	**1024**	195	190.6	4.4	2.26	4	3	355	54.93	6.1	6.01
1	**3**	**747**	183.6	179.2	4.4	2.40	3	2	350	52.46	5.68	5.8
1	**3**	**714**	198	194.2	3.8	1.92	3	2	360	55.00	5.34	5.69
1	**3**	**1032**	207	203	4	1.93	3	3	360	57.50	5.41	5.8
1	**3**	**912**	177.3	174.2	3.1	1.75	4	2	330	53.73	5.3	5.71
1	**3**	**720**	200.2	196.4	3.8	1.90	3	2	355	56.39	6.03	5.99
1	**3**	**603**	187.8	184	3.8	2.02	3	4	350	53.66	5.3	5.77
1	**3**	**600**	161	156.2	4.8	2.98	3	2	305	52.79	5.4	5.71
1	**3**	**632**	173	168.8	4.2	2.43	3	2	310	55.81	5.96	5.69
2	**5**	**1316**	203	198.2	4.8	2.36	3	2	380	53.42	5.4	5.6
2	**5**	**1283**	217.4	213.4	4	1.84	3	2	400	54.35	5.96	5.81
2	**5**	**568**	191.6	188.4	3.2	1.67	3	2	365	52.49	5.54	5.63
2	**5**	**595**	184.2	181.2	3	1.63	3	2	355	51.89	5.58	5.53
2	**5**	**722**	212.8	208.4	4.4	2.07	4	2	390	54.56	5.85	5.76
2	**5**	**546**	193.6	189.4	4.2	2.17	3	2	350	55.31	5.94	5.81
2	**5**	**707**	167.2	164	3.2	1.91	3	3	320	52.25	5.43	5.55
2	**5**	**529**	192.2	189.2	3	1.56	4	3	355	54.14	5.46	5.62
2	**5**	**872**	207	202.2	4.8	2.32	3	2	380	54.47	6.03	5.9
2	**5**	**839**	153	148.4	4.6	3.01	3	2	285	53.68	5.85	5.58
2	**5**	**588**	181.8	178.4	3.4	1.87	3	2	335	54.27	5.44	5.63
2	**5**	**868**	176	172	4	2.27	3	2	315	55.87	5.1	5.51
3	**4**	**662**	185	181.4	3.6	1.95	3	2	335	55.22	6	5.78
3	**4**	**573**	190.2	187	3.2	1.68	3	2	350	54.34	5.82	5.66
3	**4**	**535**	178.4	175.6	2.8	1.57	3	2	350	50.97	5.3	5.6
3	**4**	**719**	192.8	189	3.8	1.97	3	2	365	52.82	5.9	5.69
3	**4**	**652**	198.2	194.8	3.4	1.72	4	2	365	54.30	5.36	5.57
3	**4**	**611**	207.6	203.4	4.2	2.02	3	2	385	53.92	5.8	5.64
3	**4**	**1027**	210.2	206.8	3.4	1.62	3	2	380	55.32	5.33	5.58
3	**4**	**620**	203.6	199.4	4.2	2.06	3	2	380	53.58	5.33	5.63
3	**4**	**549**	134	131	3	2.24	4	2	265	50.57	5.92	5.83
3	**4**	**741**	177.4	173.2	4.2	2.37	4	2	335	52.96	5.79	5.65
3	**4**	**1274**	205.2	201.2	4	1.95	3	2	360	57.00	5.49	5.59
3	**4**	**628**	166.4	162	4.4	2.64	4	2	320	52.00	5.4	5.62
4	**6**	**756**	219.2	213	6.2	2.83	3	2	400	54.80	5.56	5.63
4	**6**	**763**	213.4	209.4	4	1.87	3	2	380	56.16	5.5	5.59
4	**6**	**867**	204.2	199.4	4.8	2.35	3	2	360	56.72	5.2	5.6
4	**6**	**764**	197.4	193.4	4	2.03	3	2	345	57.22	5.39	5.69
4	**6**	**635**	190.8	187	3.8	1.99	3	2	365	52.27	5.28	5.51
4	**6**	**718**	205.8	201.4	4.4	2.14	3	2	380	54.16	5.65	5.6
4	**6**	**555**	174.6	171	3.6	2.06	3	2	350	49.89	6.02	5.96
4	**6**	**1020**	192.6	187.4	5.2	2.70	3	2	355	54.25	5.5	5.61
4	**6**	**1028**	200.8	195.4	5.4	2.69	3	2	360	55.78	5.4	5.6
4	**6**	**1298**	176.2	172	4.2	2.38	3	2	330	53.39	5.2	5.56

APPENDIX C.3: CARCASS CHARACTERISTICS OF FEEDLOT CATTLE FED SODIUM SELENITE AND DIFFERENT FORMS OF CHROMIUM – EXPERIMENT 3 (CONTINUED)

TTT	PEN	TAG	WCM	CCM	SHR	SHRP	CF	FC	LW117	DPP	PH1	PH2
4	**6**	**842**	175.4	171.2	4.2	2.39	4	2	320	54.81	6.03	5.96
5	**1**	**669**	220.4	216	4.4	2.00	3	2	385	57.25	5.39	5.65
5	**1**	**866**	221.8	217.4	4.4	1.98	3	2	405	54.77	5.57	5.59
5	**1**	**6707**	225.4	221	4.4	1.95	4	2	400	56.35	5.37	5.6
5	**1**	**1031**	210.4	207.4	3	1.43	3	4	370	56.86	5.37	5.37
5	**1**	**710**	178.4	175.6	2.8	1.57	3	2	320	55.75	5.48	5.68
5	**1**	**821**	181.4	177.2	4.2	2.32	4	2	330	54.97	6.3	5.61
5	**1**	**1317**	219	214	5	2.28	3	2	390	56.15	6	5.82
5	**1**	**1012**	201	196.4	4.6	2.29	3	2	360	55.83	6.36	5.94
5	**1**	**1034**	198.8	194.2	4.6	2.31	3	2	360	55.22	5.98	5.91
5	**1**	**524**	190.2	186.2	4	2.10	3	3	330	57.64	6.2	5.98
5	**1**	**636**	200.4	193.4	7	3.49	3	2	360	55.67	5.88	5.8
5	**1**	**735**	200.4	196.2	4.2	2.10	3	2	355	56.45	6.1	5.91
6	**2**	**527**	187.2	181.6	5.6	2.99	3	2	370	50.59	5.93	5.81
6	**2**	**526**	215.4	210.2	5.2	2.41	3	2	370	58.22	6.09	5.89
6	**2**	**670**	180.4	177	3.4	1.88	3	2	315	57.27	5.55	5.63
6	**2**	**1022**	202.4	198.2	4.2	2.08	3	2	350	57.83	5.48	5.71
6	**2**	**566**	189.2	183.5	5.7	3.01	4	2	370	51.14	5.27	5.76
6	**2**	**748**	192.8	190.2	2.6	1.35	3	3	380	50.74	5.41	5.68
6	**2**	**586**	180.5	177.2	3.3	1.83	3	2	330	54.70	5.71	5.7
6	**2**	**561**	191.2	187.2	4	2.09	3	2	345	55.42	5.56	5.76
6	**2**	**1258**	217.6	212.4	5.2	2.39	3	2	400	54.40	6.04	6
6	**2**	**1046**	195.2	191.4	3.8	1.95	4	3	355	54.99	5.3	5.73
6	**2**	**547**	204.4	200.4	4	1.96	3	2	380	53.79	5.89	5.72

APPENDIX C.4: CONCENTRATIONS (PPM) ON WET BASIS OF MINERAL ELEMENTS IN THE LIVER TISSUE OF FEEDLOT CATTLE FED SODIUM SELENIUM AND DIFFERENT CHEMICAL FORMS OF CHROMIUM – EXPERIMENT 3

TTT	PEN	TAG	CA	P	MG	CO	CU	FE	MN	SE	ZN	CR
1	**3**	**912**	60.7	4742	110.6	8.8	73.6	31.8	4.3	2.7	52.5	1.7
1	**3**	**1295**	64.9	2837	108.5	7.5	97.4	52	4.4	0.9	40.6	0.9
1	**3**	**1032**	49.6	3590	33.56	7.2	110	56.2	3.9	2.5	38.8	1.3
1	**3**	**720**	41.1	5356	37.8	3.8	88.5	78.8	3.1	0.7	41.7	1.6
1	**3**	**714**	45.6	2386	79.6	6.5	65.2	32	3.5	0.6	20.5	2.1
1	**3**	**1024**	28.4	2389	63.9	8.2	74.5	42.3	3.9	0.7	28.5	0.8
1	**3**	**632**	148.9	2734	101	5.7	63	39.6	4.1	1.5	19.9	1.8
1	**3**	**747**	25.8	3793	79.56	6.5	64.5	78.8	4.2	1.6	25.2	2.8
1	**3**	**1261**	99.8	3457	63.9	6.7	71.5	37.2	3.7	0.9	37.2	2.4
1	**3**	**600**	97.2	2310	17.3	4.2	89.7	31.9	4.5	2.2	37.5	2.5
1	**3**	**603**	17.9	2561	38.5	3.3	70.3	56.3	3.5	3.6	28	1.3
1	**3**	**O**	26.3	2965	24.1	3.8	63.8	46.2	3.1	2.6	19.9	0.6
2	**5**	**707**	155.6	3975	161.25	7.4	102.5	44.9	3.8	0.8	33.5	1.1
2	**5**	**1283**	131.3	4431	105.5	8.1	91.2	58.8	4.2	2.2	45.2	1.9
2	**5**	**588**	134.7	3098	114.2	6.9	78	36.5	3.9	1.1	48.1	0.9
2	**5**	**546**	125.6	3327	117.8	7.4	74.5	44.8	3.8	1.2	39.1	1.2
2	**5**	**839**	124.5	2804	91.5	4.9	108.7	44.8	3.9	1.7	45.3	1.7
2	**5**	**872**	126.3	1720	105.5	4.9	90	42.3	3.7	2.3	39.1	1.1
2	**5**	**568**	133.8	3475	49.13	6.9	80.5	68.2	4.2	1.7	34.2	0.9
2	**5**	**1316**	133.5	3860	51.9	1.1	80.7	66.4	3.4	3.2	25.2	2.2
2	**5**	**529**	132.4	4168	65.5	4.8	49.9	35.2	4.8	0.3	45.3	1.65
2	**5**	**595**	128.7	4376	23.75	6.4	47.1	46.2	4.2	3.7	38.7	0.9
2	**5**	**722**	135.6	1441	99	4.9	89.7	34.5	3.5	0.8	31.5	2.3
2	**5**	**868**	138.8	3627	87.4	6.4	90.5	34	3.4	0.6	30.9	1.5
3	**4**	**628**	96.4	4168	38.2	1.1	85.9	59.6	3.4	2.2	26.4	1.2
3	**4**	**741**	52.5	4541	16.9	1.9	71.6	66.7	3.5	0.9	23.5	1.1
3	**4**	**549**	43.5	6541	45.2	4.5	37.6	86.4	3.6	1.6	33.3	0.7
3	**4**	**1027**	38.7	3999	44.5	8.7	95	50.3	4.8	2	32.4	2.3
3	**4**	**1274**	22.5	2965	96.6	9.7	97	44.6	3.9	2.1	41.1	1.7
3	**4**	**620**	31.3	3095	93.4	9.5	95	50.1	4.8	1.9	36.5	3.1
3	**4**	**611**	41.3	3975	98.2	11	110	50.2	4.4	1.1	25.4	0.8
3	**4**	**719**	70.5	3837	102.5	12.1	121	60.3	4.9	1.2	29	
3	**4**	**662**	40.6	2561	34.25	8.4	74	50.1	4.5	1.1	47.1	3.1
3	**4**	**652**	41.3	2669	36.56	4.6	42.8	66.5	3.6	1.5	41.6	2.1
3	**4**	**535**	67.3	2758	93.1	4.5	92	59.6	4.8	1.2	45.1	2.4
3	**4**	**573**	15.6	2785	103.4	11.1	90.5	51.4	4.9	1.2	36.8	2.5
4	**6**	**842**	35.6	3159	114.5	4.9	79.3	36.6	4.7	0.9		2.7
4	**6**	**867**	93.8	1317	50.69	7.3	58	56.3	3.6	0.6	36	2.8
4	**6**	**635**	24.5	1720	58.9	4.8	90.5	46.5	4.2	0.5	34.8	1.1
4	**6**	**763**	50.5	3860	132.25	5.6	121	50.9	3.6	0.7	42.1	1.9
4	**6**	**756**	34.4	1441	66.75	5.4	89.6	40.2	4.4	0.5	71.5	2
4	**6**	**555**	41.3	4376	43.2	7.2	79.5	51.4	4.7	0.5	42.7	2.8
4	**6**	**764**	23.8	4168	71	4.8	88.6	46.1	4.2	1	35.5	0.6
4	**6**	**1028**	37.75	3475	94.8	5.4	125.6	56.3	3.6	9	41.7	0.9
4	**6**	**718**	38	2669	90	5.4	89.4	39.8	4.2	2.2	31.5	1.4

APPENDIX C.4: CONCENTRATIONS (PPM) ON WET BASIS OF MINERAL ELEMENTS IN THE LIVER TISSUE OF FEEDLOT CATTLE FED SODIUM SELENIUM AND DIFFERENT CHEMICAL FORMS OF CHROMIUM – EXPERIMENT 3 (CONTINUED)

TTT	PEN	TAG	CA	P	MG	CO	CU	FE	MN	SE	ZN	CR
4	**6**	**1020**	26.3	3837	54.1	4.9	88.5	36.9	4.2	1.2	52.4	1.75
4	**6**	**1298**	67.4	3627	38.6	7.2	58	58.9	4.9	0.8	57.2	1.81
5	**1**	**6707**	52.5	3999	101.6	6.5	72.7	50.8	4.5	1.7	30.9	1.4
5	**1**	**1317**	161.3	3194	112.9	9	90.5	58.8	4.3	1	32.1	2.1
5	**1**	**1034**	26.3	4150	98.8	5.5	89.6	44.6	4.4	0.92	34	2
5	**1**	**821**	52.5	3600	121.5	6.5	90.5	50.8	4.3	1.1	68.5	4.92
5	**1**	**524**	21.3	3098	90.4	5.2	111.2	39.4	4.5	1.2	59	2.54
5	**1**	**735**	48.2	3975	43.1	6.5	71.2	40.8	4.2	2.1	42.3	3.81
5	**1**	**1012**	85.4	3249	50.6	10	137.9	54	3.3	2.3	28.9	1.7
5	**1**	**1031**	52.6	4431	32.6	8.5	88.5	40.2	4.3	2.5	71.8	1.7
5	**1**	**866**	40.6	2804	51.2	9	92.4	52.8	4.8	2.1	34.2	1.4
5	**1**	**669**	35.6	4160	116.7	5.5	89.6	58.8	3.5	1.8	58.3	1.9
5	**1**	**710**	88.8	3327	92	11.1	53.1	40.8	4.9	0.9	40.6	1.4
5	**1**	**636**	48.1	1183	129.18	4.6	71.2	58.4	4.5	1.5	52.5	2.3
6	**2**	**586**	56.5	4211	102.5	5.4	123.6	44.5	4	1.6	37	1.4
6	**2**	**1258**	35.2	2666	66.75	5.4	70.1	37.3	5.2	2.1	34	3.2
6	**2**	**1046**	78.4	2188	65.4	4.5	72.4	67.6	3.8	2.3	42	1.6
6	**2**	**561**	33.8	2481	93.4	4.8	88.5	35.8	3.6	1.8	48	1.8
6	**2**	**1022**	16.3	3832	81.9	10.2	10.2	58.7	4	1.1	53.6	2.1
6	**2**	**526**	44.3	3383	102.9	11	11	54.8	4.2	1.13	34.5	1.2
6	**2**	**748**	77.5	3299	164.4	4.6	4.7	61.5	5.7	1.8	37.2	1.6
6	**2**	**670**	33.6	2861	72	4.5	52.3	67.6	3.2	1.98	42.4	2.5
6	**2**	**547**	52.5	4253	91.3	10.1	92.1	43.3	4.4	1.8	36.5	1.9
6	**2**	**566**	43.1	3579	93.7	9	92.3	41.8	4	1.3	35.4	2.1
6	**2**	**527**	26.5	3038	107	12.6	47.6	45.1	4.4	2.2	36.4	2.7

APPENDIX D.1: BLOOD CORTISOL (nmol) AND GLUCOSE (mmol) CONCENTRATIONS OF FEEDLOT CATTLE FED DIFFERENT COMBINATIONS OF SELENIUM AND CHROMIUM – EXPERIMENT 4

DAY	NO	TAG	WEIGHT	ADG	PFCR	CORT	GLUC
0	**1**	**R1**	270	0	0	55.59	4.8
0	**1**	**R2**	200	0	0	27.9	4.2
0	**1**	**R3**	220	0	0	78.47	5
0	**1**	**R4**	200	0	0	84.82	4.3
0	**1**	**R5**	200	0	0	108.81	4.7
0	**1**	**R6**	230	0	0	152.76	5.8
0	**2**	**Y1**	230	0	0	86.41	5.2
0	**2**	**Y2**	270	0	0	114.53	5.2
0	**2**	**Y3**	225	0	0	44.75	4.2
0	**2**	**Y4**	225	0	0	75.43	4.6
0	**2**	**Y5**	185	0	0	96.61	5.1
0	**2**	**Y6**	260	0	0	153.28	4.8
0	**3**	**B1**	250	0	0	58.23	4.8
0	**3**	**B2**	230	0	0	35.59	3.1
0	**3**	**B3**	230	0	0	28.85	4.5
0	**3**	**B4**	240	0	0	36.38	4.7
0	**3**	**B5**	200	0	0	210.24	7.5
0	**3**	**B6**	190	0	0	70.53	4.8
0	**4**	**O1**	265	0	0	47.06	5
0	**4**	**O2**	230	0	0	115.04	4.4
0	**4**	**O3**	225	0	0	100.47	5.6
0	**4**	**O4**	225	0	0	90.92	4.6
0	**4**	**O5**	190	0	0	48.97	3.9
0	**4**	**O6**	190	0	0	84.61	4.8
0	**5**	**G1**	285	0	0	97.94	4.8
0	**5**	**G2**	230	0	0	60.59	4.4
0	**5**	**G3**	210	0	0	136.14	4.6
0	**5**	**G4**	265	0	0	56.53	4.3
0	**5**	**G5**	190	0	0	151.54	4.8
0	**5**	**G6**	180	0	0	107.94	4.2
0	**6**	**W1**	260	0	0	69.66	4.4
0	**6**	**W2**	250	0	0	75.38	4.7
0	**6**	**W3**	165	0	0	96.44	3.9
0	**6**	**W4**	220	0	0	57.23	5.2
0	**6**	**W5**	190	0	0	78.57	5
0	**6**	**W6**	165	0	0	102.4	4.9
13	**1**	**R1**	300	2.308	3.576	166.14	5.2
13	**1**	**R2**	210	0.769	9.067	73.36	4.5
13	**1**	**R3**	240	1.538	5.815	76.25	4.5
13	**1**	**R4**	225	1.923	4.569	101.53	4.5

APPENDIX D.1: BLOOD CORTISOL (nmol) AND GLUCOSE (mmol) CONCENTRATIONS OF FEEDLOT CATTLE FED DIFFERENT COMBINATIONS OF SELENIUM AND CHROMIUM – EXPERIMENT 4 (CONTINUED)

DAY	NO	TAG	WEIGHT	ADG	PFCR	CORT	GLUC
13	**1**	**R5**	230	2.308	3.576	110.54	4.7
13	**1**	**R6**	260	2.308	3.576	135.69	4.4
13	**2**	**Y1**	250	1.538	5.815	112.47	4.7
13	**2**	**Y2**	300	2.308	3.576	130.5	4.3
13	**2**	**Y3**	255	2.308	3.576	90.48	4
13	**2**	**Y4**	250	1.923	4.569	79.39	3.9
13	**2**	**Y5**	200	1.154	7.314	15.91	4.9
13	**2**	**Y6**	270	0.769	9.067	65.02	4.2
13	**3**	**B1**	260	0.769	9.067	117.75	4.6
13	**3**	**B2**	250	1.538	5.815	116.84	5.5
13	**3**	**B3**	255	1.923	4.569	23.54	3.9
13	**3**	**B4**	255	1.154	7.314	138.86	5
13	**3**	**B5**	210	0.769	9.067	186.27	5.8
13	**3**	**B6**	195	0.385	11.072	68.15	5.2
13	**4**	**O1**	295	2.308	3.576	90.59	4.7
13	**4**	**O2**	250	1.538	5.815	124.64	4.5
13	**4**	**O3**	255	2.308	3.576	99	4.9
13	**4**	**O4**	250	1.923	4.569	85.21	4
13	**4**	**O5**	210	1.538	5.815	86.86	4.4
13	**4**	**O6**	210	1.538	5.815	111.9	4.5
13	**5**	**G1**	300	1.154	7.314	49.89	4.3
13	**5**	**G2**	255	1.923	4.569	64.97	4.1
13	**5**	**G3**	225	1.154	7.314	128.76	4.5
13	**5**	**G4**	280	1.154	7.314	76.08	4
13	**5**	**G5**	200	0.769	9.067	81.22	5
13	**5**	**G6**	190	0.769	9.067	100.85	4.1
13	**6**	**W1**	290	2.308	3.576	48.89	5
13	**6**	**W2**	270	1.538	5.815	55.23	5.2
13	**6**	**W3**	180	1.154	7.314	166.37	4
13	**6**	**W4**	240	1.538	5.815	64.59	5
13	**6**	**W5**	205	1.154	7.314	91.65	4.5
13	**6**	**W6**	180	1.154	7.314	118.22	4.5
47	**1**	**R1**	370	2.128	4.009	102.67	4.7
47	**1**	**R3**	285	1.383	6.391	110.12	4.8
47	**1**	**R4**	280	1.702	5.254	134.7	4.4
47	**1**	**R5**	270	1.489	5.993	77.59	4.6
47	**1**	**R6**	295	1.383	6.391	134.17	5
47	**2**	**Y1**	300	1.489	5.993	93.01	4.8
47	**2**	**Y2**	315	0.957	8.178	216.19	5.2
47	**2**	**Y3**	310	1.809	4.914	28.42	4.3
47	**2**	**Y4**	250	0.532	10.274	145.23	4.7
47	**2**	**Y5**	260	1.596	5.614	97	4.6

APPENDIX D.1: BLOOD CORTISOL (nmol) AND GLUCOSE (mmol) CONCENTRATIONS OF FEEDLOT CATTLE FED DIFFERENT COMBINATIONS OF SELENIUM AND CHROMIUM – EXPERIMENT 4 (CONTINUED)

DAY	NO	TAG	WEIGHT	ADG	PFCR	CORT	GLUC
47	**2**	**Y6**	300	0.851	8.673	131.68	4.5
47	**3**	**B1**	320	1.489	5.993	124.12	4.4
47	**3**	**B2**	320	1.915	4.593	63.3	5.1
47	**3**	**B3**	290	1.277	6.808	87	4.3
47	**3**	**B4**	300	1.277	6.808	19.82	5
47	**3**	**B5**	250	1.064	7.702	154.61	5.4
47	**3**	**B6**	245	1.170	7.246	73.05	4.3
47	**4**	**O1**	360	2.021	4.291	82.89	5.3
47	**4**	**O2**	320	1.915	4.593	121.3	4.4
47	**4**	**O3**	315	1.915	4.593	197.88	5.2
47	**4**	**O4**	285	1.277	6.808	108.47	4.6
47	**4**	**O5**	280	1.915	4.593		5.7
47	**4**	**O6**	240	1.064	7.702	124.98	4.7
47	**5**	**G1**	350	1.383	6.391		4.1
47	**5**	**G2**	310	1.702	5.254	43.88	4
47	**5**	**G3**	280	1.489	5.993	124	5.4
47	**5**	**G4**	320	1.170	7.246	91.53	4.4
47	**5**	**G5**	250	1.277	6.808	133.3	6
47	**5**	**G6**	250	1.489	5.993	92.22	4.2
47	**6**	**W1**	345	1.809	4.914	108.4	5
47	**6**	**W2**	320	1.489	5.993	123.3	4.8
47	**6**	**W3**	245	1.702	5.254	197.87	5.7
47	**6**	**W4**	300	1.702	5.254	133.2	5
47	**6**	**W5**	250	1.277	6.808		4.7
47	**6**	**W6**	240	1.596	5.614	122.88	4.7

APPENDIX D.2: LIVE WEIGHT, AVERAGE DAILY GAIN AND PREDICTED FEED CONVERSION RATIO OF FEEDLOT CATTLE FED DIFFERENT COMBINATIONS OF SELENIUM AND CHROMIUM – EXPERIMENT 4

NO	TAG	D 0	D 13	ADG13	PFCR13	D27	ADG27	PFCR27	D 47	ADG47	PFCR47	D62	ADG62	PFCR62
1	R1	270	300	2.308	3.576	330	2.222	3.774	370	2.128	4.009	385	1.855	4.772
1	R2	200	210	0.769	9.067	240	1.481	6.021						
1	R3	220	240	1.538	5.815	250	1.111	7.497	285	1.383	6.391	300	1.290	6.754
1	R4	200	225	1.923	4.569	250	1.852	4.781	280	1.702	5.254	285	1.371	6.437
1	R5	200	230	2.308	3.576	250	1.852	4.781	270	1.489	5.993	300	1.613	5.554
1	R6	230	260	2.308	3.576	280	1.852	4.781	295	1.383	6.391	300	1.129	7.420
2	Y1	230	250	1.538	5.815	270	1.481	6.021	300	1.489	5.993	335	1.694	5.282
2	Y2	270	300	2.308	3.576	310	1.481	6.021	315	0.957	8.178	345	1.210	7.081
2	Y3	225	255	2.308	3.576	260	1.296	6.730	310	1.809	4.914	340	1.855	4.772
2	Y4	225	250	1.923	4.569	250	0.926	8.322	250	0.532	10.274	275	0.806	8.886
2	Y5	185	200	1.154	7.314	210	0.926	8.322	260	1.596	5.614	285	1.613	5.554
2	Y6	260	270	0.769	9.067	270	0.370	11.151	300	0.851	8.673	325	1.048	7.770
3	B1	250	260	0.769	9.067	280	1.111	7.497	320	1.489	5.993	340	1.452	6.132
3	B2	230	250	1.538	5.815	275	1.667	5.372	320	1.915	4.593	340	1.774	5.021
3	B3	230	255	1.923	4.569	260	1.111	7.497	290	1.277	6.808	310	1.290	6.754
3	B4	240	255	1.154	7.314	270	1.111	7.497	300	1.277	6.808	300	0.968	8.131
3	B5	200	210	0.769	9.067	230	1.111	7.497	250	1.064	7.702	275	1.210	7.081
3	B6	190	195	0.385	11.072	195	0.185	12.211	245	1.170	7.246	275	1.371	6.437
4	O1	265	295	2.308	3.576	300	1.296	6.730	360	2.021	4.291	395	2.097	4.089
4	O2	230	250	1.538	5.815	260	1.111	7.497	320	1.915	4.593	345	1.855	4.772
4	O3	225	255	2.308	3.576	270	1.667	5.372	315	1.915	4.593	340	1.855	4.772
4	O4	225	250	1.923	4.569	250	0.926	8.322	285	1.277	6.808	310	1.371	6.437
4	O5	190	210	1.538	5.815	220	1.111	7.497	280	1.915	4.593	300	1.774	5.021
4	O6	190	210	1.538	5.815	210	0.741	9.207	240	1.064	7.702	260	1.129	7.420
5	G1	285	300	1.154	7.314	305	0.741	9.207	350	1.383	6.391	390	1.694	5.282
5	G2	230	255	1.923	4.569	280	1.852	4.781	310	1.702	5.254	340	1.774	5.021
5	G3	210	225	1.154	7.314	230	0.741	9.207	280	1.489	5.993	300	1.452	6.132
5	G4	265	280	1.154	7.314	290	0.926	8.322	320	1.170	7.246	350	1.371	6.437
5	G5	190	200	0.769	9.067	205	0.556	10.149	250	1.277	6.808	280	1.452	6.132
5	G6	180	190	0.769	9.067	205	0.926	8.322	250	1.489	5.993	285	1.694	5.282
6	W1	260	290	2.308	3.576	295	1.296	6.730	345	1.809	4.914	370	1.774	5.021
6	W2	250	270	1.538	5.815	290	1.481	6.021	320	1.489	5.993	340	1.452	6.132
6	W3	165	180	1.154	7.314	200	1.296	6.730	245	1.702	5.254	265	1.613	5.554
6	W4	220	240	1.538	5.815	260	1.481	6.021	300	1.702	5.254	335	1.855	4.772
6	W5	190	205	1.154	7.314	230	1.481	6.021	250	1.277	6.808	285	1.532	5.837
6	W6	165	180	1.154	7.314	195	1.111	7.497	240	1.596	5.614	265	1.613	5.554

APPENDIX D.2: LIVE WEIGHT, AVERAGE DAILY GAIN AND PREDICTED FEED CONVERSION RATIO OF FEEDLOT CATTLE FED DIFFERENT COMBINATIONS OF SELENIUM AND CHROMIUM – EXPERIMENT 4 (CONTINUED)

NO	TAG	D76	ADG76	PFCR76	D89	ADG89	PFCR89	D 002	ADG102	PFCR102
1	R1	405	1.776	5.015	440	1.910	4.607	460	1.863	4.748
1	R3	315	1.250	6.916	350	1.461	6.098	380	1.569	5.708
1	R4	320	1.579	5.672	330	1.461	6.098	345	1.422	6.244
1	R5	295	1.250	6.916	350	1.685	5.309	360	1.569	5.708
1	R6	325	1.250	6.916	335	1.180	7.205	340	1.078	7.638
2	Y1	340	1.447	6.147	350	1.348	6.525	375	1.422	6.244
2	Y2	360	1.184	7.187	415	1.629	5.498	445	1.716	5.210
2	Y3	360	1.776	5.015	390	1.854	4.774	410	1.814	4.898
2	Y4	290	0.855	8.653	315	1.011	7.935	350	1.225	7.016
2	Y5	300	1.513	5.906	350	1.854	4.774	360	1.716	5.210
2	Y6	350	1.184	7.187	385	1.404	6.309	395	1.324	6.622
3	B1	360	1.447	6.147	390	1.573	5.693	410	1.569	5.708
3	B2	360	1.711	5.226	400	1.910	4.607	410	1.765	5.051
3	B3	315	1.118	7.465	345	1.292	6.746	360	1.275	6.817
3	B4	315	0.987	8.044	340	1.124	7.443	380	1.373	6.431
3	B5	290	1.184	7.187	305	1.180	7.205	325	1.225	7.016
3	B6	300	1.447	6.147	315	1.404	6.309	350	1.569	5.708
4	O1	400	1.776	5.015	430	1.854	4.774	445	1.765	5.051
4	O2	350	1.579	5.672	390	1.798	4.947	405	1.716	5.210
4	O3	300	0.987	8.044	335	1.236	6.973	365	1.373	6.431
4	O4	310	1.118	7.465	335	1.236	6.973	350	1.225	7.016
4	O5	315	1.645	5.446	335	1.629	5.498	360	1.667	5.372
4	O6	280	1.184	7.187	295	1.180	7.205	325	1.324	6.622
5	G1	400	1.513	5.906	435	1.685	5.309	470	1.814	4.898
5	G2	350	1.579	5.672	385	1.742	5.126	410	1.765	5.051
5	G3	310	1.316	6.652	345	1.517	5.893	360	1.471	6.061
5	G4	375	1.447	6.147	400	1.517	5.893	440	1.716	5.210
5	G5	300	1.447	6.147	315	1.404	6.309	340	1.471	6.061
5	G6	285	1.382	6.396	305	1.404	6.309	320	1.373	6.431
6	W1	385	1.645	5.446	415	1.742	5.126	425	1.618	5.538
6	W2	360	1.447	6.147	385	1.517	5.893	365	1.127	7.427
6	W3	270	1.382	6.396	315	1.685	5.309	315	1.471	6.061
6	W4	350	1.711	5.226	385	1.854	4.774	400	1.765	5.051
6	W5	295	1.382	6.396	320	1.461	6.098	340	1.471	6.061
6	W6	275	1.447	6.147	295	1.461	6.098	310	1.422	6.244

APPENDIX D.3: CARCASS CHARACTERISTICS OF FEEDLOT CATTLE FED DIFFERENT COMBINATIONS OF SELENIUM AND CHROMIUM – EXPERIMENT 4

TTT	TAG	D 002	ADG	WCM	CCM	WCM-CCM	DP	FC	CF
1	**R1**	460	1.9	255.200	249.800	5.400	55.48	2	3
1	**R3**	380	1.6	201.400	197.200	4.200	53.00	2	4
1	**R4**	345	1.4	179.000	174.800	4.200	51.88	2	3
1	**R5**	360	1.6	195.600	192.000	3.600	54.33	2	3
1	**R6**	340	1.1	198.200	194.400	3.800	58.29	2	3
2	**Y1**	375	1.4	192.400	187.800	4.600	51.31	2	3
2	**Y2**	445	1.7	238.400	234.200	4.200	53.57	2	4
2	**Y3**	410	1.8	225.000	220.300	4.700	54.88	2	3
2	**Y4**	350	1.2	172.000	168.200	3.800	49.14	2	4
2	**Y5**	360	1.7	197.600	194.000	3.600	54.89	2	3
2	**Y6**	395	1.3	223.800	219.400	4.400	56.66	2	3
3	**B1**	410	1.6	239.600	236.000	3.600	58.44	2	3
3	**B2**	410	1.8	229.000	225.200	3.800	55.85	3	3
3	**B3**	360	1.3	203.200	199.800	3.400	56.44	2	3
3	**B4**	380	1.4	203.800	200.400	3.400	53.63	3	3
3	**B5**	325	1.2	184.400	180.600	3.800	56.74	2	3
3	**B6**	350	1.6	190.800	187.000	3.800	54.51	2	4
4	**O1**	445	1.8	253.400	248.200	5.200	56.94	2	4
4	**O2**	405	1.7	223.000	218.800	4.200	55.06	2	3
4	**O3**	365	1.4	187.200	183.200	4.000	51.29	2	3
4	**O4**	350	1.2	187.400	183.800	3.600	53.54	2	3
4	**O5**	360	1.7	186.000	182.000	4.000	51.67	2	3
4	**O6**	325	1.3	173.000	169.600	3.400	53.23	2	3
5	**G1**	470	1.8	246.200	242.000	4.200	52.38	2	3
5	**G2**	410	1.8	225.800	222.200	3.600	55.07	2	3
5	**G3**	360	1.5	193.800	189.800	4.000	53.83	2	3
5	**G4**	440	1.7	242.600	237.800	4.800	55.14	2	3
5	**G5**	340	1.5	199.600	195.200	4.400	58.71	3	4
5	**G6**	320	1.4	174.400	171.200	3.200	54.50	2	3
6	**W1**	425	1.6	239.400	234.800	4.600	56.33	2	3
6	**W2**	365	1.1	201.200	197.800	3.400	55.12	2	3
6	**W3**	315	1.5	166.800	163.400	3.400	52.95	2	3
6	**W4**	400	1.8	223.000	218.600	4.400	55.75	3	4
6	**W5**	340	1.5	188.200	184.800	3.400	55.35	3	3
6	**W6**	310	1.4	168.000	164.600	3.400	54.19	2	3

APPENDIX D.4: CONCENTRATIONS (PPM) ON WET BASIS OF MINERAL ELEMENTS IN THE LIVER TISSUE OF FEEDLOT CATTLE FED DIFFERENT COMBINATIONS OF SELENIUM AND CHROMIUM – EXPERIMENT 4

NO	TAG	FE	CU	MN	ZN	CO	CR	CA	MG	SE	P
1	R1	51.25	63.60	2.77	35.95	2.66	3.01	18.13	95.56	0.56	3900
3	R3	219.95	131.73	5.86	36.22	4.63	1.46	60.23	110.08	0.81	2800
4	R4	190.34	100.00	5.15	36.93	2.48	1.39	52.71	114.20	0.40	3500
5	R5	210.36	121.92	4.83	39.95	2.10	1.29	60.91	102.50	1.21	5200
6	R6	49.61	94.15	3.28	37.33	2.53	3.59	42.36	119.35	1.19	2100
1	Y1	193.20	94.69	8.97	34.30	4.41	1.46	53.31	119.73	1.28	3200
2	Y2	39.97	56.98	3.80	39.62	2.86	3.78	49.86	120.52	1.92	4000
3	Y3	253.97	100.67	6.05	28.60	3.36	2.02	63.61	113.27	1.79	4000
4	Y4	279.46	97.59	5.52	43.22	1.95	1.64	60.28	114.42	0.45	2400
5	Y5	46.23	99.59	3.28	36.80	3.63	4.06	47.17	123.95	0.59	4900
6	Y6	183.54	122.42	4.44	64.02	2.89	4.28	53.79	128.24	0.59	6300
1	B1	205.77	126.78	8.34	68.53	2.95	1.45	39.83	103.53	1.69	3200
2	B2	208.38	111.19	5.29	32.56	2.67	1.90	61.85	121.96	1.65	3500
3	B3	43.00	80.21	4.01	31.52	1.67	4.77	47.94	105.60	1.44	4200
4	B4	189.53	84.36	6.09	35.15	2.99	3.24	63.90	139.36	1.81	4900
5	B5	61.19	93.83	3.77	58.97	3.64	4.67	56.47	122.27	1.67	5200
6	B6	192.72	148.76	5.94	28.73	3.64	3.88	56.12	113.99	1.93	3700
1	O1	55.79	102.06	4.12	32.89	2.03	5.58	55.33	134.62	0.99	2100
2	O2	59.51	65.64	4.00	34.55	2.01	4.74	44.18	107.23	0.78	2400
3	O3	97.34	83.15	3.35	27.94	2.58	4.53	47.09	103.28	0.98	3200
4	O4	47.85	119.00	3.63	35.82	3.79	4.80	48.59	118.56	0.88	4500
5	O5	41.85	113.07	3.53	34.57	3.30	4.84	50.58	117.14	1.16	3400
1	G1	218.85	77.02	5.39	27.32	3.47	3.00	52.31	102.83	0.50	3600
2	G2	218.52	76.08	6.23	29.22	2.79	3.48	62.33	118.02	0.29	4000
3	G3	62.70	57.34	4.28	34.54	2.20	5.16	48.78	119.47	0.53	3200
4	G4	125.64	62.29	3.19	30.97	3.18	4.84	48.30	127.70	0.41	4600
5	G5	63.67	61.88	4.33	37.38	2.04	4.69	65.23	129.76	0.36	4000
6	G6	44.67	101.09	3.20	32.01	3.02	4.60	53.79	135.37	0.41	3200
1	W1	42.56	96.73	3.39	53.09	0.71	4.87	49.80	116.59	0.32	3800
2	W2	72.76	75.83	2.93	60.27	3.45	5.83	54.65	123.07	0.24	4200
3	W3	62.43	90.87	3.45	26.78	2.78	5.16	51.03	137.65	0.03	2800
4	W4	210.16	114.60	5.94	59.79	3.09	3.62	60.11	132.92	0.31	4200
5	W5	54.15	93.55	3.86	30.49	2.30	4.96	43.14	117.40	0.81	4200
6	W6	179.24	117.18	6.46	33.44	2.61	3.53	57.80	122.62	0.31	4000