Beef production and quality of Malawi Zebu steers fed diets containing rangeland-based protein sources under feedlot conditions

by
Gregory Chingala

Thesis presented in fulfilment of the requirements for the degree of Doctor of Philosophy (Animal Science) in the Faculty of AgriSciences at Stellenbosch University

Supervisor: Dr. Cletos Mapiye
Co-supervisor: Dr. Emiliano Raffrenato
Co-supervisor: Prof. Kennedy Dzama
Co-supervisor: Prof. Louwrens C. Hoffman

March 2018

Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third-party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Gregory Chingala　　　　　　　　　　　　　　Date

Abstract

The current study evaluated smallholder farmers perceptions towards climate change, their identification of potential protein sources during drought, the nutrition profile of these protein sources and their actual production value when fed to Malawi Zebu steers under feedlot conditions. Using a structured questionnaire, 182 smallholder farmers were interviewed to determine socio-economic factors affecting their perceptions of impacts of climate change on beef production, and to identify potential protein sources they may use during drought periods in Malawi. All farmers were aware of the impacts of climate change on beef production including knowledge around the causes of deterioration of grazing rangelands, which culminated in poor animal reproduction and production performances. Perceptions of farmers were influenced more by the biophysical factors such as agroecological zone than socio-economic factors (P<0.05) indicating sensitivity of some areas to climate change in Malawi. Farmers had limited options to minimise the impacts of climate change on beef production including use of intake bulls to promote growth and increasing grazing hours. The indigenous oil-seeds and browse legume trees that farmers considered as potential protein supplements in the dry season included: *Adansonia digitata* (Baobab, 15% of respondents) seeds, *Dolichos kilimandscharicus* (wild lupin, 21%) and *Vachellia polyacantha* (White thorn tree) leaves 2%). Chemical composition and *in vitro* ruminal digestibility values of these potential rangeland-based protein sources were evaluated across two growing seasons: 2015 and 2016 and where applicable, compared to *Glycine max* (soybean) as a standard protein supplement. Regardless of season, soybean had the highest content of crude protein (CP) and starch followed by baobab seed (P<0.05). Crude fat content of baobab seed irrespective of season superseded all the assayed protein sources (P<0.05). The neutral detergent fibre (NDF) content was only affected by species (P<0.05), with soybean and baobab seed meals having the lowest NDF contents (P<0.05). Overall, leaves of *V. polyacantha* had the highest total phenols, tannins, calcium, iron and lowest *in vitro* NDF digestibility compared to other species across seasons (P<0.05). The largest content of phosphorus, copper and zinc was recorded in baobab seed collected regardless of season (P<0.05). Regardless of season, soybean meal had the highest content for most amino acids followed by baobab seeds, with *V. polyacantha* having the lowest contents (P < 0.05)Overall, irrespective of the season baobab seed had a better mineral profile and similar contents of CP, starch, NDF and amino acids compared to soybean.

The effects of *A. digitata* seed and *V. polyacantha* leaf-meal on *in vivo* nutrient digestibility and microbial nitrogen supply, and growth performance, carcass and meat quality attributes were evaluated using Malawi Zebu steers. Three diets made up of rangeland hay and maize bran with either baobab seed meal, *V. polyacantha* leaf-meal or soybean meal (control) as protein source, respectively, were randomly allocated to 30 individually housed Malawi Zebu steers (182±21.4 kg and 29 months old) for 120 days. Feed offered and refused were measured daily and live weight of the steers were obtained every four weeks. Apparent *in vivo* nutrient digestibility was estimated usingn faecal grab samples which were collected over four days and *in vitro* indigestible neutral detergent fibre was used as an internal indicator. The rumen fluid was donated by a fistulated Malawi Zebu cow. Microbial nitrogen supply was calculated based on urinary purine derivative concentration of spot urine samples. On day 120, all steers were slaughtered and carcass measurements were recorded. The *M. longissimus thoracic et lumborum* (LTL) of each animal was sampled for meat quality measurements. Steers fed diets containing soybean and baobab seed meal had similar apparent total tract digestibility, DMI and ADG (P<0.05). However, steers fed baobab seed meal had the highest rumen microbial nitrogen supply followed by Soybean- and *Vachellia*-fed steers (P<0.05). Steers fed the diet containing baobab had the highest gross margins followed by steers fed *V. polyacantha* leaf-meal and soybean meal, in that order (P<0.05). Carcasses from Malawi Zebu steers fed baobab and Vachellia diets had higher ultimate pH than those animals fed the soybean diet (P<0.05). Muscle colour from animals fed the Soybean diet was brighter than that from animals on the baobab and *Vachellia* diets. During a 7-day retail display, *Vachellia* diet produced beef muscle with the highest resistance to browning (lowest hue angle values; P<0.05). Steers on baobab and *Vachellia* diets had muscles with higher (P<0.05) water holding capacity than those on soybean diet. Baobab-fed steers had muscle with the highest zinc and manganese contents compared to the other treatments. Overall, feeding steers with rangeland-based protein sources, especially baobab seed diet improved beef production and quality of Malawi Zebu steers. Although incorporation of *V. polyacantha* leaf-meal improved meat quality attributes, its inclusion should be minimal because of its adverse effects on animal performance. Data from the feeding trial, dry matter intake (DMI) and average daily gain (ADG) of the steers, was fitted into the two nutritional models to aid their predictions. The models used were the Beef Cattle Nutrient Requirements Model (BCNRM) and Large Ruminant Nutrition System (LRNS). The BCNRM was more accurate and precise in predicting the DMI (r^2=0.95; mean bias, MB=2.5%; mean square prediction error, MSPE=0.16; and concordant correlation coefficient, CCC=0.96) than the LRNS (r^2 =0.79; MB=11%; MSPE=0.19; CCC=0.82). Similarly, BCNRM was more accurate and precise in forecasting ADG (r^2=0.87; MB=10%; MSPE=0.029; CCC=0.75) than LRNS (r^2=68; MB=24%; MSPE=0.038; CCC=0.33). Overall, the BCNRM was more accurate and precise than the LNRS model in predicting DMI and ADG of Malawi Zebu steers fed rangeland based diets under feedlot conditions. To enhance adoption of strategies aimed at equipping smallholder beef producers to deal with climate change related feed shortages, it could be important to realign carcass classification and grading systems to suit smallholder beef production associated with rangeland-finished indigenous cattle breeds. Current beef carcass classification and grading systems in selected Southern African countries do not appropriately reward smallholder beef production associated with rangeland-finished indigenous cattle. Supportive policies and regulations have been recommended to promote value addition of rangeland-finished indigenous cattle breeds in the smallholder areas of Malawi.

Opsomming

Die huidige studie het kleinboere se persepsies oor klimaatsverandering geëvalueer, hul identifikasie van potensiële proteïenbronne tydens droogte, die voedingsprofiel van hierdie proteïenbronne en hul werklike produksiewaarde geëvalueer wanneer Malawi Zebu ramme onder voerkraaltoestande met dit gevoer word. Met behulp van 'n gestruktureerde vraelys is daar met 182 kleinboere onderhoude gevoer om te bepaal hoe en tot watter mate sosio-ekonomiese faktore hul persepsies van klimaatsverandering op vleisproduksie beïnvloed, te identifiseer en vas te stel watter potensiële proteïenbronne hulle tydens droogtydperke in Malawi sal gebruik. Al die boere was bewus van die impak van klimaatsverandering op vleisproduksie, insluitend ook dat daar kennis heers oor die oorsake van die agteruitgang van weidingslande, wat gelei het tot swak lewering van geslag voortsetting en voortplanting, diereproduksie en algehele produksie vlakke. Die persepsies van boere is meer beïnvloed en bepaal deur die biofisiese faktore invloede soos die agro-ekologiese sone as sosio-ekonomiese faktore ($P < 0.05$) wat duidelike aanduidings gee van die sensitiwiteit van sommige gebiede vir klimaatsverandering in Malawi. Boere het beperkte opsies gehad om die impak van klimaatsverandering op vleisproduksie te verminder. Pogings wat aangewend was sluit in die potensiaal om inheemse blare-peulvrugte asook blare te gebruik as proteïenbronne in die droë seisoen.

Die mees algemeen beskikbare inheemse oliesade en blare wat hierbo genoem word, sluit in: Adansonia digitata (Baobab, 15% van die respondente) sade, Dolichos kilimandscharicus (wilde lupien, 21%) en Vachellia polyacantha (Witdoringboom, 2%) blare in die droë seisoen. Chemiese samestelling en in vitro-spatale verteerbaarheidswaardes van hierdie potensiële grondgebaseerde proteïenbronne is oor twee groeiseisoene geëvalueer: 2015 en 2016 en waar van toepassing, vergelyk met Glycine max (sojaboon) as 'n standaard proteïenaanvulling. Ongeag die seisoen, het sojabone die hoogste inhoud van ru-proteïen (CP) en stysel, gevolg deur kremetartsaad ($P < 0.05$). Ruwe vetinhoud van kremetartsaad, ongeag die seisoen, het al die geasseseerde proteïenbronne ($P < 0.05$) oorskrei. Die inhoud van die neutrale skoonmaakmiddelvesel (NDF) is slegs beïnvloed deur spesies ($P < 0.05$), met sojaboon- en kremetartsaadmaaltye met die laagste NDF-inhoud ($P < 0.05$). Oor die algemeen het blare van Vachellia polyacantha die hoogste totale fenole, tanniene, kalsium, yster en laagste in vitro NDF verteerbaarheid gehad in vergelyking met ander spesies oor seisoen tydperke ($P < 0.05$). Die grootste inhoud van fosfor, koper en sink is aangeteken in kokaobab saad wat ingesamel is, ongeag die seisoen ($P < 0.05$). Ongeag die seisoen het sojameel die hoogste inhoud vir die meeste aminosure gevolg deur kremetartaad, met Vachellia polyacantha die laagste inhoud ($P < 0.05$) vlak. Oor die algemeen en ongeag die seisoen, het kremetartaad 'n beter mineraalprofiel en soortgelyke inhoud van CP, stysel, NDF en aminosure in vergelyking met sojabone gehad.

Die effekte van A. digitata saad en V. polyacantha blaarmeel op in vivo voedingstof verteerbaarheid en mikrobiese stikstoftoevoer, en groeivoorstelling, karkas en vleiskwaliteit eienskappe is geëvalueer met behulp van Malawi Zebu ramme. Drie diëte wat bestaan uit heuwelhooi en mielies semels met onderskeidelik kremetartaad-ete, V. polyacantha-blaarmeel of sojameel (beheer) as proteïenbron, is nie-bepalend toegedien aan 30 individueel gehuisvestigde Malawi Zebu ramme (182 ± 21.4 kg en 29 maande oud) oor ǹ tydperk van 120

dae. Voedsel aangebied en geweier is daagliks gemeet en eintlike deurlopende gewigte van die ramme is elke vier weke gemeet en verhaal. Skynbare in vivo voedingstof verteerbaarheid is geskat met behulp van fekale gryp monsters wat oor vier dae versamel is en in vitro onverdiverbare neutrale skoonmaakmiddel vesel is gebruik as 'n interne aanwyser. Die rumenvloeistof is geskenk deur 'n gefistileerde Malawi Zebu-koei. Mikrobiese stikstofvoorsiening is bereken op grond van urinêre purien afgeleide konsentrasie van geteikende urine monsters. Op dag 120 is alle ramme geslag en karkasmetings is aangeteken. Die M. longissimus torakale et lumborum (LTL) van elke dier is bemonster vir vleiskwaliteitmetings. Ram gevoerde diëte wat sojabone- en kremetartaad-ete bevat, het soortgelyke skynbare totale kanaalverteerbaarheid, DMI en ADG (P <0.05) gehad. Ramme wat met kremetartaad-etes gevoer is het egter die hoogste speenmikrobiese stikstofvoorsiening gehad naas en gevolg deur ramme wat Sojaboon- en Vachellia-voer (P <0.05) ontvang het. Ramme wat met die dieet met kremetart gevoer is, het die hoogste bruto rig-wysigings perke gehad , gevolg deur ramme gevoed met V. polyacantha blaarmeel en sojameel, in daardie volgorde (P <0.05).

Karkasse uit Malawi Zebu-ramme gevoer met kokaob-voeding en Vachellia-dieet het hoër uiteindelike pH gehad as die diere wat die sojaboon-dieet gevoer was (P <0.05). Spierkleur van die diere wat die sojaboon-dieet gevoer het, was helderder as dié van die diere op die kremetart- en Vachellia-dieet. Tydens 'n 7-dae kleinhandel vertoning, was aangedui dat die Vachellia dieet vleis spier die hoogste weerstand bied teen bruin etsing of bruin verkleuring of verbranding (laagste tint hoek waardes, P <0,05). Ramme op kremetart- en Vachellia-dieet het spiere gehad met hoër (P <0.05) waterhouvermoë as dié wat sojaboondieet toegedien was. Baobab-gevoerde ramme het spiere gehad met die hoogste sink- en mangaaninhoud in vergelyking met die wat ander behandeling ontvang het. Oor die algemeen het voedselsoorte met die oorsprong van proteïenbronne, veral kremetartaaddieet, die vleisproduksie en kwaliteit van die Malawi Zebu ramme verbeter. Alhoewel die inkorporering of insluiting van V. polyacantha-blaarmeel die eienskappe van vleiskwaliteit verbeter, moet die insluiting daarvan minimaal wees weens die nadelige gevolge daarvan op dier-prestasie. Data van die voedingstoets, droëstofinname (DMI) en die gemiddelde daaglikse wins (ADG) van die ramme is in die twee voedingsmodelle toegepas om hul voornemende voorspellings te bepaal en die uitwerking daarvan aan te help.

Die modelle wat gebruik is, was die Beefvleisvoedingstofbehoeftesmodel (BCNRM) en die Groot Rundervoedingstelsel (LRNS). Die BCNRM was meer akkuraat en presies in die voorspelling van die DMI (r2 = 0.95; gemiddelde vooroordeel, MB = 2.5%; gemiddelde vierkantige voorspellingsfout; MSPE = 0.16; en ooreenstemmende korrelasiekoëffisiënt, CCC = 0.96) as die LRNS (r2 = 0.79; MB = 11%; MSPE = 0,19; CCC = 0,82). Net so ook was BCNRM meer akkuraat in die voorspelling van ADG (r2 = 0.87; MB = 10%; MSPE = 0.029; CCC = 0.75) as LRNS (r2 = 68; MB = 24%; MSPE = 0.038; CCC = 0.33). Oor die algemeen was die BCNRM meer akkuraat en presies as die LNRS-model in die voorspelling van DMI en ADG van die Malawi Zebu-ramme wat gevulde grondgebaseerde diëte onder voerkraaltoestande gevoer was. Om die aanvaarding van strategieë te verbeter wat daarop gemik is om kleinboerevleisprodusente toe te rus om die tekort aan voedseldoeleindes in verband met klimaatsverandering te hanteer, kan dit belangrik wees om karkasklassifikasie en graderingstelsels te hersien om kleinvee-beesvleisproduksie wat verband hou met inheemse beesrasse wat van herkoms afkomstig is, toegerus met wat paslik is, aanvaarding te bied. Huidige vleiskarkas klassifikasie en graderingstelsels in geselekteerde Suider-Afrikaanse lande beloon nie kleinvee-vleisproduksie wat geassosieer word met beweerde inheemse beeste. Ondersteunende beleide en regulasies is aanbeveel om waarde-toevoeging van inheemse beesrasse in die kleinboere van Malawi te verbeter.

Acknowledgements

I am grateful to my supervisors; Dr. Cletos Mapiye, Dr. Emiliano Raffrenato, Prof. Kennedy Dzama and Prof. Louwrens C. Hoffman for their inspiration, guidance and assistance in the development of the dissertation. Special thanks go to Prof. Luis O. Tedeschi, Department of Animal Science, Texas A&M University, College Station 77843-2471 for his immense input in shaping the nutritional mathematical modelling in Chapter 5 of this thesis. I am grateful to Mr. Vincent for diligently taking care of the experimental animals in Malawi. To Mrs. L. Uys and B. Ellis of Stellenbosch University, I say thank you for your invaluable support with meat and feed analyses. Michael and Jannine you were great people to work with in the laboratory. I am indebted to Mr. Obert Chikwanha for his assistance in meat sampling and quality measurements and thesis editing. I would also like to thank the management of Lilongwe University of Agriculture and Natural Resources for granting me a study leave for the whole period of my study. I am grateful to the following fellow students for their support during my study at Stellenbosch University: Tawanda Marandure, Obvious Mapiye, Tawanda Tayengwa, Liesel van Emmenes, Tulimo Mushona and Trust Pfukwa. My heartfelt gratitude goes to the smallholder farmers in Salima, Lilongwe, Dowa and Mzimba for their active participation and cooperation during the survey. This study was made possible through the financial assistance of the Royal Kingdom of Norway through the Capacity Building for Managing Climate Change Programme in Malawi, implemented by Lilongwe University of Agriculture and Natural Resources in conjunction with Life Sciences University of Norway. Finally, my heartfelt thanks go to my family, Dinna, for the inspiration, love and unwavering support during my studies.

Table of Contents

Abstract ii
Opsomming iv
Acknowledgements vii
List of Tables xiv
List of Figures xvi
List of publications xvii
List of Appendices xviii
Chapter 1: Introduction 1
1.1 Background 1
1.2 Justification for the study 5
1.3 Study objectives 6
1.4 Hypotheses 7
1.5 Thesis layout 7
1.6 References 8
Chapter 2: Literature Review 12
2.1 Introduction 12
2.2 Beef production systems in Malawi 14
2.4 Strategies for improving quality and feed availability for beef cattle in smallholder production systems in Malawi 16
2.4.1 Improved rangeland and pasture production 16
2.4.2 Improved utilisation of crop residues in Malawi 17
2.4.3 Mineral supplementation 17
2.4.4 Fodder from multipurpose tree legumes as protein supplements 18

2.5 Potential rangeland-based protein sources for beef cattle production in Malawi 19

2.5.1 Nutritional mathematical models as a tool for predicting animal requirements 24

2.6 Beef marketing in the smallholder sector as a hindrance to adoption of new technologies 25

2.7 Summary 26

2.7 References 27

Chapter 3: A survey on determinants of farmers' perceptions of impacts on climate change of beef production in Malawi 36

Abstract 36

3.1 Introduction 37

3.2 Methods 39

3.3 Results 42

3.4 Discussion 50

3.5 Conclusion 56

3.6 References 57

Chapter 4: Nutritional composition of selected rangeland protein sources for smallholder beef cattle in Malawi 62

Abstract 62

4.1 Introduction 63

4.2 Material and Methods 65

4.3 Results 68

4.3.1 Proximate composition and in vitro digestibility 68

4.3.2 Mineral composition 71

4.4 Discussion 73

4.5 Conclusion 76

4.6 References 76

Chapter 5: Intake, digestibility, rumen protein synthesis, growth performance and economic viability of Malawi Zebu steers fed diets containing rangeland-based protein sources 82

Abstract 82

5.1. Introduction 83

5.2. Materials and methods 86

5.2.1 Study site 86

5.2.2 Animals, experimental design and diets Study site 86

5.2.3 Feed preparation Study site 87

5.2.4 Diet formulation 87

5.2.5 Chemical analyses of experimental diets....................88

5.2.6 Collection of faecal and urine samples....................89

5.2.7 Total tract nutrient digestibility 90

5.2.8 Ruminal microbial nitrogen supply 91

5.2.9 Measurements of animal performance 92

5.2.10 Gross margin analysis....................92

5.2.11 Statistical Analyses....................93

6.1 Results 93

5.3. Discussion 97

5.4. Conclusion....100

5.5. References 100

Chapter 6: Prediction of dry matter intake and average daily gain of Malawi Zebu steers fed rangeland-based diets using different nutritional computer models 105

Abstract 105

6.1 Introduction 105

6.2 Material and Methods....108

6.2.1 Model inputs 109

6.2.2 Model predictions 112

6.2.3 Model adequacy evaluations 112

6.3 Results 113

6.3.1 Dry matter intake 113

6.3.2 Average daily gain....113

6.4 Discussion 116

6.5 Conclusion....118

6.6 References 118

Chapter 7: Carcass attributes and physicochemical meat quality characteristics of Malawi Zebu steers fed diets containing rangeland-based protein sources 122

Abstract 122

7.1 Introduction 123

7.2 Materials and Methods....124

7.2.1 Location of study, experimental design, treatments and animals........................124

7.2.2 Chemical analyses of experimental diets..124

7.2.3 Slaughter and carcass attribute measurements 125

7.2.4 Sampling and physical meat quality measurements 125

7.2.5 Drip loss and water-holding capacity 126

7.2.6 Proximate and mineral composition 127

7.2.7 Cooking loss and warner-Bratzler shear force 127

7.2.8 Beef colour stability during the refrigerated conditions.....................................128

7.2.9 Statistical analyses 128

7.3 Results 130

7.3.1 Carcass characteristics 130

7.3.2 Physicochemical meat quality characteristics 131

7.3.3 Proximate and selected mineral composition 132

7.3.4 Beef colour stability during refrigerated storage conditions 133

7.4 Discussion 134

7.5 Conclusion...138

7.6 References 139

Chapter 8: Evaluation of shortcomings of selected beef carcass grading and classification systems in southern Africa...143

Abstract...143

8.1 Introduction 144

8.2 Beef production and marketing systems in Southern Africa 146
8.3 Selected beef carcass grading and classification systems in Southern Africa 148
8.4 Shortcomings of the current beef carcass grading and classification systems in Southern Africa 156
8.5 Opportunities for improving beef carcass grading and classification systems in Southern Africa 162
8.6 Towards a regional carcass classification system 170
8.7 Conclusions 175
8.8 References 176
Chapter 9: General discussion, conclusion and recommendations.......................................186
9.1 General discussion...186
9.2 Conclusions 191
9.3 Conclusions 192
9.4 Recommendations 192
9.4 References 193
Appendix A 196
The baseline survey questionnaire on determinants of farmers' perceptions on impacts of climate change on beef production 196

List of Tables

Table 2.1 Chemical composition of Vachellia browse species in African environments 20

Table 2.2 Mineral composition of Vachellia browse species in African environments 21

Table 3.1 Pedo-climatic and vegetation characteristics of the study areas 41

Table 3.2 Uses of cattle in communal areas of Malawi as ranked by farmers 44

Table 3.3 Logit coefficients of determinants affecting smallholder farmers' perceptions of the impacts of climate change on beef production and quality in Malawi 46

Table 4.1: Nutritional composition (g/kg DM) and phenolic content (g/kg DM) of selected rangeland-based protein sources for beef in Malawi 70

Table 5.1: Ingredient proportions and chemical constituents in the experimental diets..........89

Table 5.2: Effect diets containing soybean meal, baobab seed meal and Vachellia polyacantha a leaf-meal on productive performance of Malawi Zebu..94

Table 5.3 Effect of feeding Malawi zebu steers with diets containing soybean meal, baobab seed meal and Vachellia polyacantha leaf-meal on apparent total tract nutrient digestibility.95

Table 5.4: Effect of feeding Malawi zebu steers with diets containing soybean meal, baobab seed meal and Vachellia polyacantha leaf-meal on urinary output and purine derivative excretion, and microbial nitrogen supply...95

Table 5.5. Gross margins (US$) for Malawian Zebu steers fed containing soybean meal, baobab seed meal and Vachellia polyacantha leaf-meal 96

Table 6.1 Chemical composition (g/kg DM) of feed ingredients used to evaluate the models 109

Table 5.2 The kinetic digestibility rate (%/ hr) of feedstuffs used for evaluating the models 110

Table 5. 3 Animal type and environment inputs..111

Table 6.4: Model fit comparison between observed and predicted DMI and ADG of Beef Cattle Nutrient Requirement Model and Large Ruminant Nutrition System 114

Table 7.1 Carcass characteristics of Malawi zebu steers fed with diets containing soybean meal, baobab seed meal and Vachellia polyacantha a leaf-meal 130

Table 7.2 Physical meat quality attributes of Longissimus thoracic et lumborum of Malawi Zebu steers fed diets containing the rangeland-based protein sources 131

Table 7.3 Proximate and selected micromineral composition of Longissimus thoracic et lumborum from Malawi zebu steers fed rangeland based diets 132

Table 7.4 Objective colour of thoracic longissimus et lumborum muscle from steers fed diets containing Baobab seed meal, Vachellia polyacantha and Soybean over 8-day of retail display. 133

Table 7.5 Overall objective colour of thoracic longissimus et lumborum muscle from Malawi zebu steers fed diets containing soybean meal, baobab seed meal and Vachellia polyacantha leaf-meal over 8-day retail display 134

Table 8.2: South African and Namibian beef carcass classification system 153

Table 8.3: Zimbabwean beef carcass classification system 155

List of Figures

Figure 6.1. The relationship between the observed daily DMI and the BCNRM- and LRNS-predicted intake 115

Figure 6.2 The relationship between the observed ADG and the BCNRM- and LRNS predicted ADG 116

List of publications

Journal Articles

Chingala, G., Mapiye, C., Raffrenato, E. & Hoffman, L., 2017. Determinants of smallholder farmers' perceptions of impact of climate change on beef production in Malawi. Climatic Change. 142, 129-14. http://doi.org/10.1007/s10584-017-1924-1.

Chingala, G., Raffrenato, E., Dzama, K., Hoffman, L. C. & Mapiye, C. 2017. Towards a regional beef carcass classification system for Southern Africa Beef production and marketing systems in Southern Africa. South African Journal of Animal Science, 47, 408–423. http://doi.org/10.4314/sajas.v47i4.1.

Conference proceedings

Chingala, G., Raffrenato, E., Dzama, K., Hoffman, L. C. & Mapiye., C. 2017. Growth performance and carcass attributes of Malawi Zebu steers fed rangeland protein sources alternative to soybean meal. Oral presentation done at the 50th South African Society for Animal Science Congress, 18th-21st September, 2017, Port Elizabeth, South Africa. The 50th SASAS Congress Book of Abstracts, p 347

Chingala G., Mapiye C., Raffrenato E., Hoffman L. and Dzama, K. 2016. Smallholder cattle producers' views of the effects of climate change on beef production and quality in Malawi. Oral presentation at the49th South African Society for Animal Science (SASAS) Congress, 3rd-6th July, 2016, Stellenbosch, Western Cape Province, South Africa. Abstract number 41 in 49th SASAS Congress Book of Abstracts.

List of Appendices

Appendix A: Baseline survey questionnaire on determinants of farmers' perceptions on impacts of climate change on beef production................................196

Chapter 1: Introduction

1.1 Background

Malawi has an agrarian economy with over 85% of its population directly depending on smallholder agriculture (Ricker-Gilbert et al., 2014). About 90% of beef consumed in Malawi is produced by smallholder farmers who graze the indigenous Malawi Zebu on communal rangelands (Changadeya et al., 2012; Dzanja et al., 2013). Malawi Zebu is a small-framed *Bos indicus* breed with a mature weight of 265kg for females and 300kg for males (Butterworth and McNitt, 1984). In general, beef cattle production on communal rangelands in southern Africa is mainly constrained by low feed supply in the dry season (Mapiye et al., 2011). This problem exists because tropical rangeland grasses exhibit nutritional constraints, particularly low crude protein and high lignin content that reduce intake, digestibility and animal performance (Detmann et al., 2014) and, subsequently, negatively affects meat quality (Muchenje et al., 2008).

To improve beef production and quality in Malawi, feedlot systems were introduced in the smallholder areas where cattle are confined and finished on diets containing cereal grains, crop residues, forage legumes and oilseeds (Nkhonjera et al., 1988). Nonetheless, use of forage legumes and oilseeds as protein sources is limited by scarcity and the high cost of agronomic inputs (Mapiye et al., 2011). Furthermore, recently Malawi has frequently been experiencing prolonged dry spells and droughts induced by climate change, that has adversely affected crop and forage production, (World Bank, 2016) rendering the prospect of using forage legumes out of reach for most smallholder farmers. The situation of extreme weather events including droughts are anticipated to occur more often than before, due to a rapid increase in the atmospheric concentrations of greenhouse gases (IPCC, 2013). In general, the low latitude areas where Malawi is located are predicted to become hotter and drier (IPCC, 2007), which will result in changes in rangeland biomass quantity and quality, thereby reducing rangeland potential to support smallholder beef production especially in the dry season (Descheemaeker et al., 2016). Under such circumstances, it would, therefore, be important to harvest rangeland feed resources during the rainy season, and conserve them for use in the dry season. In addition, a protein supplementation approach involving rangeland-based protein sources might be useful for resource-poor beef cattle farmers in the face of these changing climatic conditions (Khanyile et al., 2014).

Potential rangeland-based protein sources in Malawi include leaf-meal from indigenous leguminous trees, shrubs, herbs, and tree-borne oilseeds. The potential natural browse tree legumes which are common in Malawi include *Vachellia spp*, *Erythrina spp*, *Faidherbia albida* , however, of all these leguminous tree legumes, Vachellia species are the most important feed resource that could be used as protein supplements to ruminants because of their wide and abundant availability (Reynols, 2006). However, little is known about the potential use of naturally grown perennial herbaceous legumes including wild lupins (*Dolichos kilimandscharicus*), which occurs in most grasslands in most African countries (Mackinder, 1999). For natural oilseeds, baobab (*Adansonia digitata*) seed could also be used as a protein supplement. In general, Mlambo and Mapiye (2015) pointed out that due to high nutrient content in some rangeland-based protein resources, they have potential to improve ruminant production and meat quality in poor-resource households that cannot afford to buy the conventional protein supplements such as crop oilseeds and cakes because of the high prices.

Malawian natural vegetation has been modified due to changes in land use given the high human population growth (Kuyah et al., 2014), which may have affected the availability of some of the rangeland-based protein resources in smallholder areas. Research is, therefore, warranted to document potential animal feed resources available in the smallholder areas in Malawi. To ensure the effective supplementation of these rangeland protein sources to cattle, it would be important to evaluate their nutritive value, including anti-quality factors as some are reported to contain high levels of secondary plant compounds that negatively affect animal performance. While rangeland protein sources could potentially be used as protein supplements in beef diets (Mapiye et al., 2011), there are still information gaps on the nutritional composition of of rangeland protein sources. On the other hand, there is limited information on the utilization of oilseeds from indigenous trees as protein supplements in beef diets. Also, how Malawi Zebu steers under feedlot conditions would respond to the diets containing these protein sources as the main protein source is unknown.

To improve the production performance of cattle fed rangeland-based diets, precise and accurate supplementation programmes are or would be vital. Currently, nutritional mathematical models are available that aid in formulating and evaluating diets precisely and accurately by accounting for feed composition, animal and environmental factors (Tedeschi et al., 2014). Most of the available models were developed in the U.S. and Europe where the breeds used (Bos taurus) and management sytems are different compared to the developing countries such as Malawi. Therefore it would be important to find out how accurate these models are for *Bos indicus* cattle under the low input sytems. Use of the models could help farmers to achieve precise feeding and improve on feed inventory management throughout the year, thereby reducing the risks of critical seasonal feed shortages.

Interventions aimed at enhancing farmers' capacity to deal with climate change, should go beyond food security and climate change, and focus on areas including that of changing agricultural policies to promote profitable smallholder agriculture (Masikati et al., 2015). Whilst the constraints of poor nutrition is well-known to smallholder beef farmers, carcass evaluation systems used often limit the adoption of innovative feeding practices in the smallholder beef production sector, which is dominated by indigenous cattle breeds (Nkhonjera et al., 1988). Usually indigenous cattle do not achieve the premium grades or classes, due to their inherent characteristics such as slow growth and small frame size (Soji et al., 2015). Utilisation of indigenous cattle breeds for beef production over exotic breeds could be essential in adaptation to climate change, especially in Malawi where most of the cattle population is made up of indigenous cattle. Indigenous cattle have low feed requirements, and are well adapted to heat stress, diseases and parasites (Strydom, 2008; Mwai et al., 2015), the features that make indigenous animals suitable for the changing climate. Overall, research is needed to evaluate different feeding strategies for indigenous cattle breeds, including the use of rangeland-based protein feedstuffs as alternatives to traditional supplements such as soybean meal (SBM).

Utilisation of adaptive indigenous cattle genotypes with the correct dietary regime, could result in superior meat yield and quality that meets both producers' and customers' expectations (FAO, 2007). In that regard, it is important to have in depth literature review analysis of the carcass valuation systems in Southern Africa, to highlight their shortcomings and strengths and make suggestions for a better carcass classification system.

Despite the fact that climate change ~~being~~ is a global phenomenon, its adverse effects are experienced to severe extents at local and community levels (Sivakumar et al., 2013). Research aimed at evaluating farmers' perceptions on the effects of climate change on beef production and quality, would provide much needed insight into vulnerability to climate change, challenges, coping strategies and opportunities for the Malawian smallholder beef production sector. Understanding farmers' perceptions regarding the impacts of climate change on rangeland cattle production, would be essential in improving smallhoder production efficiency for example incorporation of rangeland protein sources to improve beef production and quality.

1.2 Justification for the study

Because of climate change, the tropical regions where Malawi is located, are predicted to become warmer and drier. This will affect crop and forage production adversely, and consequently reduce smallholder beef production. In the face of such changes in the climate, it could be important to replace grains and exotic legumes currently used by farmers, with the more affordable and locally adapted alternative feed sources. Utilisation of adapted indigenous, underutilised and underexploited rangeland protein sources might, therefore, play a significant role in achieving and ensuring sustainable food and nutrition security for smallholder farmers. Such interventions can also enhance the smallholder beef farmers' capacity to deal with the adverse effects of climate change. In that context, use of the nutritional models could help smallholder farmers to improve the efficiency of the utilization of alternative feed sources, thereby reducing the risks of critical feed shortages. More importantly, development and implementation of appropriate marketing policies and/or regulations may improve the profitability of indigenous beef cattle production.

1.3 Study objectives

The overall objective of the present study was to evaluate strategies that address the climate-change related challenges to enhance beef production in the smallholder areas in Malawi. The specific objectives were to:

1. Evaluate determinants influencing farmers' perceptions of the impacts of climate change on beef production and to identify potential protein sources for use as cattle feed in Malawi;
2. Assess the nutritional composition and digestibility of selected rangeland-derived protein sources in Malawi over 2 growing seasons;
3. Predict dry matter intake and average daily gain of Malawi Zebu steers fed rangeland-based diets using different nutritional mathematical models;
4. Determine the intake, digestibility, ruminal microbial protein synthesis, growth performance and economic viability of Malawi Zebu steers fed diets containing rangeland-based protein sources;
5. Evaluate carcass and meat quality attributes of Malawi Zebu steers fed diets containing rangeland-based protein sources; and
6. Analyse the weaknesses and strengths of select beef carcass evaluation systems when classifying indigenous cattle in southern Africa and then more significantly as well to make recommendations of the ideal system for the region.

1.4 Hypotheses

The hypotheses for the current study was:

1. Farmers' socio-economic factors do not affect their perceptions on the impacts of climate change on beef production, and there are no potential protein sources for use during drought periods in Malawi;
2. The nutritional value of rangeland-derived protein feedstuffs is adequate for animal production across the harvesting seasons in Malawi;
3. It is possible to predict dry matter intake and average daily gain of Malawi Zebu steers fed with rangeland-based diets under the Malawian environmental conditions, using the existing nutritional mathematical models
4. Intake, digestibility, rumen protein synthesis, growth performance and economic viability of Malawi Zebu steers fed diets containing rangeland-based protein sources are similar;
5. There is no difference in carcass and meat quality attributes of Malawi Zebu fed diets containing rangeland-based protein sources.

1.5 Thesis layout

This thesis is organised into nine separate chapters, comprising a general background of the study; literature review; six chapters of the research findings. Each chapter on the research findings is organised into a manuscript with its own abstract, materials and methods, and a list of literature cited. The reference style for all the chapters was written according to the South African Journal of Animal Science.

1.6 References

Butterworth, M.H, & McNitt, J.I., 1994. The Malawi Zebu. World Animal. Review. Article No.49.

Changadeya, W., Ambali, A., Nyirenda, J., Chagunda, M. & Kaunda, E., 2012. Genetic diversity and population structure of Malawi Zebu cattle. Int. J. Phys. Soc. Sci. 2, 59–81.

Descheemaeker, K., Oosting, S.J., Homann-Kee Tui, S., Masikati, P., Falconnier, G.N. & Giller, K.E., 2016. Climate change adaptation and mitigation in smallholder crop–livestock systems in sub-Saharan Africa: a call for integrated impact assessments. Reg. Environ. Chang. 16, 2331–2343.

Detmann, E., Valente, É.E.L., Batista, E.D. & Huhtanen, P., 2014. An evaluation of the performance and efficiency of nitrogen utilization in cattle fed tropical grass pastures with supplementation. Livest. Sci. 162, 141–153.

Dzanja, J., Kapondamgaga, P. & Tchale, H., 2013. Value Chain Analysis of Beef in Central and Southern Malawi (Case Studies of Lilongwe and Chikhwawa Districts). Int, J of Phy. and Soc.Sci.4, 92–103

FAO, 2007. Sub-regional report on animal genetic resources: Southern Africa. Annex to the State of the World's Animal Genetic Resources for Food and Agriculture (pp1–37). Rome, Italy

IPCC, 2007. Climate Change 2007: Impacts, adaptation and vulnerability. Intergovernmental Panel on Climate Change

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group

I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Khanyile, M., Ndou, S.P. & Chimonyo, M., 2014. Influence of Acacia tortilis leaf meal-based diets on growth performance of pigs. Livest. Sci. 167, 211–218.

Kuyah, S., Sileshi, G.W., Njoloma, J., Mng'omba, S. & Neufeldt, H., 2014. Estimating aboveground tree biomass in three different miombo woodlands and associated land use systems in Malawi. Biomass and Bioenergy 66, 214–222.

Mackinder, B. 1999. Three New Taxa and a New Name in Dolichos L. (Leguminosae: Papilionoideae: Phaseoleae). Kew Bulletin, 54, 415–423.

Mapiye, C., Chimonyo, M., Marufu, M.C. & Dzama, K., 2011. Utility of *Acacia karroo* for beef production in Southern African smallholder farming systems: Anim. Feed Sci. Technol. 164, 135–146.

Mlambo, V. & Mapiye, C., 2015. Towards household food and nutrition security in semi-arid areas: What role for condensed tannin-rich ruminant feedstuffs? Food Res. Int. 76, 953–961.

Masikati P., Homann-Kee Tui S., Descheemaeker K., Crespo O., Walker S., Lennard C. J., Claessens L., Gama A. C., Famba S., van Rooyen A. F. & Valdivia R.O., 2015. Crop–livestock intensification in the face of climate change: exploring opportunities to reduce risk and increase resilience in southern Africa by using an integrated multi-modeling approach. In: Rosenzweig C, Hillel D (eds) Handbook of climate change and agroecosystems: the Agricultural Model Intercomparison and Improvement Project (AgMIP) Integrated Crop and

Economic Assessments. Joint Publication with American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Imperial College Press, London, pp 159–200.

Muchenje, V., Dzama, K., Chimonyo, M., Raats, J. G. & Strydom, P. E., 2008. Tick susceptibility and its effects on growth performance and carcass characteristics of Nguni, Bonsmara and Angus steers raised on natural pasture. Anim. 2, 298-304

Mwai, O., Hanotte, O., Kwon, Y.J. & Cho, S., 2015. African Indigenous Cattle: Unique Genetic Resources in a Rapidly Changing World. Asian-Aust. J. of Anim. Sci. 28, 911–921.

Nkhonjera, L., Agymang, K. & Butterworth, M.H., 1988. Performance of cattle stall-fed for beef in Malawi. Trop. Anim Health Prod. 20, 155-60.

Reynolds, L., 2006. Malawi: country pasture/forage resource profiles. FAO, Rome, Italy.

Ricker-Gilbert, J., Jumbe, C. & Chamberlin, J., 2014. How does population density influence agricultural intensification and productivity? Evidence from Malawi. Food Policy. 48, 114-128.

Sivakumar, M.V.K., Tarasova, O., Nickovic, S., Terblanche, D. & Asrar, G., 2013. Contribution of WPO programs in addressing climate change in agriculture. In: Handibook of climate change and agroecosystems: globe and regional aspects and implications. D.H and C. Rosenzweig (eds), pp235-261. Imperial College Press, London.

Soji, Z., Chikwanda, D., Chikwanda, A.T., Jaja, I.F., Mushonga, B. & Muchenje, V., 2015. Relevance of the formal red meat classification system to the South African informal livestock sector. S. Afr. J. Anim. Sci. 45, 263–277.

Strydom, P. E., 2008. Do indigenous Southern African cattle breeds have the right genetics for commercial production of quality meat? Meat Sci. 80, 86–93.

Tedeschi, L.O., Cavalcanti, L.F.L., Fonseca, M.A., Herrero, M. & Thornton, P.K., 2014. The evolution and evaluation of dairy cattle models for predicting milk production: An agricultural model intercomparison and improvement project (AgMIP) for livestock. Anim. Prod. Sci. 54, 2052–2067

World Bank, 2016. Malawi Economic Monitor, May 2016: Absorbing Shocks, Building Resilience. World Bank, Lilongwe, Malawi. World Bank.

Chapter 2: Literature Review

2.1 Introduction

Compelling and unequivocal evidence shows that there has been an increase in the atmospheric concentrations of carbon dioxide, methane, and nitrous oxide, the important greenhouse gases, over the last few centuries (IPCC, 2013). This increase in concentration is driving the increase in global mean surface air temperatures over land and ocean, leading to a high likelihood of the occurrence and/or strength of extreme weather and climate events. Regionally, global warming has resulted in lower precipitation and hotter environments in Southern African countries, including Malawi (IPCC, 2007). In terms of the livestock sector, the effects of global warming, especially low precipitation, would result in short and long-term shortages of animal feeds (Nardone et al., 2010). Within the agricultural sector, smallholder farmers are the most vulnerable to climate change, because of their dependence on climate-sensitive resources and low management levels (Morton, 2007). Therefore, it is important to equip and/or enhance the capacity of smallholder farmers to deal with both the short- and long-term reduction in feed supply induced by climate change.

Before interventions are developed aimed at equipping farmers to deal with climatic induced challenges, it is important to evaluate their perceptions on climate change. In general, farmers's perceptions show agreement with long time series data on changes of cattle production conditions (Mergersa et al 2014). Their perceptions could therefore be used for making important decisions and for formulating a particular farming system. Besides bio-physical factors, other factors endogenous to the society, including socio-economic factors moderate farmers' ability to perceive and adapt to climate change (Adger et al., 2009). In-depth knowledge of factors influencing farmers' perceptions on climate change are crucial when formulate locally applicable adaptation and mitigation strategies, which could reduce the impact of climate change on beef production, and improve its contribution to household food security and income for resource-poor smallholder farmers (Megersa et al., 2014). Perceptions also have a strong influence on how farmers deal with climate-induced risks and opportunities, and the precise nature of their behavioural responses to these perceptions will shape adaptation and mitigation options, the process involved and adaptation and mitigation outcomes (Adger et al,. 2009; Debela et al., 2015). The development therefore of strategies aimed at equipping farmers to deal with climate may require involving farmers at an early stage, to formulate appropriate interventions for the farmers.

Strategies that explore the use of animal feeds that are more adaptable to the local environments would help deal with severe feed shortages. Some of feeds that are adaptable are rangeland-based protein sources, which include leaf-meals from indigenous leguminous browse and tree-borne oilseeds. These resources have the potential of replacing conventional protein sources in cattle diets in smallholder production systems (Mlambo and Mapiye, 2015; Madzimure et al., 2011). However, evidence-based information on the role of rangeland-based protein sources in improving beef production and product quality, would be important for their adoption in the smallholder areas. This review offers an insight into strategies that may be pursued to improve feed availability, particularly protein supply for beef cattle in the smallholder areas. The potential of rangeland-based feed resources as protein supplements for improving beef production, and as an adaptation to climate change, is also reviewed. The review further explores effective ways of utilizing rangeland-based protein sources as protein supplements.

2.2 Beef production systems in Malawi

Beef production in Malawi is classified into commercial and smallholder systems (Dzanja et al., 2013). The commercial system consists of pasture-based production on large farm estates, and feedlots, which are limited to a small area around a sugar factory in the Chikwawa District, south of Malawi (Chintsanya et al., 2004). Despite its potential, beef production on large farm estates is limited, since it is considered as a secondary activity to crop production (Chintsanya et al., 2004). Product quality and marketing of beef from the commercial sector are controlled and organized, with animals slaughtered through abattoirs and sold either to the abattoirs or directly to super-markets, butcheries or hotels (Dzanja et al., 2013).

Smallholder beef production is divided into the small-scale (subsistence-cum-commercial farmers) and subsistence communal sectors. Over 97% of the cattle kept in the smallholder areas in Malawi are of the indigenous Malawi Zebu breed (Changadeya., 2013). The average herd size is eight cattle per farmer (Tanganyika et al., 2011). Cattle have multipurpose roles in the smallholder areas, with the main reasons given for keeping cattle being income generation, milk and manure production (Tanganyika et al., 2011). Smallholder beef production contributes over 90% of the total beef produced in Malawi (Dzanja et al., 2013). Malawi Zebu is a small-framed *Bos indicus* breed (Strydom, 2008) and has a mature weight of 265 kg for cows and 300 kg for bulls (Butterworth and McNitt, 1984). Morphologically, Malawi Zebu is similar to most East African Zebu breeds such as Maasai and Kamba Zebu (Mwacharo et al., 2006). Malawi Zebu cattle have a mean carcass dressing percentage of 52% (Butterworth and McNitt, 1984) but their meat quality attributes are, however, not known.

Beef from smallholder areas is usually of suboptimal carcass yield because animals are drawn from herds traditionally kept on communal rangelands, where feed quantity and quality fluctuate with season and grazing management is poor (Dzanja et al., 2013). Consequently, most cattle are marketed through an informal marketing channel, which is characterised by unscrupulous middlemen/speculators as the main buyers who offer low prices. Dzanja et al. (2013) also observed that the profitability of cattle from the smallholder sector in Malawi improves when farmers place their cattle in feedlots and sell them through formal markets. In addition, the low profitability in the informal markets is caused by the low participation of high-income consumers, because of food safety concerns, as cattle are normally slaughtered in unhygienic slaughter slabs including slaughtering along road-sides, without any stunning and aging (World Food Logistic Organisation Report, 2005). Several strategies for improving the nutrition of cattle in the smallholder areas are known and include pasture production, processing of crop residues, and protein supplementation (Owen et al., 2012). The following section will review nutrition improvement strategies that have been implemented in Malawi and smallholder farming systems in general, for improving beef production and the role rangeland protein sources.

2.4 Strategies for improving quality and feed availability for beef cattle in smallholder production systems in Malawi

2.4.1 Improved rangeland and pasture production

Quantity and quality of feed in natural grasslands in the tropics, where most smallholder farming is practiced, is limited by seasonality, and becomes critically low during the long dry season (Mapiye et al., 2011). To improve forage quality and quantity in Malawi, the following strategies have been implemented: under-sowing of improved grasses and legumes into rangelands; fencing and demarcating rangelands into paddocks; and over-sowing or intercropping of grass and forage legume species with food crops for the land-constrained farmers (Msiska and Nkhonjera, 1991; Kumwenda and Ngwira, 2003). Rangeland reinforcement and cultivated pastures in Malawi are constrained due to a lack of land tenure in communal grazing areas, as well as the high cost of agronomic inputs, fencing materials and irrigation equipment (Kumwenda and Ngwira, 2003).

Although rangeland improvement might increase animal productivity and incomes, it is important to realise that smallholder cattle production is inherently complex due to the multipurpose functions of cattle, and external constraints including marketing systems and climatic conditions (MacLeod et al., 2011). Simple technologies such as hay-making using rangeland grasses, which are abundant during the rainy season could be important in smallholder livestock systems (Sundstöl, 2013). Sundstöl (2013) observed that high quality hay could be obtained from rangeland grasses if they were harvested at the early stages of maturity. Crop residues, mostly from arable crops are important feeds for cattle in mixed-crop smallholder farming systems as they contribute over 50% of the feeds for cattle (Herrero et al., 2013). Therefore, improved utilization of crop residues could improve beef cattle production in Malawi.

2.4.2 Improved utilisation of crop residues in Malawi

Maize stover is an abundant crop residue in Malawi (Tanganyika et al., 2011). However, maize stover, which is seasonal, is bulky, has high lignin, and low CP, vitamin and mineral content, low digestibility, and poor palatability (Kamanzi and Mapiye, 2012). Urea and/or ammonia, and enzyme treatments are used for improving the digestibility and palatability of crop residues (Owen et al., 2012). However, these technologies are not utilised in smallholder cattle production in Malawi (Tanganyika et al., 2011). Unavailability and the requirement for technical know-how prevent the use of urea and/or ammonia and enzyme treatments in the smallholder cattle production systems (Owen et al., 2012).

2.4.3 Mineral supplementation

Common natural grasses in tropical environments have low mineral content including phosphorus, calcium, magnesium, copper, and zinc, which can be below the minimum requirement for optimal animal production (Ndebele et al., 2005). Several forms of mineral supplements are available including urea-molasses-mineral blocks and multi-mineral blocks, to reduce these mineral deficiencies. However, the high cost and unavailability of these mineral supplements limit their use in the smallholder areas of Malawi (Mtimuni, 2013). It is, therefore, important to find locally available and cheap feedstuffs that have high level of minerals that could meet animal requirements for both maintenance and production purposes.

2.4.4 Fodder from multipurpose tree legumes as protein supplements

Use of conventional protein supplements including cereal grains and oilcakes such as corn, soybean, cotton and sunflower seedcake is limited in smallholder cattle production because of their high prices due to low production (Mtimuni, 2013). In addition, use of herbaceous forage legumes such as *Lablab purpureus* and *Centrosema pubescens* is not common (Mtimuni, 2013) due to the constraints previously discussed in Section 2.4.1. To improve protein supplementation, smallholder farmers are encouraged to grow multipurpose tree legume (MPTL) species including *Calliandria calothyrsus, Acacia anguistissima*, *Leucaena spp.*, *Sesbania sesbania* and *Morus alba* as affordable protein sources for cattle (Franzel et al., 2014). Singh et al. (2014) reported higher CP content and greater fibre degradability of tropical grasses when MPTL leaf-meals were added to the grasses-based diets. *Calliandra spp. and Leucaena spp* are currently the most widely recommended fodder trees due to their high biomass yield, CP content, palatability and digestibility (Herrero et al., 2013). However, their adoption in the smallholder sector is low in Africa due to small landholding sizes, which are primarily devoted to cereal production, initial capital outlay, unavailability of seed, pest and diseases, and poor extension services (Franzel et al., 2014). On the other hand, rangeland-based protein sources including leaves, pods and seeds from indigenous browse trees can play an important role as protein supplements in the smallholder beef sector because of their low-cost, abundance and wide distribution in the local environments (Khanyile et al., 2014; Mlambo and Mapiye, 2015).

2.5 Potential rangeland-based protein sources for beef cattle production in Malawi

Owing to their ubiquity, *Vachellia spp*, formerly *Acacia* (Kyalangalilwa et al., 2013), have the highest potential for use as protein supplements for beef cattle in smallholder areas in southern Africa (Mlambo and Mapiye, 2015). *Vachellia spp.* occur across all semi-arid regions in Africa where some species emerge as encroachers in grazing areas (Mapiye et al., 2009b). Leaves and pods of *Vachellia* trees contain high levels of protein and minerals (Table 2.1 and 2.2) that could meet beef cattle protein and mineral requirements. Mapiye et al. (2010) supplemented leaf-meals of *Vachellia karroo* to grazing Nguni cattle in South Africa and observed an improvement in average daily gain (ADG) and meat quality.

Extensive use of *Vachellia spp* in ruminant diets is constrained by the presence of tannins (Ben Salem et al., 2005), which can be as high as 260 g/kg DM (Table 2.1 and 2.2). Dietary condensed tannin concentration less than 20 g/kg DM typically does not compromise feed intake, digestibility and nutrient absorption (Orlandi et al., 2015). Besides, tannins in the diet can bind dietary protein and reduce its degradation in the rumen, and if the bound-protein is digestible in post-ruminal sites, it can contribute to metabolizable protein supply (Makkar, 2003). Environmentally, feeding tannin-rich diets results in a shift in the route of nitrogen excretion from urine to faeces, thereby, reducing environmental pollution caused by urinary urea-nitrogen (Grainger et al., 2009). In addition, tannins do not remain inert along the whole gastrointestinal tract in animals; rather, some could undergo chemical modifications in the gut leading to their depolymerization and catabolism into smaller molecules which, in turn, are absorbed and have stabilising effects on haem pigment concentration and metmyoglobin formation in the meat (Luciano et al., 2009). Given that tannins have antioxidant and antimicrobial properties, their presence in meat is known to improve product quality (Luciano et al., 2009).

Table 2.1 Chemical composition of *Vachellia* browse species in African environments

Chemical	Part	Range	Source
CP, g/ kg DM	Leaves	148-195	Rubanza et al., 2007; Mapiye et al., 2009; Kanyile et al., 2014
	Fruit	88-169	Mlambo et al., 2008
	Seeds	250-366	Mlambo et al., 2008; Embaby and Rayan, 2016
Fat, g/kg DM	Leaves	20-33	Mapiye et al., 2009, Kanyile et al., 2014
	Fruit	-	
	Seed	84-99	Embaby and Rayan, 2016
NDF, g/ kg DM	Leaves	400-602	Rubanza et al.,2007; Mapiye et al., 2009; Kanyile et al., 2014
	Fruit	236-543	Mlambo et al., 2008
	Seed	227-356	Mlambo et al., 2008
ADF, g/ kg DM	Leaves	95-290	Rubanza et al., 2007; Mapiye et al., 2009; Kanyile et al., 2014
	Fruit	172-400	Mlambo et al., 2008
	Seed	205-296	Mlambo et al., 2008
Lignin, g/ kg DM	Leaves	50-130	Rubanza et al., 2007; Mapiye et al., 2009
	Fruit	45-114	Mlambo et al., 2008
	Seed	37-56	Mlambo et al., 2008
Starch, g/ kg DM	Leaves		
	Fruit	12-11	Mlambo et al., 2008
	Seed	13-20	Mlambo et al., 2008
ivNDFD,48 h, %	Leaves	440	Mapiye et al., 2009
Total phenols, g/ kg DM	Leaves	104-281	Rubanza et al., 2007
	Fruit	1.4-11	Mlambo et al., 2008
	Seeds	6.7–12.0	Mlambo et al., 2008; Embaby and Rayan, 2016;
Condensed tannins, g/ kg DM	Leaves	40-93	Rubanza et al., 2007; Kanyile et al., 2014
	Fruit	0.5-5.0	Mlambo et al., 2008
	Seeds	0.4-4.0	Mlambo et al., 2008

ivNDFD= *In vitro* neutral detergent fibre digestibility

Table 2.2 Mineral composition of Vachellia browse species in African environments

Mineral	Part	Range	Sources
Ca g/kg	Leaves	4-21	Mapiye et al., 2009; Kanyile et al., 2014
	Seeds	69–72	Embaby and Rayan, 2016
P g/kg	Leaves	0.08	Mapiye et al., 2009; Kanyile et al., 2014
	Seeds	64.0–71.	Embaby and Rayan, 2016
Fe, g/kg	Leaves	0.16-0.37-	Mapiye et al., 2009 g/kg
	Seeds	3.11–4.30	Embaby and Rayan., 2016
Cu, mg/kg	Leaves	2-14	Mapiye et al., 2009; Kanyile et al., 2014
	Seeds	6.3–8.6	Embaby and Rayan, 2016
Zn, mg/kg	Leaves	12-22	Mapiye et al; 2009; Kanyile et al 2014

As reviewed by Mapiye et al. (2011) and Mueller-Harvey (2006), methods used for alleviating the deleterious effects of tannins in browse trees include chemical treatment with urea, ammonia, calcium hydroxide, sodium hydroxide, potassium hydroxide, potassium dichromate, potassium permanganate; wood ash and charcoal, polyethylene glycol and sun-drying. Although sun-drying is not a highly effective method for reducing tannin content (Makkar, 2003), it is a less expensive method for smallholder farmers (Mapiye et al., 2011). Co-feeding tannin rich feeds with sun-drying could further moderate the effects of tannins through the diluting effect (Mueller-Harvey, 2006; Mlambo and Mapiye, 2015). However, the authors encouraged studies to explore how the diluting effects of tannins through co-feeding would affect nutrient digestibility and animal performance.

Besides *Vachellia spp*., some indigenous tree legume species including *Erythrina spp* (*Erythrina abbyssinia* and *Erythrina livingstoniana* have also been identified as potential browse legume trees because of their high protein content (up to 203 g/kg DM) and low toxicity (Yinnesu and Nurfeta, 2012; Reigner et al, 2013). *Erythrina spp*. is a fast-growing deciduous legume tree of small to medium height (2-15 m) native to subtropical regions (Hyde et al., 2014). The major anti-nutritional factors in *Erythrina spp*. are alkaloids, phenols and flavonoids (Régnier et al., 2013). *Erythrina spp.* contain erysodine, erysopine, erythraline and erythroidine alkaloids which are neuromuscular blocking agents (Wink, 2013). The *Erythrina* alkaloids are more concentrated in seeds (13 mg/kg DM) than stems and leaves (2mg/kg DM; Garcıa-Mateos et al., 1998). Interestingly, Erythrina leaf-meals have been fed to pigs (Reigner et al., 2013) without observations of alkaloid toxicity. With limited information available on alkaloid toxicosis, it is important to be cautious and check for similar signs of alkaloid toxicosis when feeding cattle with *Erythrina* leaf-meals. On the other hand, issues of sustainable use of these resources must be dealt with including pruning of the trees to promote regrowth or planting them. *Vachellia* and *Erythrina spp.* could be ideal due to their abundant availability, adaptability, rapid growth and easy propagation (Hyde, et al. 2014).

Besides leaves of leguminous trees, natural environments in the tropics offer tree-borne oilseeds (TBO) such as baobab seed (Vermaak et al., 2011). The TBO contain high protein and mineral contents; for example, baobab seeds contain up to 360 g CP/kg DM (Assogbadjo et al., 2012) and an appreciable level of phosphorus (6 g/kg DM), calcium (4 g/kg DM), and zinc (26 mg/kg DM).

Therefore, TBO may be used as a protein supplement (Rahul et al., 2015). However, baobab seed contains antinutritional factors including tannins, oxalate and trypsin inhibitors (Proll et al., 1998; Osman, 2004) but their levels are too low to bring about any adverse effects in animals. Consequently, baobab have been used in poultry (Mwale et al., 2008) and dairy cattle (Madzimure et al., 2011) diets without adverse effects on performance. Nevertheless, there are inconsistent reports on the chemical composition of baobab seed; for instance, Muthai et al., (2017) reported CP values less than 150g/kg DM. In addition, there is sparse information on the use of natural tree-borne oilseeds and on their effects on beef production and quality when included in beef cattle diets. Research is, therefore, encouraged to evaluate the nutritive value and effects of feeding cattle with baobab seed meal or seed-cake on the production performance, carcass and beef quality characteristics.

Supplementation strategies to improve the nutrition of cattle in smallholder production systems are often focused on providing specific nutrients, particularly protein (Garg et al., 2013), without considering the dynamic nature of nutrient requirements in the animals as influenced by several factors including the physiological stage of production, and environmental conditions. However, maximum efficiency of feed utilization in animals is attained by providing them with nutritionally balanced diets (NRC, 2000). For example, when energy is first limiting, any supplemental protein, will be used to meet energy requirements until both energy and protein are equally limiting (NRC, 2000). On the other hand, if protein is first limiting, energy supplementation may not improve animal performance. In addition, for supplementation to be effective, diets should be formulated by not only accounting for feed composition, but also the changes in the nutrient requirements of animals as influenced by several factors including the physiological state and environmental conditions (Fox et al., 2004). This is achieved with aid of nutritional models, which are used for formulating diets based on simulations that account for feed composition, animal and environmental factors (NRC 2000; Fox et al., 2004).

2.5.1 Nutritional mathematical models as a tool for predicting animal requirements

There are several models available for establishing precision feeding of animals including the Beef Cattle Nutrient Requirement Model (BCNRM; National Academies of Sciences, Engineering, and Medicine, 2016), the Ruminant Nutrition System (RNS; Tedeschi and Fox (2016) and the Large Ruminant Nutritional Systems (LRNS, Fox et al., 2004; Tedeschi et al., 2014). The LRNS, RNS, and BCNRM models are based on the Cornell Net Carbohydrate Protein System (CNCPS). The CNCPS enables predictions for animal performance based on several variables including feed composition, rumen function, microbial growth, feed digestion and passage rates, the animal's physiological state and environment (Fox et al., 2004). By accounting for specific animal-feed-environment factors, use of CNCPS based models are applicable in diverse cattle production systems (Tylutki et al., 2008). Although the CNCPS based models contain biological and environmental factors, which theoretically allow their application in various environmental conditions and management systems, on different breeds and feeds, there are inconsistent reports on their application in different production environments (Molina et al., 2004; Zhao et al., 2008; Du et al., 2010; Morenz et al., 2012; Parsons et al., 2012). Their application in a new environment, therefore, require prior evaluation and possible adjustments for optimization, particularly regarding animal requirements emanating from breed and pedo-climatic differences, and variation in forage nutrient composition and digestibility (Morenz et al., 2012).

Precision feeding would help farmers organize and plan for utilization of rangeland feed resources. However, to apply the models in smallholder farming system would require participation of different stakeholders. These stakeholders will include; 1) feed manufacturers for formulating and producing compound feeds based on the models, 2) beef production specialist for guiding the model input and outcome, 3) sellers of leaf-meals and oilseeds, 4) extension workers, and 5) smallholder farmers. This arrangement has a potential of improving beef production and the adaptation capacity of farmers to climate change. However, it is important to evaluate predictions of animal performance of the different models under smallholder environments before recommending their application.

2.6 Beef marketing in the smallholder sector as a hindrance to adoption of new technologies

Due to its unpredictability, informal marketing may not enhance the adoption of new innovations by smallholder farmers. One of the reasons why smallholder farmers participate in informal markets is that the standards in the formal markets, including classification or grading often penalises their indigenous animals due to their inherent traits such as their small size and slow growth that can reduce beef tenderness (Soji et al., 2015). Several authors including Strydom et al. (2015) have argued for the improvement of the beef carcass classification and grading systems in southern Africa, especially in South Africa but their focus has been on meeting consumers' expectations on the eating quality of beef. In that regard, it is important to identify shortcomings in the principle criteria of the current classification or grading systems that do not favour indigenous animals and suggest where improvements should be made.

2.7 Summary

Rangeland-based protein feed resources might provide farmers with the means to adapt to short- and long-term feed shortages induced by climate change. Although they can contain a high amount of several nutrients, the use of rangeland protein sources as protein supplements, especially tree-oilseeds, in beef diets is limited in the smallholder farming sector. To guide the use of rangeland-based protein sources, it is important to evaluate their nutrient composition and the effects of feeding steers with diets containing indigenous browse leaf-meals and tree borne-oilseeds on animal performance and meat quality. To ensure precision feeding of these resources, nutritional computer models could be of importance as they account for the nutrient composition of the feeds, animal factors and environmental factors when formulating and evaluating the diets. Also, policy issues should not be ignored as they directly impact the rate and extent of adoption of innovations in the smallholder sector. The objective of the current study was, therefore to evaluate the perceptions of smallholder farmers towards climate change, identify and evaluate nutrition profile of potential protein sources during drought, and their actual production value when fed to Malawi Zebu steers under feedlot conditions.

2.7 References

Adger, W.N., Dessai, S., Goulden, M., Hulme., M., Lorenzoni, I., Nelson, D.R. & Wreford, A., .2009. Are there social limits to adaptation to climate change? Clim. Chang. 93,335–354.

Assogbadjo, A.E., Chadare, F.J., Kakaï, R.G., Fandohan, B. & Baidu-Forson, J.J., 2012. Variation in biochemical composition of baobab (*Adansonia digitata*) pulp, leaves and seeds in relation to soil types and tree provenances. Agric. Ecosyst. Environ. 157, 94–99.

Ben Salem, H., Abidi, S., Makkar, H.P.S. & Nefzaoui, A., 2005. Wood ash treatment, a cost-effective way to deactivate tannins in *Acacia cyanophylla* Lindl. foliage and to improve digestion by Barbarine sheep. Anim. Feed Sci. Technol. 122, 93–108.

Butterworth, M.H, & McNitt, J.I., 1994. The Malawi Zebu. Wrld Anim. Rev. Article No. 49.

Changadeya, W., Ambali, A., Nyirenda, J., Chagunda, M. & Kaunda, E., 2012. Genetic diversity and population structure of Malawi Zebu cattle. Int. J. Phys. Soc. Sci. 2, 59–81.

Chintsanya, N. C., Chinombo, D. O., Gondwe, T. N., Wanda, G., Mwenda, A. R. E., Banda, M. C. & Hami, J. C., 2004. Management of farm animal genetic resources in the SADC region: Malawi. (SADC/UNDP/FAO Report, Ministry of Agriculture, Lilongwe)

Debela, N., Mohammed, C., Bridle, K., Corkrey, R. & McNeil, D., 2015. Perception of climate change and its impact by smallholders in pastoral/agropastoral systems of Borana, South Ethiopia. SpringerPlus 4, 236.

Du, J., Liang, Y., Xin, H., Xue, F., Zhao, J., Ren, L. & Meng, Q., 2010. Evaluation of dry matter intake and average daily gain predicted by the cornell net carbohydrate and protein system in crossbred growing bulls kept in a traditionally confined feeding system in China. Asian-Aust. J. Anim. Sci. 23, 1445–1454.

Dzanja, J., Kapondamgaga, P., Tchale. & H., 2013. Value Chain Analysis of Beef in Central and Southern Malawi (Case Studies of Lilongwe and Chikhwawa Districts). Int. J. Phys, Soci. Sci. 4, 92–103.

Embaby, H. E. & Rayan, A. M. 2016. Chemical composition and nutritional evaluation of the seeds of *Acacia tortilis* (Forssk.) Hayne ssp. raddiana. Food Chem. 200, 62–68.

Fox, D., Tedeschi, L.., Tylutki, T.., Russell, J.., Van Amburgh, M., Chase, L., Pell, A.N. & Overton, T., 2004. The Cornell Net Carbohydrate and Protein System model for evaluating herd nutrition and nutrient excretion. Anim. Feed Sci. Technol. 112, 29–78.

Franzel, S., Carsan, S., Lukuyu, B., Sinja, J.& Wambugu, C., 2014. Fodder trees for improving livestock productivity and smallholder livelihoods in Africa. Curr. Opin. Environ. Sustain. 6, 98–103.

Garcia-Mateos, R., Soto-Hernandez, M and Kelly, D. 1998. Alkaloids from six Erythrina species endemic to Mexico. Biochem. Syst. Ecol. 26, 545-551.

Garg, M.R., Sherasia, P.L., Bhanderi, B.M., Phondba, B.T., Shelke, S.K., Makkar & H.P.S., 2013. Effects of feeding nutritionally balanced rations on animal productivity, feed conversion efficiency, feed nitrogen use efficiency, rumen microbial protein supply, parasitic load, immunity and enteric methane emissions of milking animals under field conditions. Anim. Feed Sci. Technol. 179, 24-35.

Grainger, C., Clarke, T., Auldist, M.J., Beauchemin, K.A., McGinn, S.M., Waghorn, G.C. & Eckard, R.J., 2009. Potential use of *Acacia mearnsii* condensed tannins to reduce methane emissions and nitrogen excretion from grazing dairy cows. Can. J. Anim. Sci. 89, 241–251.

Herrero, M., Havlik, P., Valin, H., Notenbaert, A., Rufino, M.C., Thornton, P.K., Blummel, M., Weiss, F., Grace, D. & Obersteiner, M., 2013. Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. Proc. Natl. Acad. Sci. 110, 20888–20893.

Hyde, M.A., Wursten, B.T., Ballings, P. & Coates Palgrave, M. 2014. Flora of Zimbabwe: Species information: *Erythrina livingstoniana*. http://www.zimbabweflora.co.zw/speciesdata/species.php?species_id=132460. Accessed on 22nd September 2014.

IPCC, 2007. Climate Change 2007: Impacts, adaptation and vulnerability. Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kamanzi, M. & Mapiye, C., 2012. Feed inventory and smallholder farmers' perceived causes of feed shortage for dairy cattle in Gisagara District, Rwanda. Trop. Anim. Health Prod. 44,1459-68

Khanyile, M., Ndou, S.P., Chimonyo, M., 2014. Influence of *Acacia tortilis* leaf meal-based diets on growth performance of pigs. Livest. Sci. 167, 211–218.

Kumwenda, M. & Ngwira, A., 2003. Forage demand and constraints to adoption of forage technologies by livestock keepers in Malawi. Trop. Grass., 37, 274–278.

Kyalangalilwa, B., Boatwright, J.S., Daru, B.H., Maurin, O. & Van der Bank, M., 2013. Phylogenetic position and revised classification of *Acacia* s.l. (Fabaceae: Mimosoideae) in Africa, including new combinations in *Vachellia* and *Senegalia*. Bot. J. Linn. Soc. 172, 500–523.

Luciano, G., Monahan, F.J., Vasta, V., Biondi, L., Lanza, M. & Priolo, A., 2009. Dietary tannins improve lamb meat colour stability. Meat Sci. 81, 120–225.

MacLeod, N., Doyle, P.& Winter, B., 2011. Successfully implementing crop–livestock research, development and extension projects in Vietnam: Beef Production in Crop–livestock Systems: Simple Approaches for Complex Problems. Australian Centre for International Agricultural Research, pp. 11–28

Madzimure, J., Musimurimwa, C., Chivandi, E., Gwiriri, L.& Mamhare, E., 2011. Milk yield and quality in Guernsey cows fed cottonseed cake-based diets partially substituted with baobab (*Adansonia digitata L.*) seed cake. Trop. Anim. Health Prod. 43, 77–82.

Makkar, H.P.S., 2003. Effects and fate of tannins in ruminant animals, adaptation to tannins, and strategies to overcome detrimental effects of feeding tannin-rich feeds. Small Rumin. Res. 49, 241–256.

Mapiye, C., Chimonyo, M., Dzama, K., Strydom, P. E., Muchenje, V. & Marufu, M. C., 2009. Nutritional status, growth performance and carcass characteristics of Nguni steers supplemented with *Acacia karroo* leaf-meal. Liv. Sci. 126, 206–214.

Mapiye, C., Chimonyo, M., Dzama, K., Muchenje, V. & Strydom, P. E., 2010. Meat quality of Nguni steers supplemented with *Acacia karroo* leaf-meal. Meat Sci. 84, 621–7.

Mapiye, C., Chimonyo, M., Marufu, M.C. & Dzama, K., 2011. Utility of *Acacia karroo* for beef production in Southern African smallholder farming systems: A review. Anim. Feed Sci. Technol. 164, 135–146.

Megersa, B., Markemann, A., Angassa, O.J.O., Piepho, H.P. & Valle Zaráte, A. 2014. Impacts of climate change and variability on cattle production in southern Ethiopia: perceptions and empirical evidence. Agric. Syst. 130, 23–34.

Mlambo, V., Mould, F. L., Sikosana, J. L. N., Smith, T., Owen, E. & Mueller-Harvey, I., 2008. Chemical composition and in vitro fermentation of tannin-rich tree fruits. Anim. Feed Sci. and Technol. 140, 402–417.

Mlambo, V. & Mapiye, C., 2015. Towards household food and nutrition security in semi-arid areas: What role for condensed tannin-rich ruminant feedstuffs? Food Res. Int. 76, 953–961.

Molina, D., Matamoros, I., Almeida, Z., Tedeschi, L. & Pell, A., 2004. Evaluation of the dry matter intake predictions of the Cornell Net Carbohydrate and Protein System with Holstein and dual-purpose lactating cattle in the tropics. Anim. Feed Sci. Technol. 114, 261–278.

Morenz, M.J.F., da Silva, J.F.C., Aroeira, M. L.J., Deresz, F., Vásquez, H.M., Lopes, F.C. F., Paciullo, D.S.C. & Tedeschi L. O., 2012. Evaluation of the Cornell Net Carbohydrate and Protein System model on the prediction of dry matter intake and milk production of grazing crossbred cows. R. Bras. Zootec, 41, 398-406

Morton, J.F., 2007. The impact of climate change on smallholder and subsistence agriculture. Proc. Natl. Acad. Sci. 104, 19680–19685.

Msiska, H.D.C. & Nkhonjera, L.P., 1991. The status of livestock production in communal grazinglands of Ma1awi, Proc. A workshop for SADCC countries. Mahale's Hoek, Lesotho, pp.30-40

Mtimuni, J.P., 2011. Forage and seed resources, Scoping papers under Optimising Smallholder Dairy Project. Scotish Agricultural College, Edinnburgh. FSC mix paper No SC 0003712

Muchenje, V., Dzama, K., Chimonyo, M., Raats, J. G. & Strydom, P. E., 2008. Tick susceptibility and its effects on growth performance and carcass characteristics of Nguni, Bonsmara and Angus steers raised on rangeland. Animal. 2, 298 – 304

Mueller-Harvey, I., 2006. Unravelling the conundrum of tannins in animal nutrition and health. J. Sci. Food Agric. 86, 2010–2037.

Muthai, K.U., Karori, M.S., Muchugi, A., Indieka, A.S., Dembele, C., Mng'omba, S.& Jamnadass, R., 2017. Nutritional variation in baobab (*Adansonia digitata L.*) fruit pulp and seeds based on Africa geographical regions. Food Sci. Nutr. 1–14.

Mwacharo, J.M., Okeyo, A.M., Kamande, G.K. & Rege , J.E.O., 2006. The small East African shorthorn zebu cows in Kenya. I: Linear body measurements. Anim Health Prod 38, 65-74.

Mwale, M., Mupangwa, J.F., Mapiye, C., Saina, H. & Chimvuramahwe, J., 2008. Growth performance of guinea fowl keets fed graded levels of baobab seed cake diets. Int. J. Poult. Sci. 7, 429–432.

Nardone, A., Ronchi, B., Lacetera, N., Raneiri, M.S. & Bernabucci, U. 2010. Effect of climate change on animal production and sustainability of livestock systems. Liv. Sci. 130, 57-59.

National Academies of Sciences, Engineering, and Medicine. 2016. Nutrient Requirements of Beef Cattle. (8th ed.). Nutrient requirements of domestic animals. National Academy Press, Washington, DC.

Ndebele, N., Mtimuni, J.P., Mpofu, I.D.T., Makuza, S. & Mumba, P., 2005. The status of selected minerals in soil, forage and beef cattle tissues in a semi-arid region of Zimbabwe. Trop. Anim. Health Prod. 37, 381–393.

NRC, 2000. Nutrient Requirements of Beef Cattle: Seventh Revised Edition. Update 2000 Washington, DC: The National Academies Press.

Orlandi, T., Kozloski, G. V., Alves, T.P., Mesquita, F.R. & Ávila, S.C., 2015. Digestibility, ruminal fermentation and duodenal flux of amino acids in steers fed grass forage plus concentrate containing increasing levels of Acacia mearnsii tannin extract. Anim. Feed Sci. Technol. 210, 37–45.

Osman, M.A., 2004. Chemical and nutrient analysis of baobab (Adansonia digitata) fruit and seed protein solubility. Plant Foods Hum. Nutr. 59, 29–33.

Owen, E., Smith, T. & Makkar, H., 2012. Successes and failures with animal nutrition practices and technologies in developing countries: A synthesis of an FAO e-conference. Anim. Feed Sci. Technol. 174, 211–226.

Parsons, D., Van, N.H. Malau-Aduli, A.E.O., Ba, N.X., Phung, L.P., Peter A. Lane, P.A., Ngoan, L.D., Tedeschi, L.O., 2012. Evaluation of a nutrition model in predicting performance of Vietnamese Cattle Asian-Aust. J. Anim. Sci. 25, 1237 – 1247.

Proll, J., Petzke, K.J., Ezeagu, I.E. & Metges, C.C., 1998. Low nutritional quality of unconventional tropical crop seeds in rats. J. Nutr. 128, 2014–2022.

Rahul, J., Jain, M. K., Singh, S. P., Kamal, R. K., Anuradha, Naz, A. & Mrityunjay, S. K., 2015. *Adansonia digitata L*. (baobab): A review of traditional information and taxonomic description. Asian Pac. J. of Trop. Biomed., 5: 79–84.

Régnier, C., Bocage, B., Archimède, H., Noblet, J.& Renaudeau, D., 2013. Digestive utilization of tropical foliages of cassava, sweet potatoes, wild cocoyam and *Erythrina* in Creole growing pigs. Anim. Feed Sci. Technol. 180, 44–54.

Rubanza, C.D.K., Shem, M.N., Bakengesa, S.S., Ichinohe, T. & Fujihara, T., 2007. Effects of *Acacia nilotica*, *A. polyacantha* and *Leucaena leucocephala* leaf meal supplementation on performance of Small East African goats fed native pasture hay basal forages. Small Rumin. Res. 70, 165–173.

Singh, S., Anele, U.Y., Edmunds, B.& Südekum, K.H., 2014. *In vitro* ruminal dry matter degradability, microbial efficiency, short chain fatty acids, carbohydrate and protein fractionation of tropical grass-multipurpose tree species diets. Livest. Sci. 160, 45–51.

Soji, Z., Chikwanda, D., Chikwanda, A.T., Jaja, I.F., Mushonga, B. & Muchenje, V., 2015. Relevance of the formal red meat classification system to the South African informal livestock sector. S. Afr. J. Anim. Sci. 45, 263-277.

Strydom, P.E., 2008. Do indigenous Southern African cattle breeds have the right genetics for commercial production of quality meat? Meat Sci. 80, 86–93.

Strydom, P.E., Frylinck, L., Heerden, S.M. Hugo, A.& Webb, E.C., 2015. Sources of variation in quality of South African beef : Case studies in relation to the red meat classification system 45.

Sundstøl, F., 2013. East African farmers benefit from quality hay. Appropr. Technol. 40, 61-63

Tanganyika, J., Bandason, E., Gondwe, T.N.& Homann-Kee Tui, S., 2011. Use of crop residues for sustainable livestock production in -Mzimba district , Malawi. African Crop Sci. Conf. Proc. 10, 495–498.

Tedeschi, L. O., Cavalcanti, L. F. L., Fonseca, M. A., Herrero, M. & Thornton, P. K., 2014. The evolution and evaluation of dairy cattle models for predicting milk production: An agricultural model intercomparison and improvement project (AgMIP) for livestock. Anim. Prod. Sci. 54, 2052–2067.

Tedeschi, L. O., and D. G. Fox. 2016. The Ruminant Nutrition System: An Applied Model for Predicting Nutrient Requirements and Feed Utilization in Ruminants. XanEdu, Acton, MA.

Tylutki, T.P., Fox, D.G., Durbal, V.M., Tedeschi, L.O., Russell, J.B., Van Amburgh, M.E., Overton, T.R., Chase, L.E. & Pell, N., 2008. Cornell Net Carbohydrate and Protein System: A model for precision feeding of dairy cattle. Anim. Feed Sci. Technol. 143, 174–202

Vermaak, I., Kamatou, G.P.P., Komane-Mofokeng, B., Viljoen, A.M. & Beckett, K., 2011. African seed oils of commercial importance - Cosmetic applications. S.Afr. J. Bot. 77, 920–933.

Wink, M. 2013. Evolution of secondary metabolites in legumes (Fabaceae). S.Afri. J. Bot. 89, 164-175.

World Food Logistic Organisation, 2005. The integrated cold chain in southern Africa: Cold chain development in Malawi. Assessment report and recommendations. World Food Logistic Organisation, Alexandria, VA 22314

Yinnesu, A.& Nurfeta, A., 2012. Effects of supplementing *Erythrina brucei* leaf as a substitute for cotton seed meal on growth performance and carcass characteristics of Sidama goats fed basal diet of natural grass hay. Trop. Anim. Health Prod. 44, 445–451.

Zampaligré, N., Dossa, L.H.& Schlecht, E., 2013. Contribution of browse to ruminant nutrition across three agro-ecological zones of Burkina Faso. J. Arid Environ. 95, 55–64.

Zhao, J.S., Zhou, Z.M., Ren, L.P., Xiong, Y.Q., Du, J.P.& Meng, Q.X., 2008. Evaluation of dry matter intake and daily weight gain predictions of the Cornell Net Carbohydrate and Protein System with local breeds of beef cattle in China. Anim. Feed Sci. Technol. 142, 231–246.

Chapter 3: A survey on determinants of farmers' perceptions of impacts on climate change of beef production in Malawi

(Part of the chapter was published in *Climatic Change* Journal , see Appendix A)

Abstract

Climate change is projected to intensify and smallholder farmers will be the most affected because they entirely rely on climate-sensitive livelihoods and have low adaptive capacity. Appropriate coping strategies for smallholder farmers depend on an accurate description of the effects of agro-ecological and farmers' socio-economic factors on climate change. A total of 182 structured questionnaires were administered to determine socio-economic factors affecting smallholder farmers' perceptions of the impacts of climate change on beef production, and identify potential protein sources for use during drought periods in Malawi. Male heads had a higher perception of having increased cattle feed intake and decreased mortality than female heads, suggesting that the former plausibly had better control and access to animal feed and health resources. Young farmers had a greater perception of experiencing a decrease in cattle water supply than adults, implying that they posibly lacked experience required to cope with water scarcity. More educated household heads had a higher perception of experiencing decreased tick loads and increased cattle sales than less educated household heads as they are posited to have increased knowledge of parasite control and understanding of market dynamics and possibly make better marketing decisions. High-income farmers had a lower perception of having decreased rangeland biomass and growth rates than low-income farmers indicating that they might have better access to capital to acquire resources required to improve rangeland and cattle production. Farmers had limited options to minimise the impacts of climate change on beef production including the potential use of indigenous browse legume seeds and leaves as protein sources in the dry season. The most abundantly available indigenous oil-seed trees and browse legume trees mentioned included: *Adansonia digitata* (Baobab, 15% of respondents) seeds, *Dolichos kilimandscharicus* (wild lupin, 21%) and *Vachellia polyacantha* (White thorn tree, 2%) leaves in the dry season. Gender, age, education and income level were the major socio-economic factors that influenced farmers' perceptions on the impact of climate change on beef production. This highlights the importance of incorporating socio-economic factors when devising climate change adaptation and vulnerability reduction strategies for smallholder beef producers.

Keywords: beef production, climate change, smallholder farmers, socio-economic factors.

3.1 Introduction

More than 90% of beef production in Malawi is in smallholder farming areas (Dzanja et al. 2013). Overall, there is growing evidence that smallholder cattle production in sub-Saharan Africa is getting extremely vulnerable to climate change (Kasulo et al., 2012; Megersa et al., 2014). This vulnerability to climate change comes is a product of this region being predominantly located in the a low-latitude regions area where the climate is getting drier and hotter (IPCC, 2007). Various socio-economic factors influencing cattle herd dynamics and farmers' limited capacity to adapt to change also exacerbate smallholder cattle production's susceptibility to climate change (Morton, 2007; Mapiye et al. 2009a). Consequently, the depth severity and persistence of poverty and food insecurity are likely to increase in the smallholder farming areas (Debela et al., 2015).

A recent climate change vulnerability assessment in Malawi showed a prominent substantial change decrease in the mean annual rainfall of 630-1650 mm in the period of 1997-2011 from the historical range of 750-2550 mm (Wood and Moriniere, 2013). In the same period, Wood and Moriniere (2013) reported an sharp increase in maximum temperature of between 0.8 and 2.0 °C in the months of October and November, with maximum temperature in on most days of the summer months exceeding the upper comfort threshold of 32 °C critical above which heat stress occurs for most cattle breeds (Archer van Garderen 2011). Overall, changes in temperature and rainfall have adverse effects on forage and livestock production (Thornton and Herrero, 2014), and can consequently destabilise smallholder cattle producers' livelihoods (Megersa et al., 2014). In Malawi, for example, smallholder farmers are experiencing fluctuations in temperature and rainfall, which can lead to a decline in quantity and quality of crops and forages, and subsequent reduction in animal performance (Kasulo et al., 2012). Rise in temperature and decline in rainfall impact on affects beef production by reducing feed supply and intake, and increasing the prevalence of diseases and parasites (Van den Bossche and Coetzer, 2008). This in turn leads to a decrease in milk production, weight gains, reproductive rates, meat yield and quality (Gregory, 2010).

Besides pedo-climatic factors, socio-economic factors endogenous to the society moderate farmers' ability to perceive and adapt to climate change (Adger et al., 2009). In-depth knowledge of factors influencing farmers' perceptions on climate change are crucial to formulating locally applicable adaptation and mitigation strategies, which could reduce the impact of climate change on beef production and improve its contribution to household food security and income for resource-poor smallholder farmers (Megersa et al., 2014). Perceptions also have a strong influence on how farmers deal with climate-induced risks and opportunities, and the precise nature of their behavioural responses to these perceptions will shape adaptation and mitigation options, the process involved and adaptation and mitigation outcomes (Adger et al,. 2009; Debela et al., 2015). However, information on how socio-economic factors influence farmers' perceptions of on the impact of climate change on smallholder beef cattle production is limited. To understand the impact of climate change on smallholder agriculture, detailed studies that accurately describe the local conditions and background socio-economic conditions in which climate change occurs could be important (Jones and Thornton, 2009). The current study was, therefore, conducted to evaluate socio-economic factors affecting farmers' perceptions of the impact of climate change on beef production in the smallholder farming areas of Malawi and identify potential protein sources for use as cattle feed during drought periods.

3.2 Methods

3.2.1 Sampling procedures and data collection

A multistage purposive sampling method based on the cattle population was used to select the surveyed regions, districts and Extension Planning Areas (EPAs). The survey was conducted in the Northern and Central Regions of Malawi as they have the highest cattle populations. Within each region, the selection of survey areas was stratified based on agro-ecological zones, namely; plateaus, low-altitude, mid-altitude and high-altitude areas. Within each agro-ecological zone, the following districts with the highest cattle population were selected: Salima in low-altitude, Lilongwe in mid-altitude, Dowa in high-altitude and Mzimba in plateau areas. In each district, two EPAs were selected: Chinguluwe and Tembwe in Salima, Chileka and Chiwamba in Lilongwe, except in Dowa (Nachisaka) and Mzimba (Champhira) in where only EPA was selected. An EPA is a point of extension delivery to farming families and each EPA covers five to 15 sections with each section comprising approximately 1500 households.

In each EPA, smallholder farmers owning at least five cattle were randomly selected for interviews from a list of smallholder farmers obtained from a local agricultural office. A total of 182 smallholder beef cattle farmers were interviewed using a pre-tested structured questionnaire in December 2014. Trained enumerators administered the questionnaires in vernacular Chichewa and Tumbuka languages. The pedo-climatic and vegetation characteristics and sample size of respondents in the surveyed districts are shown in Table 3.1.

The data collected included farmers' socio-economic characteristics, farmers' perceptions of impact of climate change on beef production and barriers to climate change adaptation. Data captured also included information on beef cattle herd size, composition and performance. Since browse tree legumes are considered as a more sustainable drought mitigation strategy in low-altitude areas, data on feed availability with a particular emphasis on browse tree legumes was also collected.

Table 3.1 Pedo-climatic and vegetation characteristics of the study areas

Item	Agro-ecological zones			
	Low-altitude (Salima)	Mid-altitude (Lilongwe)	High-altitude (Dowa)	Plateau (Mzimba)
Elevation*, m	33-600	600-1200	1000-1500	800-1200
Temperature* , °C	18-30	16-28	16-28	16-24
Precipitation*, mm	<800	900-1000	900-1000	800-900
Soil type*	Clay loam	Red clay loamy	Sandy clay loam	Red sandy clay
Vegetation*	Savannah	Miombo	Uphill Miombo	Miombo
Sample framework#	241	367	117	434
Respondents interviewed	47	63	39	33

Number of the total farmers; *Sources: Department of Climate Change and Meteorological Services; Reynolds (2006)

3.2.2 Statistical analyses

All the data were analysed using SAS 9.3 (2012). Chi-square tests were computed to determine the association between agro-ecological zone and farmers' socio-economic factors with cattle herd size and composition. Kruskal-Wallis test was used to rank cattle uses and farmers' limitations to effective implementation of climate change adaptation and mitigation strategies. Socio-economic factors affecting farmers' perceptions of impact of climate change on beef production were analysed using an ordered logistic regression model. The model estimated log odds of being at a cut-off point as opposed to being at a lower or higher category of the ordered outcomes (Fullerton, 2009). The main dependent ordered variables were farmers' responses to the impact of climate change on beef production coded: 1 = decreased, 2 = increased and 3 = constant. The independent variables were the determinants of farmers' perceptions. Independent variable (determinants) data set was regrouped to make it binary. Only independent variables whose maximum likelihood estimates converged and had non-significant score test for proportional odds assumptions were included in the model. Forward selection model option embedded in PROC LOGISTIC procedure was used for selecting determinants that were included in the model. The following was the ordered logistic regression model used:

$$\text{Log}\left(\frac{\Pr(Y \leq m \mid x)}{\Pr(Y < m \mid x)}\right) = \tau_m - x\beta(1 \leq m < M$$

Where, m = category (ordered category: 1 = decreased, 2 = increased and 3 = constant); x = effect of the determinant on farmers' perception outcomes; τ = cut-off point; β = vector of logit coefficients; τm = log odds of being in category m or a lower as opposed to a higher category (M) where the ordering of cut points was constrained to τ<1 < τ2…< τM−1. Results were reported as logit coefficients estimate of being at a cut-off point as opposed to being at a lower or higher category of the ordered outcomes. A negative logit coefficient estimate denotes that the category was lower than the cut-off point while a positive logit coefficient estimate indicated the category was higher than the cut-off point.

3.3 Results

3.3.1 Farmers' socio-economic characteristics

Beef production in the surveyed areas was dominated by males (85% of respondents). The majority of interviewees were aged between 40 and 59 years (47%) followed by those aged over 60 years (29%) and less than 40 years (24%). Most of the farmers had primary school education (63%) whereas 11% had secondary education and 26% had no formal education. The majority of the respondents (70%) mentioned crops as their major source of income with the remaining 30% relying on livestock. Apart from crops and livestock, over 60% of the farmers obtained extra income from non-farm activities including wages, remittances, pensions and small businesses to sustain their livelihoods.

3.3.2 Herd size and reasons for keeping cattle in the smallholder farming areas

The majority of farmers (88%) considered cattle as the most important livestock followed by goats (6%), pigs (4%) and chickens (2%). More than 90% of the respondents kept Malawi Zebu and only 7% kept non-descript crosses largely of Malawi zebu with Brahman and Sussex. The results of the chi-square test showed a significant association between agro-ecological zone and cattle herd size ($P<0.05$).

Overall, a greater proportion of farmers (40% of respondents) with large herd sizes (>15) were located in low-altitude areas compared to those the plateau (24%), mid-latitude (20%) and high-latitude (16%) areas. Nonetheless, the chi-square results showed that there was no association ($P<0.05$) between agro-ecological zone and socio-economic factors with herd composition. Overall, cash, followed by manure, were ranked as the most important reasons for keeping cattle in the surveyed areas (Table 3.1). The reasons for keeping cattle, however, varied from one agro-ecological zone to another. Cash was ranked as the most important reason for keeping cattle in all the agro-ecological zones except the plateau area where draught power was ranked first. Respondents in the mid- and high-altitude areas ranked manure as the second most important reason for keeping cattle, while those in the low-altitude and plateau ranked it third. Female and male farmers had similar rankings for use of cattle except source of manure, which was ranked highly by males.

Table 3.2 Uses of cattle in communal areas of Malawi as ranked by farmers

Reason	Rank (mean rank) *				
	Low-attiltude (Salima)	Medium altitude (Lilongwe)	High-altitude (Dowa)	Plateau (Mzimba)	Significance
Cash	1 (1.41)	1 (1.26)	1 (1.73)	2 (2.67)	*
Milk	2 (3.27)	3 (3.30)	4 (4.83)	4 (3.69)	*
Manure	3 (3.33)	2 (2.13)	2 (1.82)	3 (2.72)	*
Draught power	4 (3.91)	4 (3.50)	3 (2.56)	1 (1.72)	*
Meat	5 (4.00)	5 (4.56)	5 (4.83)	6 (4.48)	*
Dowry	6 (5.00)	6 (5.00)	6 (5.00)	4 (2.90)	*

[a]The lower the rank of a reason, the greater is its importance
*Mean ranks of the different reasons are significantly different at $P < 0.05$

3.3.3 Farmers' perceptions of impact of climate change on rangeland production

All the respondents in the surveyed areas were aware of the changes in climate in their location. There was a general perception among the farmers that the amount of annual rainfall received decreased (80% of the respondents) and ambient temperatures rose (76%) over the past two decades. All the interviewees reported that the frequency of prolonged dry spells and droughts increased over the last 20 years.

All the respondents relied on communal rangelands for cattle grazing. Farmers in low- and medium-altitude areas relied on dambos (seasonal wetlands), while those in high-altitude and plateau areas depended on marginal upland areas for grazing cattle. Overall, farmers reported that the decrease in rainfall and the increase in temperatures over the past 20 years had negatively impacted rangeland production and availability of drinking water for cattle. About 80% of the farmers indicated that rangeland biomass yield and quality decreased over the past 20 years. Ordered logit model results showed that agro-ecological zone and level of income influenced (P<0.05) farmers' perceptions of impact on the climate change on rangeland biomass yield and quality (Table 3.3). Farmers in low-altitude areas had a higher perception of experiencing reduced (P<0.05) rangeland biomass yield and quality over the past two decades than those in the other agro-ecological zones. Low-income farmers had a greater (P<0.05) perception of having decreased rangeland quality than high-income farmers. The majority of the farmers (90%) mentioned the disappearance of palatable grass species as the major cause of rangeland deterioration in the surveyed areas.

Table 3.3 Logit coefficients of determinants affecting smallholder farmers' perceptions of the impacts of climate change on beef production and quality in Malawi

	Coefficient Estimates						
	Agro – zone Low vs others	Gender Male vs female	Age Youth vs older	Education Less vs more	Cattle use Cash vs others	Income source Farm vs others	Income level Low vs high
Biomass yield	-0.0840	NS	NS	NS	NS	NS	NS
Biomass quality	-0.589*	NS	NS	NS	NS	NS	-0.085*
Water supply	NS	NS	0.673*	NS	-1.297*	NS	NS
Age at first calving	0.658***	NS	NS	NS	NS	0.7378*	0.846*
Calving rate	-0.684***	NS	NS	NS	NS	NS	NS
Milk production	-0.691*	NS	NS	NS	NS	NS	NS
Feed intake	NS	1.100*	NS	NS	NS	NS	NS
Growth rate	-1.043***	NS	NS	NS	-1.054*	NS	-0.083 *
Body condition	-0.592*	NS	NS	NS	NS	NS	NS
Frame sizes	-0.890*	NS	NS	NS	NS	NS	NS
Carcass yield	-0.534*	NS	NS	NS	NS	NS	NS
Carcass fatness	-0.673**	NS	NS	NS	-0.928*	NS	NS
Flavour/taste	-0.549**	NS	NS	NS	-0.993*	NS	NS
Tenderness	-0.503**	NS	NS	NS	-0.845*	NS	NS
Calf mortality	-0.3179*	NS	NS	NS	0.802*	NS	NS
Cattle mortality	NS	0.961*	NS	NS	NS	NS	NS
Tick-loads	NS	NS	NS	0.621*	NS	NS	NS
Cattle sales	NS	NS	NS	-0.933*	NS	NS	NS

[a] Logit coefficient of being beyond a cut-off point of the ordered outcomes where the ordered outcomes are: 1 = decreased; 2=increased; 3=Constant. Significance level, * P<0.05; ** P<0.01; ****= P<0.001; ns=not significant.

Nearly half of the interviewees reported that grazing patterns changed, with cattle spending more time browsing than grazing over the past two decades. Seventy percent of the farmers noted an increase in distance travelled by cattle to get access to rangelands. About 80% of the farmers reported a decrease in the availability of drinking water for cattle. Farmer's age and reasons for keeping cattle moderated farmers' perception of the impact of climate change on drinking water supply for cattle ($P<0.05$; Table 3.3). Adult farmers had a greater ($P<0.05$) perception of experiencing an decrease in availability of drinking water for cattle than young farmers. Farmers who kept cattle for cash had a greater ($P<0.05$) perception of experiencing a decrease in cattle water supply than those who kept cattle for non-cash generating objectives.

Farmers' strategies to cope with the negative impact of climate change on rangeland biomass and water supply included watering animals at boreholes meant for human consumption (46% of the respondents), providing supplementary feeds (16%) and reducing cattle herd sizes to match with the available feed quality and quantity (5%). Maize bran was ranked as the most common feed supplement (86% of the respondents). Few farmers (2%) used exotic multipurpose trees, mostly *Leucaena leucocephala* and *Gliricidia sepium* as protein supplements. None of the farmers used indigenous legume tree species as protein supplements. Farmers, however, reported that cattle browsed *Bauhinia thonningii* (30% of the respondents), *Dolichos kilimandscharicus* (21%), *Adansonia digitata* (15%), *Erythrina abyssinica* (6%), *Vachellia polycantha* (2%) and *Dichrostachys cinerea* (>1%), especially during the dry season. Of these, *A. digitata*, *V. polyacantha* followed by *D. kilimandscharicus* were the most abundant indigenous browse species in the surveyed areas. Oxen (55% of respondents) followed by cows (30%) and calves (10%) were the most commonly supplemented cattle classes.

3.3.4 Farmers' perceptions of effects on climate change on beef production and quality

In general, beef yield and quality attributes were perceived as adversely influenced by climate change. About 40% of the farmers reported increases in age at first calving and calving intervals over the last two decades. Farmers in low-altitude areas had a higher ($P<0.05$) perception of experiencing an increase in the age at first calving and a decrease in calving rates compared to those in medium-altitude, high-altitude and plateau areas. Farmers who depended on farm income had a higher perception of increased age at first calving than those who depended on non-farm income. High-income farmers had a higher ($P< 0.05$) perception of having a decrease in age at first calving than low-income farmers. Sixty-eight percent of the farmers perceived a decrease in cow longevity over the past 20 years.

Over 70% of the farmers' perceived a decrease in cattle feed intake, milk production, growth rates, body condition scores, frame size, carcass yield and fat cover over the last 20 years. The respondents, however, had mixed perceptions on the impact of climate change on beef flavour and tenderness over the past two decades. Farmers in low-altitude areas had a higher ($P<0.05$) perception of experiencing a decrease in milk production, growth rates, body condition score, frame size, carcass yield, carcass fat cover, beef flavour and tenderness than other zones. Male-headed households had a greater ($P<0.05$) perception of increased cattle feed intake compared to female-headed households. Farmers who kept cattle for cash had a greater ($P<0.05$) perception of experiencing a decrease in growth rate, carcass fat cover, meat flavour/taste and tenderness than those who kept cattle for non-cash-generating objectives. Low-income farmers had a higher ($P<0.05$) perception of having decreased growth rates than high-income farmers.

Nearly 40% of the farmers reported an increase in calf and total cattle mortalities over the last two decades. Farmers in low-altitude areas had a higher ($P < 0.05$) perception of experiencing increases in calf mortality compared to other agro-ecological zones (Table 3.3). Farmers who kept cattle for cash had a greater ($P<0.05$) perception of experiencing a decrease in calf mortality than those who kept cattle for non-cash reasons. Female-headed households had a higher ($P<0.05$) perception of experiencing an increase in total cattle mortality compared to female-headed households.

Most of the farmers perceived an increase in the tick load (72% of the respondents) and internal parasite (64%) infestations in their herds over the past 20 years. Less-educated farmers had a higher perception of experiencing an increase in the tick load than more-educated farmers. Over half of the farmers (56%) reported that theileriosis was the most common disease followed by lumpy skin disease (30%) and bovine dermatophilosis (13%) in the past two decades. About 40% of farmers reported a decline in cattle sales in the past 20 years. Logit coefficient estimates showed that less educated farmers had a higher ($P < 0.05$) perception of experiencing a decrease in cattle sales than more-educated farmers (Table 3.3). Although they perceived the negative impact of climate change on beef yield and quality, farmers did not have clear intervention strategies. About 20% of the respondents reported that they did not castrate male calves to improve growth rates while 10% increased grazing hours with view to increasing grazing hours and feed intake.

3.3.5 Barriers to climate change adaptation

The lack of information and inadequate capital were ranked as the first and second major barriers of adaptation to climate change in all the agro-ecological zones. The ranking of other reasons, however, varied with agro-ecological zones. Farmers in low- and mid-altitude areas ranked the lack of institutional support and access to markets as the third and fourth major barriers of climate change adaptation, respectively. In high-altitude and plateau areas, farmers ranked the lack of access to markets and lack of institutional support, in that order, as major barriers. To overcome barriers to climate change adaptation, 50% of the farmers recommended training on climate change adaptation and mitigation, increased access to credit (30%), deployment of more agricultural extension workers (10%) and improved land-use planning to resolve conflicting land and water use disputes (7%).

3.4 Discussion

The association observed between low-altitude areas and farmers keeping large cattle herds could be a result of the irregular and unpredictable rainfall patterns reported in these areas, which may have caused crop failure (Wood and Moriniere, 2013), thereby making cattle production an alternative livelihood strategy. In low-latitude areas, climate change is making cropping increasingly risky compared to extensive livestock production, and the latter is increasing in importance as a livelihood strategy (Jones and Thornton, 2009).

The smallholder farmers' perception of decreasing rainfall, increasing frequency of prolonged dry spells/ droughts and rising temperatures are supported by Ngongondo et al. (2011) who reported decreasing trends for annual, seasonal and monthly rainfall since 1960 in Malawi. Similarly, IPCC (2007) forecasted that the Southern African region will get drier and warmer over the years. The general perception of decreased rangeland production, water availability and cattle performance over the 20 years could be associated with decreased rainfall and increased frequency of prolonged dry spells reported in Malawi (Wood and Moriniere, 2013). Rangeland biomass and quality are largely influenced by inter-annual, spatial and seasonal distribution of temperature and rainfall (Angassa and Oba, 2007). Typically, temperature affects the length of the growing season while rainfall through soil-water availability affects the duration of growth and the production of rangeland plants (leaf area and the photosynthetic efficiency; Cantelaube and Terres, 2005).The greater perception of experiencing decreases in rangeland condition and cattle performance reported by the farmers in low-altitude areas is attributed to the sensitive local winds and topography which favour erratic precipitation in these areas (Wood and Moriniere, 2013). Although low-altitude areas have rich alluvial and calcimorphic soils, dry conditions often limit grass growth and promote invasion by thorny bushes, which consequently reduce animal performance (Reynolds, 2006). Other agro-ecological zones in Malawi (medium-, high-altitude and plateau areas) are relatively humid (Wood and Moriniere, 2013). While it was expected that farmers' perceptions on the impact of climate change on beef production would differ more due to the socio-economic differences, agro-ecological zone, appeared to play an important role in some perceptions. It could, therefore be important to prioritise smallholder beef farmers in sensitive agro-ecological areas when formulating strategies and policies to deal with climate change.

The higher perception of a decrease in feed intake reported by female heads could be attributed to limited labour required to drive cattle to distant grazing lands, herd and/or provide supplementary feeds to cattle. Previous studies have shown that most female-headed households have limited available labour, which mainly comprised of old widows and young children (Boogaard et al., 2015). Cattle production activities are dominated by family labour, particularly male youths (Mapiye et al., 2009b).

The observation that female-headed households were more likely to experience increased cattle mortality may suggest that they could not afford veterinary drugs or had limited access to animal health information and technologies. This is supported by earlier findings reported in the current study which showed that the surveyed areas were endemic to East Coast Fever (theileriosis), which is transmitted by ticks, and causes almost 90–100% mortality rate if untreated (Mukhebi and Perry, 1993). Bryan et al. (2011) found that female cattle producers in smallholder farming systems had limited access to and control of capital to purchase anthelmintics, acaricides and antibiotics that reduce diseases and parasite burdens, and veterinary information and technologies.

The result that young farmers had a greater perception of experiencing decreases in cattle water supply than adult farmers was expected. In general, farmers' ability to notice the impact of climatic change within a given production system is shaped by knowledge and personal experiences, which typically increase with advancement in age (Niles et al., 2015; Debela et al., 2015). In addition, younger farmers are expected to be more technically constrained than older farmers who are perceived to have acquired experience of farming and resources (Obi and Pote, 2012). This is supported by an observation by Mushunje et al., (2003) that older farmers are likely to have more resources at their disposal, which may make them more likely to cover costs of climate change more readily than younger farmers. Overall, the age of the head of the household is considered a crucial factor, since it determines whether the household benefits from the experience of an older person, or must base its decisions on the risk-taking attitude of a younger farmer (Moloi, 2008). In that regard, training young farmers to monitor climate change and its impact on water and feed resources could be important in improving beef cattle production in the smallholder areas of Malawi.

The observation that less-educated farmers had a higher perception of experiencing an increase in tick load than more-educated farmers was anticipated. Smallholder farmers with low education levels in most cases tend to have low and unsteady income and may not afford veterinary drugs and advice (Tambi et al., 1999). A household head's formal education (at least secondary level), used as a proxy for human capital (Makhura et al., 2001) is posited to increase a household's access to new information and technology on parasite control. In this regard, it may be important to promote use of tick-resistant cattle breeds such as indigenous Malawi Zebu cattle among resource-poor smallholder farmers to enhance their adaptive capacity.

The finding that less-educated household heads had a greater perception of experiencing a decrease in cattle sales agree with previous findings. Earlier studies established that education plays an important role in the adoption of improved agricultural practices and decision-making process with implications on market access, marketing and profitability (Bembridge, 1984; Obi and Pote, 2012). It is speculated that less-educated farmers have limited knowledge of markets and understanding of market dynamics, and are likely to make uninformed marketing decisions (Makhura et al., 2001; Moloi, 2008). The absence of education is therefore expected to have a negative influence on market access, sales and profitability. There is also a linear association between smallholder farmers' level of education and income, with farmers that have low education having low and unsteady income (Tambi et al., 1999). In that regard, less educated farmers are likely to be compelled to sell more cattle including the breeding animals to meet household subsistence requirements associated with climate change such as food in times of droughts (Morton, 2007; Mapiye et al., 2009a). This may reduce the number of marketable cattle in the long term. Technical, financial and institutional support to improve cattle production and marketing of beef cattle in the smallholder farming areas which might make farmers' livelihoods resilient to climate change is recommended.

The high perception of experiencing a decrease in rangeland and beef production reported by farmers who kept cattle for cash was expected. This was because market-oriented farmers are not only interested in cattle numbers but productivity compared to farmers who keep cattle for non-market reasons (Tarawali et al., 2011). Conversely, a high perception of experiencing increased calf mortality reported by farmers who keep cattle for non-market reasons confirm their interest in large cattle herd sizes normally kept for prestige and socio-cultural purposes (Tarawali et al., 2011).

The finding that farmers deriving their income from farm income alone had a high perception of experiencing an increase in the age at first calving suggests that such income is not sufficient to offset cost of adaption to extreme weather events. High ambient temperatures can lead to heat stress, which directly reduces cow reproductive performance (Nardone et al., 2010). Climate change also indirectly decrease cow reproductive performance by reducing feed and water availability (Nardone et al., 2010). Owing to seasonality of farm income, farmers deriving their livelihoods from such income may experience low cow reproductive rates due to fluctuations in monetary supply required to provide shading and feed supplements required to counter the effects of climate change. Climate adaptation and mitigation strategies aimed at improving reproduction and nutrition of cattle raised by smallholder farmers relying entirely on farm income could, therefore, be important. In addition, policies aimed at addressing the vulnerabilities of agricultural households should promote non-farm enterprises at community level.

The observation that low-income farmers had a higher perception of experiencing a decrease in rangeland biomass and quality, growth rates, and an increase in age at first calving could be because they could not afford financial resources required to improve rangeland and cattle production under extreme weather events. The ability to adapt and cope with climate change impacts is a function of wealth, scientific and technical knowledge, information, skills, infrastructure, institutions and equity (IPCC, 2007). Overall, farmers with limited financial resources, low levels of technology, poor information and skills, poor infrastructure, unstable or weak institutions and inequitable empowerment and access to resources have little capacity to adapt and are highly vulnerable (IPCC, 2007). Current findings support previous evidence that smallholder farmers' perceptions of impact of climate change are modified by socio-economic factors (Adger et al., 2009). Taking cognisance of differences in socio-economic factors among smallholder beef producers could, therefore, be important in formulating appropriate strategies to minimise their vulnerability to climate change. Generally, farmers had limited options to minimise the impact of climate change on beef production. Increasing grazing hours on communal rangelands where grazing was continuous was one option but may result in overgrazing, which could lead to further rangeland deterioration. Farmers also mentioned the use of the intact bulls (non-castrated) as a coping strategy to the declining growth rates. This may, however, not be a viable option in smallholder farming areas as it can result in uncontrolled breeding and less tender meat (Gregory, 2010). Besides, handling of bulls necessitates the construction of strong handling structures and may, thus, increase farmers' production costs through construction and maintenance of fences and handling facilities. Another climate change coping strategy reported by farmers was the use of maize bran as a feed supplement. It is, however, constrained by low protein content and availability in times of drought (Banda et al., 2012). Use of exotic leguminous trees, which are high in protein may be a better option. Nevertheless, adoption of exotic leguminous trees by smallholder farmers is limited by scarcity of quality seed and difficulties associated with their establishment and maintenance (Mapiye et al., 2006). Interestingly, farmers mentioned that their animals consumed seeds and/or leaves of some of the abundantly available indigenous browse legume trees such as *A. digitata, A. polycantha and D. kilimandscharicus*. However, there is little information on how diets containing indigenous leguminous seeds, leaf-meals, pods and their combinations influence cattle production and meat quality under changing climatic conditions. Therefore, further research in such adapted and locally available feed supplements as a climate change mitigation strategy for the smallholder beef farmers is warranted.

The observation that limited capital and inadequate information were the main farmers' barriers to climate change adaptation and mitigation was reported previously by Juana et al. (2013) and Bryan et al. (2011). Provision of capital and increasing access to information and technology can shape farmers' action on the problem of climate change (Gbetibouo, 2009). Farmers' access to credit could be improved by creation of village savings and loan associations among smallholder beef farmers. Village savings and loans associations operate on the model of first accumulating assets and skills through saving rather than debt as suggested by Hendricks and Chidiac (2011). Variations in ranking of barriers by farmers in the surveyed areas are supported by Thornton et al. (2009) who reported the existence of localised interactions of climate with socio-economic status, among other factors of change, within a given production system. Overall, the provision of capital and training to smallholder farmers could be important in enabling them to overcome the barriers to climate change adaptation in the studied areas.

3.5 Conclusion

Logit model identified age, gender, education level, reasons for keeping cattle, level and source of income as key socio-economic determinants of smallholder farmers' perceptions on the impact of climate change on beef cattle production in Malawi. Besides these socio-economic factors, agro-ecological factors played a more significant role in some perceptions. One of the potential strategies to minimise the impacts of climate change on beef production was the use of seeds and leaves from indigenous browsing legume trees (e.g., *A. digitata, V. polyacantha* and *D. kilimandscharicus*) as protein supplements in the dry season. Considering differences in agro-ecological and farmers' socio-economic factors could, therefore, be important in devising suitable climate-resilient strategies and policies for increasing the adaptive capacity of smallholder beef producers. Such policies may promote involvement of young farmers and gender equity in cattle production, improve farmers' education levels and access to financial resources, increase opportunities of off-farm activities and encourage farmers to be commercially oriented. Further studies are required to evaluate the nutritive quality of the rangeland-based protein sources identified by the farmers in the current study.

3.6 References

Adger, W.N., Dessai, S., Goulden, M., Hulme., M., Lorenzoni, I., Nelson, D.R. & Wreford, A., .2009. Are there social limits to adaptation to climate change? Clim. Chang. 93,335–354.

Angassa, A. & Oba, G., 2007. Relating long-term rainfall variability to cattle population dynamics in communal rangelands and a government ranch in southern Ethiopia. Agric. Syst. 94,715–725.

Archer van Garderen, E.R.M, .2011. Re-considering cattle farming in Southern Africa under a changing climate. Weather Clim, Soc, 3, 249–253.

Banda, L.J., Kamwanja, L.A., Chagunda, M.G.G., Ashworth, C.J. & Roberts, D.J., 2012. Status of dairy cow management and fertility in smallholder farms in Malawi. Trop. Anim. Health Prod. 44, 715–727.

Bembridge, T.J., 1984. A systems approach study of agricultural development problems in Transkei. PhD thesis, University of Free State, Bloemfontein, South Africa.

Boogaard, B.K., Waithanjib, E., Pooleb, E.J. & Cadilhon J., 2015. Smallholder goat production and marketing: a gendered baseline study from Inhassoro District Mozambique NJAS - Wageningen. J. Life Sci. 74–75, 51–63.

Bryan, E., Ringler, C., Okoba, B., Roncoli, C., Silvestri, S. & Herrero, M., 2011. Coping with climate variability and adapting to climate change in Kenya: household and community strategies and determinants. Report to the World Bank

Cantelaube, P. & Terres, J.M., 2005. Seasonal weather forecasts for crop yield modelling in Europe. Tellus, A., 57,476– 487.

Debela, N., Mohammed, C., Bridle, K., Corkrey, R. & McNeil, D., 2015. Perception of climate change and its impact by smallholders in pastoral/agropastoral systems of Borana, South Ethiopia. SpringerPlus 4, 236.

Dzanja, J., Kapondamgaga, P. & Tchale, H., 2013. Value chain analysis of beef in Central and Southern Malawi (Case studies of Lilongwe and Chikhwawa Districts). Int. J. Bus. Soc. Sci. 4, 92–103.

Fullerton, A.S., 2009. A conceptual framework for ordered logistic regression models. Sociol Meth. Res. 38, 306– 347.

Gbetibouo, G.A., 2009. Understanding farmers' perceptions and adaptations to climate change and variability: the case of the Limpopo Basin, South Africa. IFPRI Discussion Paper #00849.

Gregory, N.G., 2010. How climatic changes could affect meat quality. Food. Res. Int. 43, 1866–1873.

Hendricks, L. & Chidiac, S., 2011. Village savings and loans: a pathway to financial inclusion for Africa's poorest households. Enterprise Dev. Microfin. 22, 134–146.

IPCC, 2007. Climate Change 2007: Impacts, adaptation and vulnerability. Intergovernmental Panel on Climate Change.

Jones, P.G & Thornton, P.K., 2009. Croppers to livestock keepers: livelihood transitions to 2050 in Africa due to climate change. Environ. Sci. Policy. 12, 427–437.

Juana, J.S., Kahaka, Z. & Okurut, F.N., 2013. Farmers' perceptions and adaptations to climate change in sub-Saharan Africa: a synthesis of empirical studies and implications for public policy in African Agriculture. J. Agric. Sci. 5, 121–135.

Kasulo, V., Chikagwa-Malunga, S., Chagunda & M., Roberts, D., 2012. The perceived impact of climate change and variability on smallholder dairy production in northern Malawi. Afr. J. Agric, Res. 7, 4830–4837.

Makhura, M., Kirsten, J. & Delgado, C., 2001. Transaction costs and smallholder participation in the maize market in the Northern Province of South Africa. Seventh Eastern and Southern Africa Regional Maize Conference, 11–15 February, Pretoria, South Africa

Mapiye, C., Mupangwa, J.F., Mugabe, P.H., Chikumba, N., Poshiwa, X. & Foti., R. 2006. A review of forage legume research for rangeland improvement in Zimbabwe. Trop Grassl. 40:145–149.

Mapiye, C., Chimonyo, M. & Dzama, K., 2009a. Seasonal dynamics, production potential and efficiency of cattle in the sweet and sour communal rangelands in South Africa. J Arid Environ 73, 529–536.

Mapiye, C., Chimonyo, M., Dzama, K., Raats, J.G. & Mapekula, M., 2009b. Opportunities for improving Nguni cattle production in the smallholder farming systems of South Africa. Liv. Sci. 124, 196–204.

Megersa, B., Markemann, A., Angassa, O.J.O., Piepho, H.P. & Valle Zaráte, A. 2014. Impacts of climate change and variability on cattle production in southern Ethiopia: perceptions and empirical evidence. Agric. Syst. 130, 23–34.

Moloi, M.J., 2008. A comparison of socioeconomic characteristics that determine the farm income of emerging livestock and horticultural farmers in South Africa. MSc Thesis, Unpublished. Department of Agricultural Economics University of Limpopo, South Africa.

Morton, J.F., 2007. The impact of climate change on smallholder and subsistence agriculture. Proc. Natl. Acad. Sci. 104, 19680–19685.

Mukhebi, A.W. & Perry. B.D. 1993. Economic implications of the control of East Coast fever in eastern, central and southern Africa. International Livestock Centre for Africa in Future of livestock industries in East and Southern Africa; International Livestock Centre for Africa. Addis Ababa, Ethiopia, pp. 107–112.

Mushunje, A., Belete, A. & Fraser, G., 2003. Technical efficiency of resettlement farmers of Zimbabwe. Proc. 41st Annual Conference of the Agricultural Economic Association of South Africa (AEASA), Pretoria, South Africa. pp.13.

Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M.S. & Bernabucci., U. 2010. Effects of climate changes on animal production and sustainability of livestock systems. Liv. Sci. 130, 69-76.

Ngongondo, C., Xu, C.Y., Gottschalk, L. & Alemaw, B., 2011. Evaluation of spatial and temporal characteristics of rainfall in Malawi: a case of data scarce region. Theor. Appl. Climatol. 106, 79–93

Niles, M.T., Lubel, M. & Brow, M., 2015. How limiting factors drive agricultural adaptation to climate change. Agric. Ecosyst. Environ. 200, 178–185.

Obi, A. & Pote, P., 2012. Technical constraints to market access for crop and livestock farmers in Nkonkobe Municipality, Eastern Cape province. In: van Schalkwyk HD, Groenewald J.A, Fraser GCG, Obi A, van Tilburg A (Eds). Unlocking markets to smallholders: lessons from South Africa. Wageningen Academic Publishers, Wageningen, pp. 91–112.

Reynolds, L., 2006. Malawi: country pasture/forage resource profiles. FAO, Rome, Italy.

Tambi, N.E., Mukhebi, W.A, Maina, W.O. & Solomon, H.M., 1999. Probit analysis of livestock producers' demand for private veterinary services in the high potential agricultural areas of Kenya. Agric. Syst. 59, 163–176.

Tarawali, S., Herrero, M., Descheemaeker, K., Gringsd, E. & Blümmel, M., 2011. Pathways for sustainable development of mixed crop livestock systems: taking a livestock and pro-poor approach. Liv. Sci. 139, 11–21.

Thornton, P.K. & Herrero, M., 2014. Climate change adaptation in mixed crop–livestock systems in developing countries. Global Food. Sec. 3, 99–107.

Thornton, P.K., van de Steeg, J., Notenbaert, A. & Herrero, M., 2009. The impacts of climate change on livestock and livestock systems in developing countries: a review of what we know and what we need to know. Agric. Syst. 101, 113–127.

Van den Bossche, P. & Coetzer., J.A.W., 2008. Climate change and animal health in Africa. Revue Scientifique et Technique (Intl. Off. of Epiz.). 27, 551–562

Wood, L. & Moriniere, L., 2013. Malawi climate change vulnerability assessment. https://community.eldis.org/.5b9bfce3/Malawi VAFinal Report_12Sep13_FINAL.pdf Accessed on 15 September 2014.

Chapter 4: Nutritional composition of selected rangeland protein sources for smallholder beef cattle in Malawi

Abstract

The study evaluated the nutritional composition of rangeland-based protein sources in Malawi, namely: baobab (*Adansonia digitata*) seed, wild lupin *(Dolichos kilimandscharicus),* white thorn tree *(Vachellia polyacantha)* leaf-meals and soybean (*Glycine max*). Leaves of *D. kilimandscharicus* and *V. polyacantha* were hand-harvested from the same area in 2015 and 2016. Baobab seeds and soybean were collected from a local company making baobab pulp fruit juices and from farmers around the same area where leaf-meals were harvested, respectively. Soybean from both seasons and baobab seeds from 2015 had higher dry matter (DM) than other protein sources ($P < 0.05$). Soybean had the highest crude protein (CP) and starch followed by baobab seeds irrespective of season ($P < 0.05$). Baobab seeds had the greatest fat content followed by soybean ($P < 0.05$). Soybean and baobab seeds had the lowest organic neutral detergent fibre (aNDFom) content of all protein sources ($P < 0.05$). Acid detergent lignin and phenolic contents were highest in *V. polyacantha*, irrespective of season ($P < 0.05$). *Vachellia polyacantha* had the lowest *in vitro* NDF digestibility compared to other treatments ($P < 0.05$). Regardless of season, baobab seeds had the highest phosphorus, magnesium, copper and zinc contents ($P < 0.05$). Irrespective of the season, *V. polyacantha* exhibited the highest calcium and iron content ($P < 0.05$). *Dolichos kilimandscharicus* had the highest manganese irrespective of season ($P < 0.05$). Overall, soybean meal had the highest content for most amino acids followed by baobab seeds, with *V. polyacantha* having the lowest content ($P < 0.05$). Current findings show that baobab seed had comparable better mineral contents and similar CP, starch, NDF and amino acids compared to soybean.

Key words: *Adansonia digitata* seeds, beef production, *Dolichos kilimandscharicus*, *Vachellia polyacantha*, nutritional composition, in vitro digestibility

4.1 Introduction

Cattle in smallholder areas of Malawi are finished on communal rangelands with minimal protein supplementation. Tropical grasses, however, exhibit nutritional deficiencies especially of protein and energy for optimal animal performance and therefore require protein supplementation (Detmann et al., 2014). In general, high cost of conventional protein concentrates prevent their use in smallholder cattle production systems in Sub-Saharan Africa (Anele et al., 2011). In this regard, Mlambo and Mapiye (2015) suggested that utilization of leaf-meals from rangeland leguminous trees and shrubs could alleviate this problem as they contain high crude protein and mineral contents and are abundantly available even in the dry season. Besides leguminous trees and shrubs, there is abundant availability of natural tree-borne oil-seeds in tropical environments (Vermaak et al., 2011) that could be important protein supplements for cattle because of their high protein and mineral contents.

Rangeland-based protein sources that thrive in harsh climatic conditions (Kanyile et al., 2015) could enhance the nutritional quality of animal diets during the long dry season or droughts. This is important given the strong evidence of a high likelihood of occurrence of frequent extreme weather and climate events such as droughts due to global warming (IPCC, 2013). Therefore, these feed resources which are adaptable and abundant would enhance smallholder farmers' capacity to deal with short- and long-term feed shortages induced by climate change.

Smallholder farmers in Malawi identified wild lupin (*Dolichos kilimandscharicus*), white thorn tree (*Vachellia polyacantha*) and baobab (*Adansonia digitata*) seed as potential rangeland protein sources given their abundant availability (Chapter 3). Briefly, *D. kilimandscharicus* is a perennial herbaceous legume with underground rootstock from which annual stems arise and is widely distributed in Africa and India (Mackinder, 1999). To our knowledge, the potential of *D. kilimandscharicus* leaf-meal as feed for ruminants has not been evaluated. *Vachellia polyacantha*, a semi-deciduous leguminous tree, formerly *Acacia polyacantha* (Kyalangalilwa et al., 2013), is widespread in Africa and is generally found in dry flood-plains (Sharam et al., 2009). According to Rubanza et al. (2007) leaves of *V. polyacantha* have higher crude protein (CP) and tannin contents compared to *Leucaena leucocephala* and some *Vachellia spp*. including *V. nilotica, V. drepanolobium, V. tortilis* and *Senegalia senegal*. In general, inherent high contents of tannins in leaves of *Vachellia spp.* may adversely affect feed intake and nutrient digestibility, thus limit their use as direct feed for ruminants (Ben Salem et al., 2005).

Baobab (*Adansonia digitata* L.) is a widespread tree across sub-Saharan Africa and occurs in drylands of the Savannah (Muthai et al. (2017). Baobab seed oil is commercially used for cosmetics (Vermaak et al., 2011). There are inconsistent reports on the chemical composition of baobab seeds. For instance, Glew et al. (1997) reported moderate CP content of 196 g/kg DM, whereas Assogbadjo et al. (2012) reported high CP content of 350 g/kg and Muthai et al. (2017) reported low CP content of 130-150 g/kg DM. Therefore, it is important to verify the chemical composition of these seeds. Accurate knowledge of chemical composition of feed is important for formulating diets and optimize the efficiency of nutrient utilization in animals. Chemical composition of feedstuffs could be influenced by soil type and growing seasons. It is therefore important to evaluate the chemical composition of the identified Malawian rangeland-based protein sources across seasons. The objective of this study was to evaluate the effect of species and growing seasons on chemical composition and the nutritive value of selected rangeland-based protein sources in Malawi.

4.2 Material and Methods

4.2.1 Sampling and processing of rangeland-based protein sources

The *D. kilimandscharicus* and *V. polyacantha* leaves were hand-harvested from the same area in 2015 and 2016 growing (wet) seasons at Bunda Farm, Lilongwe University of Agriculture and Natural Resources, Malawi (14º 11.013` S 33º 47.95' E). The area experiences a sub-tropical climate with three marked seasons: cool dry (May-August), hot dry (September-November) and wet season (December-April). The average daily maximum temperature for the area is 27 ºC and receives annual rainfall between 800-1000 mm.

Dolichos kilimandscharicus, was harvested by cutting the whole aerial part in January for both seasons, sun-dried for 2 days, bagged and stored under shade. January-February is the period when the D. *kilimandscharicus* plant achieves full maturity in Malawi. For *V. polyacantha* trees, only lower branches were cut between April and May when the plant had reached its full maturity. The leaves were then sun-dried on a concrete floor for 2 days. Thereafter, the dried leaves were collected from the concrete floor after whipping the branches with a stick. The resulting leaves were sieved to remove any thorns and twigs. The leaf meal was placed in 50 kg bags pending feeding. Baobab seeds, a waste product from baobab fruit juice processing, were purchased in 50 kg bags from a local company located in Lilongwe that processes baobab fruit pulp juices. Soybean was bought from local farmers surrounding the Bunda Farm. All the protein sources were collected during two growing seasons, 2015 and 2016. For each season, samples were randomly collected from six different spots (6 samples per species per season) and ground through 1 mm sieve for the chemical analyses.

4.2.2 Chemical analyses of rangeland protein sources

The dry matter (DM), ash, crude protein (CP), crude fat and starch content were analyzed following AOAC International (2002) procedures. The LECO combustion method was used for determination of CP (AOAC, 2002; method 992.15). Crude fat was determined by acid hydrolysis extraction (AOAC, 2002; Method 954.02). Starch was measured using a commercial assay (Total starch Megazyme kit KTSTA, Megazyme International Ireland Ltd., Wicklow, Ireland), following the 2-staged heat-stable α-amylase and amyloglucosidase hydrolysis in acetate buffer according to Hall (2009). Neutral detergent fiber (aNDFom) was determined using heat-stable α-amylase and sodium sulphite (Van Soest et al., 1991; Mertens et al., 2002). Acid detergent fiber (ADFom) was performed according to Raffrenato and Van Amburgh (2011). Acid detergent lignin (solubilisation of cellulose with 72% sulphuric acid) were analyzed according to Goering and Van Soest (1970) with modifications based on Mertens (2002) and Raffrenato and Van Amburgh (2011). The aNDFom, ADFom and ADL content were expressed exclusion of residual ash. The *in vitro* digestibility of NDF (30-hr incubation) was done according to Goering and Van Soest (1970). The 30-hr incubation was selected for its accuracy in predicting of dry matter intake and animal performance in cattle (Spanghero and Zanfi, 2009). Macro and micromineral elements were analyzed using a Thermo iCAP 6000 Inductively Coupled Plasma Optical Emission Spectrophotometer after acid digestion of the samples (3 % nitric acid) in a microwave digester. Forage legumes were analyzed for total phenolic compounds and total tannins (Makkar, 2000), while condensed tannins were quantified according to Porter et al. (1985). Soybean was excluded because of its known low tannin concentration.

4.2.3 Statistical Analyses

Data were analyzed using the General Linear Model (GLM) procedure of SAS Guide Enterprise 7.1 (SAS Institute, Cary, Inc.). The following statistical model was used:

$$Y_{ijk} = \mu + \beta_i + \lambda_j + \beta_i\lambda_j + \mathcal{E}_{ijk},$$

Where:

Y_{ijk}= dependent response;

μ = overall mean;

β_i = effect of the ith species (i= soybean, baobab seeds, *V. polyacantha* and *D. kilimandscharicus* leaf meal);

λ_j = effect of jth season, (j = 2015, 2016 growing seasons);

$\beta\lambda_{ij}$ = interaction of season and species and;

$\mathcal{E}_{ijk}$ = Random error.

Separation of least square means was achieved by the PDIFF option of SAS (SAS Institute Inc., Cary, NC, USA). Differences were declared significant at $P < 0.05$ with trends discussed at $0.05 \leq P \leq 0.10$.

4.3 Results

4.3.1 Proximate composition and *in vitro* digestibility

Species, growing season and their interaction had significant effects on the DM, CP, starch, crude fat and ADFom content (P < 0.05). Soybean from both seasons and baobab seeds from 2015 had a higher (P < 0.05 DM content than other protein sources across seasons (Table 4.1). Soybean meal from both seasons, whereas *V. polyacantha* and *D. kilimandscharicus* leaf-meals had the least CP content (Table 4.1). The greatest (P < 0.05) starch content was found in soybean collected from the 2016 growing season, followed by soybean from 2015 and baobab seeds from 2015 with *V. polyacantha* leaf-meal harvested in the 2015 having the lowest content (Table 4.1). Starch content was greatest (P < 0.05) in soybean from the 2016 season, followed by soybean from the 2015 season and baobab seeds from the 2015 season with *V. polyacantha* leaf-meal harvested in the 2015 growing season having the lowest content (Table 4.1). Regardless of season, baobab seeds had the highest (P < 0.05) crude fat content, followed by soybean while *V. polyacantha* and *D. kilimandscharicus* leaf-meals had the lowest content (Table 4.1). Ash content was not influenced (P > 0.05) by species, season and their interaction. The aNDFom was only influenced by species; leaves of *D. kilimandscharicus* had the highest (P < 0.05) aNDFom content followed by *V. polyacantha* while soybean meal and baobab seeds had the lowest contents (Table 4.1). Irrespective of season, *V. polyacantha* and *D. kilimandscharicus* had the highest (P < 0.05) ADFom content followed by baobab seeds and soybean in that order (Table 4.1). Regardless of season, the highest ADL content (P < 0.05) was recorded for *V. polyacantha* followed by *D. kilimandscharicus*, baobab seeds and soybean in that order (Table 4.1). Interactive effects of species and season were significant for total phenols and total tannins but condensed tannins were only affected by species (P < 0.05).

Leaves of *V. polyacantha* harvested in the 2016 growing season had the highest contents of total phenols and total tannins followed by *V. polyacantha* leaves from the 2015 growing season and baobab seed from both seasons (P < 0.05; Table 4.1). Regardless of seasons, *V. polyacantha* had the higher (P < 0.05) content of condensed tannins than baobab seeds (Table 4.1). Effects of species, season and their interaction were significant in *in vitro* aNDFom ruminal digestibility (P<0.05). Irrespective of the season, soybean had the highest fibre digestibility followed by baobab seeds and *V. polyacantha* and *D. kilimandscharicus*, in that order (P < 0.05; Table 4.1).

Table 4.1: Nutritional composition (g/kg DM) and phenolic content (g/kg DM) of selected rangeland-based protein sources for beef in Malawi

Variable	Growing season 2015				Growing season 2016				SEM	S	Seasons	S×Season
	SBM	BS	VP	DK	SBM	BS	VP	DK		P-value		
N	6	6	6	6	6	6	6	6				
Dry matter	910^{a}	906^{b}	893^{cd}	896^{c}	904^{b}	890^{d}	895^{d}	891^{d}	3.31	0.003	0.147	0.007
Crude protein	360^{b}	348^{c}	212^{d}	208^{d}	397^{a}	352^{c}	210^{d}	199^{d}	5.08	<.000	0.929	0.006
Starch	136^{b}	127^{c}	46^{f}	64^{e}	159^{a}	96^{d}	84^{d}	49^{f}	5.14	<.000	0.555	<.000
Crude fat	175^{d}	221^{b}	32^{e}	30^{e}	182^{c}	233^{a}	31^{e}	29^{e}	3.17	<.000	0.244	0.010
Ash	88^{a}	89^{a}	90^{a}	90^{a}	88^{a}	88^{a}	89^{a}	89^{a}	1.71	0.419	0.249	0.209
aNDFom	208^{d}	184^{e}	332^{c}	403^{a}	171^{e}	175^{e}	343^{c}	382^{b}	15.4	<.000	0.650	0.557
ADFom	120^{d}	160^{c}	248^{a}	229^{b}	109^{d}	158^{c}	252^{a}	251^{a}	7.49	<.000	0.227	0.034
ADL	19^{d}	56^{c}	138^{a}	94^{b}	20^{d}	64^{c}	141^{a}	103^{b}	10.2	<.000	0.726	0.104
Total phenols	-	8.5^{c}	57^{b}	0.53^{d}	-	6.5^{c}	92^{a}	0.5^{d}	1.96	<.000	<.000	<.000
Total tannins	-	3.8^{c}	51^{b}	0.30^{d}	-	3.9^{c}	67^{a}	0.30^{d}	2.00	0.002	<.000	<.011
CT	-	0.72^{b}	22.9^{a}	-		0.78^{b}	20.0^{a}	-	1.47	<.000	0.967	<.137
ivNDFD%,30 h	83^{a}	60^{c}	11^{e}	28^{d}	84^{a}	66^{b}	12^{e}	27^{d}	1.55	<.000	0.002	0.003

^{a,b,c,d,e,f} Means with different superscripts within a row are significantly different (P < 0.05). SBM = soybean meal; BS = baobab seed; VP = *Vachellia polyacantha*; DK = *Dolichos kilimandscharicus*; aNDFom = Neutral detergent fibre; CT=condensed tannins; ivNDFD= *in vitro* NDF digestibility; and SEM = standard error of difference of the means.

4.3.2 Mineral composition

Species, season and their interaction were significant for all minerals analyzed ($P < 0.05$). The baobab seed collected in the 2016 growing season had the highest ($P < 0.05$ phosphorus content, followed baobab seeds collected in 2015 (Table 4.2). Irrespective of season, the lowest ($P < 0.05$) phosphorus content was reported in *V. polyacantha*; Table 4.2). Potassium content was highest ($P <0.05$) for the baobab seeds collected in 2016 followed by baobab and soybean collected in 2016 and *D. kilimandscharicus* had the lowest content (Table 4.2). Regardless of season, *V. polyacantha* leaf-meal had the highest ($P < 0.05$) calcium content followed by *D. kilimandscharicus,* baobab seeds and soybean in that order (Table 4.2). Baobab seeds collected from 2016 had a higher magnesium content than seeds collected in 2015 ($P < 0.05$; Table 4.2).

The *Vachellia polyacantha* leaf-meal from the 2015 growing season had the highest ($P < 0.05$) iron content followed by the *V. polyacantha* leaf-meal from 2016 (Table 4.2). The *Dolichos kilimandscharicus* from the 2016 season had the highest ($P < 0.05$) manganese content followed by the *Dolichos kilimandscharicus* leaf-meal collected in the 2015 season (Table 4.2). Copper content was highest ($P < 0.05$) in baobab seeds collected in 2016, followed by the baobab seeds collected in 2015 and the *D. kilimandscharicus* sampled in 2016 had the lowest content (Table 4.2). Furthermore, baobab seeds had the greatest ($P < 0.05$) content of zinc followed by soybean, irrespective of season Table 4.2).

Table 4.2: Mineral content of selected rangeland-based protein sources for beef production in Malawi

Mineral	Growing season 2015				Growing season 2016				SEM	P value		
	SBM	BS	VP	DK	SBM	BS	VP	DK		S	Season	S×Season
Macrominerals, g/kg DM												
Phosphorus	4.2[c]	11[b]	1.7[f]	3.3[d]	4.6[c]	17[a]	1.0[f]	1.6[e]	0.04	<.000	<.000	<.000
Potassium	18[b]	18[b]	8.1[f]	13[e]	16[c]	20[a]	6.9[f]	15[d]	0.21	<.000	<.000	<.000
Calcium	1.8[d]	3.7[cd]	28[a]	12[b]	1.4[d]	6.1[c]	27[a]	11[b]	1.70	<.000	0.001	0.048
Magnesium	2.2[e]	5.7[b]	2.2[e]	4.6[c]	2.3[e]	8.5[a]	2.3[e]	4.3[d]	0.10	<.000	<.000	<.000
Microminerals, mg/kg DM												
Sodium	36[d]	30[e]	79[a]	76[a]	35[d]	32[e]	77[a]	81[a]	3.04	<.000	0.001	<.000
Iron	202[c]	119[f]	289[a]	158[e]	182[d]	116[f]	230[b]	103[g]	2.24	<.000	<.000	<.000
Manganese	28[d]	27[d]	39[c]	63[b]	27[d]	21[e]	28[d]	106[a]	1.88	<.000	00.004	<.000
Copper,	11[c]	23[b]	8.1[e]	7.8[e]	9.0[d]	38[a]	9.0[d]	6.15[f]	0.34	<.000	<.000	<.000
Zinc	43[b]	68[a]	15[d]	24[c]	45[b]	66[a]	27[c]	16[d]	3.44	<.000	0.002	0.002

. [a,b,c,d,e,f,g] Means with different superscripts within a row are significantly different ($P < 0.05$). SBM = soybean meal; BS= baobab seed; VP = *Vachellia polyacantha*; DK = *Dolichos kilimandscharicus*; and SEM = standard error of difference of the means

4.4 Discussion

The CP content recorded for soybean meal in this study was within the range (36 to 41 %) reported by Jephter et al. (2017) of sixteen soybean genotypes grown in Malawi. he CP content of baobab seeds in this study was 2-fold higher than (14.9%) reported by Muthai et al. (2017) whereas the CP content of *V. polyacantha* leaf-meal was within the range reported by Rubanza et al. (2007). The differences in CP content for soybean meal and baobab seeds across seasons could be due to differences in rainfall quantity and distribution across the seasons (Olivares et al., 2009). The high CP values for baobab seeds, which was comparable to soybean meal, is in agreement with Assogbadjo et al. (2012). Recognition of baobab seed as a protein source for livestock was reported earlier by Proll et al. (1998), but there is little information on its use as a protein supplement in beef cattle. On the other hand, the CP content of *V. polyacantha* and *D. kilimandscharicus* leaf-meals was adequate to supply the daily CP intake of more than 260 g needed for 0.5 kg daily gain for growing and finishing steers when energy is not a limiting factor for growth (NRC, 2000) assuming the animals would find the feeds palatable

The range of values of starch content for *V. polyacantha* found in this study was than the those reported by Mlambo et al. (2008). However, there is paucity of information on the starch content of baobab seed to compare with the values obtained in our study. The differences in starch content observed across protein sources in this study could arise from inherent species differences. The parts of the plants studied may also account for these differences as parts such as seeds contain more starch for embryo nourishment than leaves. However, the observation that the starch content differed with the growing seasons agrees with Burešová et al. (2010), and could be attributed to difference in weather patterns across growing seasons. Water stress can compromise starch accumulation in plants (Beckles and Thitisaksakul, 2014).

The current findings of high levels of fat in baobab seeds in both seasons compared to the rest could be related to an adaptation mechanism that enables the seed to survive the long period of dormancy, as fat is an energy reservoir during such periods (Venter and Witkowski, 2013). However, the fat content observed for the baobab seeds in the current study was higher than reported (130 g/kg DM) by Muthai et al. (2017). It is not apparent what resulted in the higher fat content in baobab seeds and soybean with in 2016 compared to 2015. However, differences in environment conditions such as rainfall distribution across seasons affects seed development (Bellaloui et al., 2015).

The variation in aNDFom content across species could have been due to the part of plant harvested/used; seeds contain less fibre compared to leaves. However, aNDFom content between soybean and baobab seeds were comparable. This is despite baobab seeds having a hard, thick and water-impermeable seed coat, which accounts for about 60% of the total seed composition (Iwu, 2014). This could be an indication that baobab seed is potentially highly degradable in ruminants. On the other hand, aNDFom content in V. polyacantha was within the recommended range of 250 to 330 NDF g/kg DM in cattle diets (NRC, 2001).

The acid detergent lignin is one of the most important parameters used for evaluating nutritional quality of diets for ruminants; a high content in the diet reduces fibre digestibility. Lignin, which is indigestible, also binds cellulose and hemicellulose making indigestible by microbes (Moore and Jung, 2001). Therefore, the higher ADL content in V. polyacantha leaf-meal may limit dry matter intake in beef cattle due to low passage rate of the feeds due to low ruminal digestion. The Vachellia species are well known for the high content of total phenols, tannins and condensed tannins (Patra and Saxen, 2010). The observed values of the preceding constituents in V. polyacantha leaf-meal across seasons is attributed to adaptation of the species to herbivory (Patra and Saxen, 2010). However, the higher content of phenolic compounds in V. polyacantha leaf-meal harvested in the 2016 compared to 2015 growing season could be related to environmental factors including foliar nutrients. According to Borges et al. (2013) low manganese level in plant leaves increases accumulation of phenolic compounds. In the current study, *V. polyacantha* leaf-meal harvested in 2016 had a lower concentration of manganese than *V. polyacantha* harvested in 2015.

The low in vitro NDF digestibility observed for V. polyacantha leaf-meal in both seasons compared to other species across seasons could be related to the high tannin and ADL content. Tannins are known for their inhibitory action on ruminal microbial fermentation through formation of stable nutrient-tannin complexes which are not breakable by microbial enzymes and under ruminal pH (Makkar, 2003). Tannins also reduce the number and activity of ruminal microbes (Makkar, 2003). After evaluating several *Vachellia* subspecies, Rubanza et al. (2007) reported that *V. polyacantha* leaf meal had the lowest in vitro DM digestibility. However, Mueller-Harvey (2006) argued that the effects of tanniferous feeds on nutrient digestibility and animal performance should be based on all other nutrients available in the diet including proteins and ADL, which influence the extent of fibre ruminal degradation.

We observed variation in mineral content of the various protein sources across growing seasons, and this could be related to differences in soil moisture, which influences mineral uptake in plants (Khan et al., 2007). However, other factors including the root system, nutrient storage structures and to some extent plant parts used to make comparison, could also account for the differences in mineral content across species. *Vachellia polyacantha* trees have deep root and extensive root system (Canadell et al., 1996), which increases access to the minerals in the sub-soil. Baobab has lateral extensive root system that increase surface area for mineral absorption and a tuber trunk, which could store minerals that can be mobilized and taken up in seeds (Rahul et al., 2015). The *D. kilimandscharicus* has an underground rootstock (Mackinder, 1996) that can store minerals, which are then mobilized to leaves during its growing season. Baobab seeds could meet mineral requirements for maintenance production of a 300 kg Malawi Zebu steer calculated based on NRC (2000) for phosphorus (4.8 g/day), calcium (4.5 g/day), magnesium (1.8 g/day), copper (10 mg/kg diet), iron (50 mg/kg diet), manganese (20mg /kg diet) and zinc (29 g/kg diet). However, *V. polyacantha* leaf-meal would only meet the requirements for calcium and iron, while *D. kilimandscharicus* would meet calcium and manganese, while soybean would meet only iron requirements.

4.5 Conclusion

Athough baobab had lower CP content than soybean be had the highest mineral profile of all feed resources investigated, it had NDF content which was similar to soybean. This indicated that baobab seed meal might be a potential protein supplement to beef cattle. Despite *Vachellia polyacantha* and *D. kilimandscharicus* having a lower CP content than baobab, their CP content was adequate to meet the CP requirements for the growing animals. However, *Vachellia polyacantha* had had high content of ADL and phenolic compounds which may limit its potential as a protein sources. It would be important to evaluate beef production and quality of Malawi Zebu cattle fed these potential rangeland-based protein sources.

4.6 References

Anele, U.Y., Sudoku, K.H., Hummel, J., Airbed, O.M., Oni, A.O., Lanita, J.A., Better, C., Oyo, V.O., Folusho, A.O., 2011. Chemical characterization, *in vitro* dry matter and ruminal crude protein degradability and microbial protein synthesis of some cowpea (*Vina unguiculata* L. Wall) haulm varieties. Anim. Feed Sci. Technol. 163, 161–169.

AOAC, 2002. Official methods of analysis of AOAC International. 17th Ed. AOAC International, Gaithersburg, MD.

Assogbadjo, A.E., Chadare, F.J., Kakaï, R.G., Fandohan, B. & Baidu-Forson, J.J., 2012. Variation in biochemical composition of baobab (*Adansonia digitate*) pulp, leaves and seeds in relation to soil types and tree provenances. Agric. Ecosyst. Environ. 157, 94–99.

Barry, T. N. & Manley, T. R., 1986. Interrelationships between the concentrations of total condensed tannin, free condensed tannin and lignin in *Lotus spp*. and their possible consequences in ruminant nutrition. J. Sci. Food Agric., 37: 248–254.

Beckles, D.M. & Thitisaksakul, M., 2014. How environmental stress affects starch composition and functionality in cereal endosperm. Starch - Stärke, 66: 58–71.

Bellaloui, N., Bruns, H. A., Abbas, H. K., Mengistu, A., Fisher, D. K. & Reddy, K. N. 2015. Agricultural practices altered soybean seed protein, oil, fatty acids, sugars, and minerals in the Midsouth USA. Front. Plant Sci., 6, 31.

Ben Salem, H., Abidi, S., Makkar, H.P.S. & Nefzaoui, A., 2005. Wood ash treatment, a cost-effective way to deactivate tannins in *Acacia cyanophylla* Lindl. foliage and to improve digestion by Barbarine sheep. Anim. Feed Sci. Technol. 122, 93–108.

Borges, L.L., Alves, S.F., Sampaio, B.L., Conceição, E.C., Bara, M.T.F. & Paula, J.R., 2013. Environmental factors affecting the concentration of phenolic compounds in *Myrcia tomentosa* leaves. Braz. J. Pharmac. 23, 230–238.

Buresova, I., Sedlackova, I., Famera, O. & Lipavsky, J., 2010. Effect of growing conditions on starch and protein content in triticale grain and amylose content in starch. Plant Soil Environ. 56, 99–104.

Canadell J., Jackson R. B., Ehleringer, J. B., Mooney H. A., Sala O. E. & Schulze E.D., 1996. Maximum rooting depth of vegetation types at the global scale. Oecol. 108, 583–595.

Detmann, E., Valente, É.E.L., Batista, E.D. & Huhtanen, P., 2014. An evaluation of the performance and efficiency of nitrogen utilization in cattle fed tropical grass pastures with supplementation. Livest. Sci. 162, 141–153.

Jephter, B.F.M., Mumba, P. & Bokosi, J.M., 2017. Assessment of the agronomic productivity and protein content in 16 soybean genotypes. Afr. J. Food Agric. Nutr. Dev. 17: 12600-12613.

Glew, R. H., VanderJagt, D. J., Lockett, C., Grivetti, L. E., Smith, G. C., Pastuszyn, A., & Millson, M., 1997. Amino acid, fatty acid, and mineral composition of 24 indigenous plants of Burkina Faso. J. Food. Compos. Anal. 10, 205–217.

Goering, H.K. & Van Soest, P.J., 1970. Forage fiber analysis. Agric. Handbook. pp 1–19.

Hall, M.B., 2009. Determination of starch, including maltooligosaccharides, in animal feeds: comparison of methods and a method recommended for AOAC collaborative study. J. AOAC Int. 92, 42-9

IPCC, 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Iwu, M, M., 2014. Handbook of African Medicinal Plants, Second Edition. CRC Press. USA.

Khan, Z.I., Ashraf, M. & Hussain. A., 2007. Evaluation of macro mineral contents of forages: Influence of pasture and seasonal variation. Asian-Aust. J. Anim. Sci. 6, 908- 913.

Khanyile, M., Ndou, S.P. & Chimonyo, M., 2014. Influence of *Acacia tortilis* leaf meal-based diets on growth performance of pigs. Livest. Sci. 167, 211–218.

Kyalangalilwa, B., Boatwright, J.S., Daru, B.H., Maurin, O. & van der Bank, M., 2013. Phylogenetic position and revised classification of *Acacia* s.l. (Fabaceae: Mimosoideae) in Africa, including new combinations in *Vachellia* and *Senegalia*. Bot. J. Linn. Soc. 172, 500–523.

Makkar, H.P.S., 2000. Quantification of tannins in tree foliage. IAEA, Vienna.

Mertens, D.R., 2002. Gravimetric determination of amylase-treated neutral detergent fibre in feeds with refluxing beakers or crucible: collaborative study. J. Assoc. Off. Assoc. Chem. Int. 85, 1217-1240.

Mlambo, V., Mould, F. L., Sikosana, J. L. N., Smith, T., Owen, E. & Mueller-Harvey, I., 2008. Chemical composition and in vitro fermentation of tannin-rich tree fruits. Anim. Feed Sci. and Technol. 140, 402–417.

Mlambo, V. & Mapiye, C., 2015. Towards household food and nutrition security in semi-arid areas: What role for condensed tannin-rich ruminant feedstuffs? Food Res. Int. 76, 953–961.

Moore, K.J. & Jung, H.G. 2001. Lignin and fibre digestion. J. Range Manage. 54, 420-430.

Mueller-Harvey, I., 2006. Unravelling the conundrum of tannins in animal nutrition and health. J. Sci. Food Agric. 86, 2010–2037.

Muthai, K.U., Karori, M.S., Muchugi, A., Indieka, A.S., Dembele, C. & Mng'omba, S., Jamnadass, R., 2017. Nutritional variation in baobab (*Adansonia digitata* L.) fruit pulp and seeds based on Africa geographical regions. Food Sci. Nutr. 1–14. doi:10.1002/fsn3.502.

NRC, 2000. Nutrient Requirements of Beef Cattle: Seventh Revised Edition. Update 2000 Washington, DC: The National Academies Press.

NRC, 2001. Nutrient requirements of dairy cattle, 7th Ed. National Press Academy, Washington, D.C., USA.

Olivares, A., Johnston, M. & Calderón, C., 2009. Effect of rainfall regimes on seed production and quality of Avena barbata. Cien. Inv. Agr. 36, 68-76.

Patra, A. & Saxen, J., 2010. A new perspective on use of plant metabolites to inhibit methanogenesis in rumen. Phytochem. 71, 1198-1222

Porter, L. J., Hrstich, L. N. & Chan, B. G., 1985. The conversion of procyanidins and prodelphinidins to cyanidin and delphinidin. Phytochem. 25, 223–230.

Proll, J., Petzke, K.J., Ezeagu, I.E. & Metges, C.C., 1998. Low nutritional quality of unconventional tropical crop seeds in rats. J. Nutr. 128, 2014–2022.

Raffrenato, E. & Van Amburgh, M.E. 2011. Technical note: Improved methodology for acid detergent fibre and acid detergent lignin. J. Dairy Sci. 94, 3613–3617.

Rahul, J., Jain, M. K., Singh, S. P., Kamal, R. K., Anuradha, Naz, A. & Mrityunjay, S.K., 2015. *Adansonia digitata* L. (baobab): A review of traditional information and taxonomic description. Asian Pac. J. of Trop. Biomed., 5: 79–84.

Rubanza, C.D.K., Shem, M.N., Bakengesa, S.S., Ichinohe, T. & Fujihara, T., 2007. Effects of *Acacia nilotica, A. polyacantha* and *Leucaena leucocephala* leaf meal supplementation on performance of Small East African goats fed native pasture hay basal forages. Small Rumin. Res. 70, 165–173.

Sharam, G.J., Sinclair, A.R.E., Turkington, R. & Jacob, A.L., 2009. The savanna tree *Acacia polyacantha* facilitates the establishment of riparian forests in Serengeti National Park, Tanzania. J. Trop. Ecol. 25, 31–40.

Spanghero, M. & Zanfi, C., 2009. Impact of NDF content and digestibility of diets based on corn silage and alfalfa on intake and milk yield of dairy cows, Ital. J. Anim. Sci., 337-339.

Van Soest, P.J., Robertson, J.B. & Lewis, B.A., 1991. Methods for dietary fibre, neutral detergent fibre, and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74, 3583–3597.

Venter, S.M. & Witkowski, E.T.F., 2013. Where are the young baobabs? Factors affecting regeneration of *Adansonia digitata* L. in a communally managed region of southern Africa. J. Arid. Environ. 92, 1-13

Vermaak, I., Kamatou, G.P.P., Komane-Mofokeng, B., Viljoen, A.M., Beckett, K., 2011. African seed oils of commercial importance - Cosmetic applications. South African J. Bot. 77, 920–933.

Chapter 5: Intake, digestibility, rumen protein synthesis, growth performance and economic viability of Malawi Zebu steers fed diets containing rangeland-based protein sources

Abstract

The study evaluated the effects of feeding Malawi Zebu steers diets containing Baobab (*Adansonia digitata*) seed meal and white thorn tree (*Vachellia polyacantha)* leaf-meal as alternative protein sources to Soybean meal on dry matter intake (DMI), apparent total tract nutrient digestibility, rumen microbial nitrogen supply, growth performance and gross margins. Thirty steers (182 ± 21.4 kg and 29 months old), laid in a completely randomized design, were randomly allocated to three diets (10 steers/ treatment) made up of rangeland hay and maize bran with either baobab seed meal, *V. polyacantha* leaf-meal or soybean meal (control) as protein sources. The diets were targeted to supply 150g/kg crude protein (CP) and metabolizable energy of 10.5 MJ/kg DM. The animals were individually fed in covered pens and randomly submitted to the diets for 120 days. The diets were offered as a total mixed ration. Live body weight (BW) were measured every three weeks and feed given and refused were measured daily. The apparent total tract nutrient digestibility was measured on faecal grab samples collected over 4 days from day 60 of experiment where indigestible *in vitro* neutral detergent fibre (iNDF) was used as the internal indicator. The rumen microbial nitrogen supply was measured using a purine derivative method from spot urine samples collected on day 64. Steers fed the Soybean and Baobab diets had higher ($P < 0.05$) DMI, final BW and average daily gain (ADG) than those fed the *Vachellia* diet. The Soybean-fed steers had the highest ($P < 0.05$) feed efficiency followed by the Baobab-fed and *Vachellia*-fed steers was the lowest ($P < 0.05$). Steers fed diets containing soybean and baobab seed meal had similar ($P > 0.05$)

apparent total tract dry matter (DM), NDF, CP and crude fat digestibility, which was greater than (P < 0.05 for steers fed the *Vachellia* leaf-meal based diet (P < 0.05). Steers fed baobab seed meal had the highest (P < 0.05) rumen microbial nitrogen supply followed by soybean and *Vachellia*-fed steers in that order. Steers fed diet containing baobab seed had the highest (P < 0.05) gross margins followed by steers fed *V. polyacantha* leaf-meal and soybean meal. Since it resulted in comparable DMI, apparent total tract DM, NDF, CP and crude fat digestibility, final BW and ADG, and higher microbial N supply than soybean based diet, baobab seed meal could be a viable alternative protein source for beef production in Malawi.

Key words: *Adansonia digitata* seed-meal, beef production, soybean meal, *Vachellia polyacantha* leaf-meal.

5.1. Introduction

Malawi has a national cattle herd size of 1.3 million and produces about 39 500 metric tons of beef annually (FAOSTAT, 2014). Over 90% of beef production is in the smallholder areas, where predominantly indigenous Malawi Zebu cattle are finished on communal rangelands (Dzanja et al., 2013; Changadeya et al., 2012). Nutrition is the most important factor limiting cattle production on communal rangelands in the tropics (Mapiye et al., 2009). This is because tropical C_4 grasses exhibit nutritional constraints, particularly, low levels of crude protein and increased lignin content in the cell wall thus reduce intake, digestibility and animal performance (Detmann et al., 2014). To improve growth rates, smallholder farmers are encouraged to supplement cattle diets with herbaceous and grain legumes, and oilseeds (Mtimuni, 2013). However, the use of such protein sources is limited by scarcity, high production costs and unfavourable growth conditions (Mapiye et al., 2011). Protein supplementation involving indigenous browse tree legume leaf meals and tree-borne oilseed meals may be a viable alternative to grain legumes and oilseed crops (Madzimure, 2011; Khanyile et al., 2014; Mlambo and Mapiye, 2015).

Vegetation in Malawi is dominantly Miombo woodland with *Brachystegia, Julbernadia, Combretum* and *Vachellia* (formerly *Acacia*) as the predominant tree species (Kuyah et al., 2014). A feed inventory survey in smallholder areas of Malawi showed abundant availability of rangeland-based protein sources including *V. polyacantha* (African catechu or white thorn tree) and tree borne-oil seeds such as *Adansonia digitata* (baobab) seeds which farmers could use along with rangeland hay to improve cattle growth rates. Leaves of *Vachellia spp*. are rich in protein ranging from 180 to 230 g/kg DM, and can be used to supplement low quality natural tropical grasses (Rubanza et al ., 2007; Mapiye et al., 2011; Zampaligré et al., 2013). However, the extensive use of leaf-meals from *Vachellia* species is restricted by their high tannin content (> 40 g/kg DM) which can reduce animal performance as they can compromise feed intake due to low palatability, and also reduce nutrient digestibility (Makkar, 2003). Sun-drying, ensiling and feeding in homogeneous mixture with other feeds are the most common methods used to reduce content of the polyphenolic compounds in feeds (Mapiye et al., 2011; Mlambo and Mapiye 2015). When added at moderate levels (20-60 g/kg DM, tannins can shift protein digestion from rumen to small intestines, which could enable dietary protein to directly contribute to metabolisable protein (Makkar, 2003). Therefore, this could explain the improvement in animal performance for animals fed rangeland grass supplemented with different *Vachellia* browse species compared to non-supplemented animals (Rubanza et al., 2007; Mapiye et al., 2010). Polyphenols from different plant species do not have the same effect on nutrient digestibility, even when fed at the same concentration (Makkar, 2003). Therefore, the investigation of the effects of supplementing various indigenous tanniferous browse legumes found in Malawi in cattle diets on nutrient supply and production performance is warranted.

Baobab seed is another potential protein source that could be used as a protein supplement. Baobab trees are abundant and widely distributed along the hot and drylands along Lake Malawi. Baobab seed contains up to 340g/kg DM of CP, high levels of fat, minerals and vitamin C (Chapter, 4; Chadare et al., 2008; Madzimure et al., 2011; Assogbadjo et al., 2012). Baobab seed meal, however, contains anti-nutritional factors such as oxalate, phytate, saponins and tannins (Proll et al., 1998; Osman, 2004) but their levels are generally assumed to be below the established toxic levels for most ruminants. However, the nutritive value of baobab seed to support its use as a protein source for beef cattle.

The regions in low latitudes, where Malawi is located, are reported to be getting hotter and receiving lower precipitation due to climate change (IPCC, 2007). Severe weather conditions including droughts are getting common in Malawi (World Bank, 2016) and have the potential to limit rangeland grass supply to support smallholder beef production especially in dry season (Chapter 3). In addition, production of conventional protein feedstuffs including soybean will be limited. It is, therefore, important to develop sustainable feeding strategies that add value to beef production, and are adaptive to climate change. The objective of this study was to evaluate effects of feeding diets containing baobab seed meal and *V. polyacantha* leaf-meal as alternative protein sources to soybean meal on intake, total tract digestibility, rumen microbial nitrogen supply and growth performance of Malawi zebu steers. Since Vachellia and baobab trees grow in the harsh dry and hot tropical climatic conditions, they could be suitable feed sources to address the feed shortages caused by extreme weather and climate change in smallholder areas. Therefore, the objective of this study was to evaluate effects of feeding diets containing baobab seed meal and *V. polyacantha* leaf-meal as alternative protein sources to soybean meal on nutrient intake and total tract digestibility, rumen microbial nitrogen supply and growth performance of Malawi zebu steers.

5.2. Materials and methods

5.2.1 Study site

The study was conducted at the Beef Unit of Department of Animal Science, Lilongwe University of Agriculture and Natural Resources, Lilongwe Malawi (14º 11.013` S 33 º 47.95' E). The area experiences subtropical climate with three seasons; cool dry (May-August), hot dry (September-November) and wet season (December-April). The area experiences daily maximum temperature of 27 ºC and 800-1000 mm of precipitation. The experiment was performed between July and November 2016. The study protocol was approved by Research Ethics Committee on Animal Care and Use of Stellenbosch University, Stellenbosch, South Africa (Protocol Number: SU-ACUD14-00075).

5.2.2 Animals, experimental design and diets Study site

Thirty Malawi Zebu (*Bos indicus*) steers (weighing 181 ± 21.4 kg; approximately 29 months old) were individually housed in covered pens, measuring 2×4 m that were fitted with feeding and water troughs. The animals, laid in a completely randomized design, were randomly assigned to three diets containing rangeland hay and maize bran (hominy chop) with either *V. polyacantha* leaf-meal, baobab meal or soybean meal (control) as protein sources (Table 5.1). The animals were fed thrice daily (08:00, 13:00 and 16:00 hours) because of the small size of the feed troughs (100×45×30 cm). Diets were offered to the steers for *ad libitum* intake as total mixed rations to minimise selective feeding behaviour. Clean fresh water was always available.

Samples of feed were collected weekly for determination of chemical composition of the diets. Clean fresh water was always available.

5.2.3 Feed preparation Study site

Rangeland hay was harvested during the rainy season (February 2016) at the boot to early heading stage, baled and stored in a shade. The hay was chopped through a 20-mm sieve before being fed to the animals. Maize bran, a by-product of shelling, was purchased from local maize grain millers. The *V. polyacantha* leaf-meal was harvested from April to May 2016 around the Beef Unit of the Department of Animal Science Farm at Lilongwe University of Agriculture and Natural Resources. Lower branches of *V. polyacantha* trees were cut and sun-dried on a concrete floor for 2 days. The dried leaves were collected by shaking them off the branches. The leaves were then sieved to remove thorns and twigs and stored in 50 kg bags under shade. Baobab seeds (a single batch), waste products of baobab juice-processing, were purchased from a local baobab juice manufacturing company in Lilongwe, Malawi.

5.2.4 Diet formulation

Diets (5.1) were formulated using Large Ruminant Nutrition System (LRNS) v1.0.33 of Cornell and Texas A and M (Texas University, USA) to supply 150 g/kg DM crude protein and metabolizable energy of 10.5 MJ/kg DM to support an average daily gain of 0.64 kg/day. Feed samples were collected from each batch of mixed diet and pooled for later chemical analyses.

5.2.5 Chemical analyses of experimental diets

The dry matter (DM), ash, crude protein (CP), crude fat and starch were analysed following AOAC International (2002) procedures. The LECO combustion method was used for determination of CP (AOAC, 2002; method 992.15). Crude fat was determined by acid hydrolysis extraction (AOAC, 2002; Method 954.02). Starch was measured using a commercial assay (Total starch Megazyme kit KTSTA, Megazyme International Ireland Ltd., Wicklow, Ireland), following the 2-staged heat-stable α-amylase and amyloglucosidase hydrolysis in acetate buffer according to Hall (2009). Neutral detergent fiber (aNDFom) was determined using heat-stable α-amylase and sodium sulphite (Van Soest et al., 1991; Mertens et al., 2002). The acid detergent fiber (ADFom) was performed according to Raffrenato and Van Amburgh (2011). The acid detergent lignin (ADL) (solubilisation of cellulose with 72% sulphuric acid) were analysed according to Goering and Van Soest (1970) with modifications based on Mertens (2002) and Raffrenato and Van Amburgh (2011). The in vitro digestibility of NDF (30-hr incubation) was done according to Goering and Van Soest (1970). Mineral elements were analysed using a Thermo iCAP 6000 Inductively Coupled Plasma Optical Emission Spectrophotometer after acid digestion of the samples (3 % nitric acid) in a microwave digester. The total phenolic compounds and total tannins were analysed following the methods of Makkar (2000) while condensed tannins were quantified according to Porter et al. (1985).

Table 5.1: Ingredient proportions and chemical constituents in the experimental diets.

	Diets[1]		
Proportions, kg	Soybean	Baobab	Vachellia
Grass Hay	59	52	30
Maize bran	19	24	20
Vachellia polyacantha leaf-meal	0	0	50
Baobab seed meal	0	24	0
Soybean meal	22	0	0
Chemical composition, g/kg DM			
Dry matter	884	889	892
Crude protein	158	157	151
Fat	27	30	12
Starch	95	108	85
Ash	85	91	92
aNDFom[2]	458	416	464
ADFom[3]	345	320	290
Acid detergent lignin	32	54	77
Total polyphenols	1.6	7.0	59
Total tannins	0.76	4.1	42
Condensed tannins	-	0.78	12
Phosphorus	0.6	1.7	0.4
Calcium	0.3	0.5	0.8
IVNDFD[4] %, 30 hrs	38	48	4

[1]Soybean = soybean meal + hominy chop + rangeland hay; Baobab = baobab seed meal+ hominy chop +rangeland hay; Vachellia = Vachellia polyacantha leaf-meal+ hominy chop+ rangeland hay
[2]aNDFom = amylase-treated neutral detergent fibre exclusive of ash
[3]ADFom = acid detergent fibre exclusive of ash
[4]IVNDFD = in vitro NDF digestibility.

5.2.6 Collection of faecal and urine samples

On day 60 of the experiment, eighteen steers (6 steers/ treatment) with similar body weight were selected for faecal grab and spot urine collection for the determination of total tract nutrient digestibility and microbial nitrogen supply. Samples from freshly dropped faeces free from urine and bedding material were carefully collected from each animal for 4 days from 8:00 am to 7:00 am of the next day each day to make a 24h cycle. The faeces were immediately dried after collection at 60 ^{o}C in a forced air oven for 48 hr. A single spot urine sample was collected day 64 following a recommendation by Valadares et al. (1999) by urethral palpation to induce urination. About 50 ml of urine was collected from individual animals into the urine sample bottles. The urine was acidified with 10 ml of 10 % sulphuric acid and diluted 1:20 with distilled water. The urine samples were filtered using glass fibre wool and frozen at -20 ^{o}C until further analyses. In addition, samples of feeds offered and refusals from the animals were collected on the same days as faecal and urine samples. The collected feed and faecal samples were ground to pass through a 1-mm sieve (Wiley Mill, Philadelphia, PA, USA) and then composited by steer in preparation for chemical analyses

5.2.7 Total tract nutrient digestibility

To estimate total tract nutrient digestibility, indigestible NDF (iNDF) was used as an inert digestibility internal marker. The 120-hr Goering and Van Soest (1970) *in vitro* digestibility method was used to determine the residual ivNDF in the both feed and faecal samples for each steer (Schalla et al., 2012). Briefly, the feed and faecal samples were weighed in a pre-weighed ANKOM filter bags, sealed and incubated in rumen fluid containing Van Soest buffer solution that was continuously gassed using carbon dioxide. The rumen fluid was obtained from a cannulated Malawi Zebu cow. Following incubation, bags were washed and analyzed for NDF using an ANKOM Fibre Analyzer ($ANKOM_{220}$Technology, Macedon, NY, USA) and expressed exclusive of ash. Dry matter, CP and crude fat in both feed and samples were analyzed as explained Section 5.2.5. To estimate apparent total tract CP, fat and NDF digestibility, the following equation (Schalla et al., 2012) was used:

$$Apparent\ nutrient\ digestibility$$
$$= 100 - \{100 \times \left[\frac{indigestible\ NDF\ in\ feed}{indigestible\ NDF\ in\ faeces} \times \frac{Nutrient\ in\ faeces}{Nutrient\ in\ feed}\right)\}$$

Dry matter digestibility was calculated using the following the equation (Cohen-Zinder et al., 2016):

$$DM\ digestibility, = (100 - \left[\frac{indigestible\ NDF\ in\ feed}{indigestibleNDF\ in\ faeces} \times 100\right])$$

5.2.8 Ruminal microbial nitrogen supply

Urinary creatinine and uric acid concentrations were analyzed using an Automatic Analyzer (Fotress Chemistry Analyzer 200, UK), whereas allantoin was analyzed according to Chen and Gomes (1992). Urinary creatinine was used to estimate the daily urine output based on the individual body weight and creatinine excretion rate of 29 mg/kg of body weight (Valadares et al., 1999). To measure intestinal protein flow of ruminal microbial origin, urinary purine derivatives (uric acid and allantoin) were used because nucleic acids leaving the rumen are essentially of microbial origin as cattle feeds (plant material) usually contain low purine which are extensively degraded in the rumen (Chen and Gomes, 1992). Urinary purine derivative excretion was calculated based on individual daily excretion multiplied by the total daily urine volume. Total absorption of microbial purines was calculated based on Chen and Gomes (1992) equations whereby, total absorption of microbial purines was calculated as purine absorption:

$$Purine\ absoprption\ (mmol/day)\ = (total\ PD\ excretion\ -\ 0.385\ \times\ BW^{0.75})/\ 0.85$$

Where, 0.85 is the absorptive efficiency of purines; $BW^{0.75}$= metabolic body weight; 0.385 mmol /kg $W^{0.75}$ per day is the constant endogenous contribution.

The ruminal microbial N supply was computed as:

$$Microbial\ N\ (g/day) = (purine\ absorption \times 70/(0.116 \times 0.83) \times 1000$$

Where, 70 is the N content of purines (mg N/ millimoles), 0.116 is the mean ratio of purine-N: total-N measured for mixed rumen microbes; 0.83 is the assumed digestibility of microbial purines.

5.2.9 Measurements of animal performance

Feed offered and refusals were measured daily to determine intake. Dry matter of feed samples was used to compute average daily DMI from feed intake data. Live weights were measured every four weeks using a digital scale (Sasco Africa, South Africa). Average daily gain for individual steers was calculated as coefficient of a linear regression of body weight against time of the data points. Feed conversion efficiency was determined as gain: feed ratio.

5.2.10 Gross margin analysis

Gross margin analysis was used in this study to determine economic viability for each diet. The gross margins for each diet were calculated by subtracting the total costs (labour and feed) related to the production of the animals from gross revenue after selling the carcasses.

5.2.11 Statistical Analyses

The data were analyzed in SAS 9.3. The following statistical model was used:

$$Y_{ijk} = \mu + \beta_i + \lambda\beta_j + \mathcal{E}_{ijk}$$

Where,

Y_{ijk}= dependent response;

μ = overall mean;

β_i = fixed effect of diet of the ith diet, i = 1, 2, 3;

$\lambda\beta_{ij}$ = covariate of initial weight of jth animal on ith diet, j = 1, 2, 3…30 and

$\mathcal{E}_{ijk}$ = Random error.

All data were analyzed using GLM with initial weight fitted as a covariate. Separation of least square means was achieved using PDIFF option of the SAS (SAS Institute IN, Cary, NC, USA). Differences were declared significant at $P < 0.05$ with trends discussed at $0.05 \leq P \leq 0.10$.

6.1 Results

Steers fed soybean and baobab seed meals had greater DM intake ($P = 0.0079$), final BW ($P = 0.0417$), and ADG ($P < .0001$) than those fed *V. polyacantha* leaf-meal (Table 5.2.). Steers fed diets containing soybean based diet had the highest ($P < 0.05$) feed efficiency followed by those on baobab and *V. polyacantha* leaf-meal in that order.

Table 5.2: Effect diets containing soybean meal, baobab seed meal and *Vachellia polyacantha* a leaf-meal on productive performance of Malawi Zebu

	Diets[1]				
Variable	Soybean	Baobab	Vachellia	SEM	P-value
Final weight, kg	241[a]	239[a]	211[b]	12.9	0.0417
DMI[2], kg	4.99[a]	5.05[a]	4.35[b]	0.20	0.0079
ADG[3], kg	0.83[a]	0.77[a]	0.38[b]	0.06	<.0001
Gain:Feed	0.17[a]	0.14[b]	0.09[c]	0.01	<.0001

[a,b,c] Means within a row carrying different superscript letter differ significantly (p< 0.05)
[1]Soybean=soybean meal + hominy chop + rangeland hay; Baobab =baobab seed meal+ hominy chop +rangeland hay; Vachellia= Vachellia polyacantha leaf-meal + hominy chop+ rangeland hay
[2]DMI= dry matter intake
[3]ADG= average daily gain

Diets containing soybean and baobab seed meals had higher ($P < 0.05$) apparent total tract nutrient DM, CP, aNDFom and fat digestibility than *V. polyacantha* leaf-meal (Table 5.3.). Diet had no effect ($P > 0.05$) on total urine volume and urinary uric acid excretion (Table 5.4). Steers fed diets containing baobab seed meal excreted a greater ($P < 0.05$) amount of urinary allantoin and total purine derivatives than steers fed soybean and *V. polyacantha* leaf-meal based diets. Steers fed baobab seed meal had the highest ($P < 0.05$) ruminal microbial nitrogen supply followed by steers fed soybean and *V. polyacantha* leaf-meal.

Table 5.3 Effect of feeding Malawi zebu steers with diets containing soybean meal, baobab seed meal and *Vachellia polyacantha* leaf-meal on apparent total tract nutrient digestibility

Apparent digestibility %	Diets[1]				
	Soybean	Baobab	Vachellia	SEM	P-value
Dry matter	52.8[a]	55.0[a]	21.7[b]	3.12	<.0001
Neutral detergent fibre	43.0[a]	39.9[a]	12.9[b]	3.47	<.0001
Crude protein	77.9[a]	74.9[a]	46.2[b]	6.76	0.0031
Fat	80.5[a]	88.4[a]	56.1[b]	10.5	0.0116

[ab]Means within a row bearing different superscript letters differ ($p < 0.05$).
[1]Soybean = soybean meal + maize bran + rangeland hay; Baobab = baobab seed meal+ maize bran +rangeland hay; Vachellia = Vachellia polyacantha leaf-meal+ maize bran+ rangeland hay

Table 5.4: Effect of feeding Malawi zebu steers with diets containing soybean meal, baobab seed meal and *Vachellia polyacantha* leaf-meal on urinary output and purine derivative excretion, and microbial nitrogen supply

Item	Diets[1]				
	Soybean	Baobab	Vachellia	SEM	P-value
Total urine, (litre/day)	3.62	3.69	2.87	0.81	0.5158
Allantoin, mmol/day	38.1[b]	69.4[a]	30.1[b]	8.94	0.0028
Uric acid, mmol/day	6.8	6.3	5.7	1.97	0.9108
PD*, mmol/day	44.9[b]	75.7[a]	35.8[b]	10.5	0.0057
Microbial N g/day	22.7[b]	46.0[a]	6.97[c]	7.61	0.0049

[a,b,c] Means within a row carrying different superscript letters differ ($p<0.05$).
[1]Soybean = soybean meal + maize bran + rangeland hay; Baobab = baobab seed meal+ maize bran +rangeland hay; Vachellia = Vachellia polyacantha leaf-meal+ maize bran+ rangeland hay
*PD = total purine derivatives (allantoin + uric acid)

The *Vachellia* diet had the least ($P < 0.05$) total variable costs, baobab seed diet had moderate costs while soybean diet had the highest costs (Table 5.5). Diets containing baobab seed meal and soybean meal, however, had higher total revenue than the Vachellia diet. The baobab seed meal diet had the highest ($P < 0.05$) gross margin, *Vachellia* had moderate gross margin and soybean diet had the lowest gross margin.

Table 5.5. Gross margins (US$) for Malawian Zebu steers fed containing soybean meal, baobab seed meal and *Vachellia polyacantha* leaf-meal

	Diets[1]				
Cost/steer	Baobab	Vachellia	Soybean	SEM	P-value
Vachellia harvesting	0	25.38	0	-	-
Hay making	25.64[b]	7.30[c]	28.67[a]	1.19	<.0001
Maize bran	6.70[a]	6.80[a]	5.26[b]	0.34	0.0001
Baobab seed	16.75	-	-	-	-
Soybean	-	-	81.33	-	-
Total variable costs	49.08[b]	39.48[c]	115.36[a]	3.20	<.0001
Revenue/steer	184.33[a]	151.02[b]	181.80[a]	11.23	0.0152
Gross margins	135.25[a]	111.54[b]	66.44[c]	11.06	<.0001

Means within a row carrying different superscript letter differ significantly ($p< 0.05$).
[1]Soybean = soybean meal + maize bran + rangeland hay; Baobab = baobab seed meal+ maize bran +rangeland hay; Vachellia = Vachellia polyacantha leaf-meal+ maize bran+ rangeland hay

5.3. Discussion

The observed low DMI and ADG in steers fed the Vachellia diet could be attributed to the low starch and high NDF, ADL and tannin content, which possibly limited nutrient supply. Tannins have an astringent taste that might have decreased palatability (Makkar, 2003). In addition to the low starch and high lignin content of the diet, tannins could have also formed stable complexes with nutrients and reduced the number and activity of rumen microbes. This in turn could have reduced the rate of digestion and passage of nutrients out of the rumen, thereby increasing gut fill, which reduces DMI. In a related study (Mapiye et al., 2009), steers fed *V. karroo* leaf-meal had higher ADG than those grazing native grass only, nonetheless, their performance did not match with those supplemented with sunflower cake. Similar results were also observed by Rubanza et al. (2007) who reported that goats fed diets containing leaf-meals of different *Vachellia* species had better ADG than goats on native hay. However, goats fed *V. polyacantha* had the lowest ADG of all species due to its high levels of tannins regardless of its highest protein content among browse species investigated (Rubanza et al., 2007).

The high dietary inclusion level (50% of diet DM) of *V. polyacantha* leaf-meal in this study was aimed at establishing animal performance where *V. polyacantha* leaf-meal could be used as the only source of protein for finishing beef cattle during the long dry seasons or droughts (Mlambo and Mapiye, 2015). Even though the use of *V. polyacantha* leaf-meal as sole source of protein was this was important in adapting to long dry seasons or droughts, having its inclusion level being higher due to low crude protein content, compromised DMI and ADG as increased lignin and tannins concentration. Therefore, further studies should focus on establishing the optimal inclusion rate of *V. polyacantha* leaf-meal in beef diets to complement adaptation strategies to severe feed shortages induced by climate change for smallholder beef production. The similar DMI and ADG for steers fed baobab and soybean diet could be explained by their comparable dietary composition, *in vitro* NDF digestibility and *in vivo* digestibility nutrient values. The potential of baobab seed meal to replace oil seeds in dairy cattle diets was also determined by Madzimure et al. (2011), who noted higher milk yield in dairy cows supplemented with baobab seed than cotton seed cake.

The low apparent *in vivo* DM, NDF and CP digestibility in steers fed *V. polyacantha* leaf-meal compared to soybean and baobab seed meal may be due to the high levels of lignin and tannins in the diet. Lignin forms strong bond with hemicellulose and cellulose, which reduces digestibility (Moore and Jung, 2001). Furthermore, tannins in the Vachelia diet might have also reduced ruminal nutrient digestibility due to the formation of a stable nutrient-tannin complex, primarily with protein, which is not degraded in the rumen. In addition, tannins reduce the number and activity of rumen microbes, which reduces digestibility (Makkar, 2003). Vachellia diet had the lowest *in vitro* NDF digestibility compared to the other diets which could be related to lignin and tannin content. However, the condensed tannin content of the Vachellia diet in the current study (12 g/kg DM) was less than the 20 g/kg DM threshold above which nutrient digestibility is compromised in cattle (Grainger et al., 2009; Orlandi et al., 2015; Avila et al., 2015). We did not evaluate the content of the different types of polyphenols, which have differences in biological activity and, thus, could compromise digestibility at different concentrations (Makkar, 2003).

The lack of differences in apparent total tract nutrient DM, NDF and CP digestibility between steers on diets containing baobab seed meal and soybean meal in the present study could be attributed to comparable NDF, CP and starch content of the two diets. The CP and energy level in a diet have the greatest influence on ruminal nutrient digestibility as rumen microbes require protein and energy substrates for nutrient digestion (Calsamiglia et al., 2010). Numerically comparable CP, starch and NDF of the two diets might have achieved similar CP: energy ratios that influenced similar ruminal degradation of the nutrients of the diets (Detmann et al., 2014). A plausible explanation for the higher microbial N supply for baobab is its lower NDF (possibly causing higher ruminal digestibility which is supported by the higher in vitro NDF digestibility and starch (possibly greater fermentable carbohydrate supply, which is important as energy is the most limiting factor for microbial protein synthesis) than the other two diets. The low purine absorption, which suggests a low microbial activity in steers fed *V. polyacantha* leaf-meal was probably due to the low CP and starch, and high lignin and tannin content, which reduced nutrient supply to support optimal microbial growth. However, the values of microbial N supply obtained in this study were comparable to the values reported by Phesatcha and Wanapat (2017) in buffaloes fed tropical grass hay with *Leucaena leucocephala* as the protein source.

In the present study, highest gross margin reported for Baobab-fed steers were a result of both higher total revenue and low input costs among the diets. Although, steers on the *Vachellia* diet had low production cost compared to Baobab-fed steers, lower average daily gain in animals on the *Vachellia* diet resulted with animals of low carcass weights, thereby reducing the total revenue. The lowest gross margin reported for soybean-fed steers was because of the high total input cost despite the group achieving high final weights. While ingredients or technologies that give optimal performance could be attractive (Owen et al., 2012), lack of economic viability of the ingredients might prevent farmers from using them. Higher gross margins of animals fed indigenous browse legume leaf-meals compared to conventional crop-based oilseed cakes were also observed by Mapiye et al. (2009). Besides improving animal performance, use of baobab seed as a protein supplement was economically viable. Further research should investigate effects of feeding Malawi zebu steers with diets containing baobab seed meal and *V. polyacantha* leaf-meal on meat attributes of Malawi zebu.

5.4. Conclusion

Steers fed *V. polyacantha* leaf-meal-based diets had low nutrient digestibility, microbial nitrogen supply and growth performance compared to those fed baobab seed meal and soybean meal. Steers fed the diet containing baobab had high gross margins compared those fed *V. polyacantha* leaf-meal and soybean meal. It was concluded that baobab seed meal has potential to replace soybean-meal as protein source as it improved gross margin without compromising animal growth performance. Further studies should investigate effects of feeding steers with diets containing baobab seed meal and *V. polyacantha* leaf-meal on carcass and meat quality characteristics.

5.5. References

Assogbadjo, A.E., Chadare, F.J., Kakaï, R.G., Fandohan, B. & Baidu-Forson, J.J., 2012. Variation in biochemical composition of baobab (*Adansonia digitata*) pulp, leaves and seeds in relation to soil types and tree provenances. Agric. Ecosyst. Environ. 157, 94–99.

Ávila, S.C., Kozloski, G. V., Orlandi, T., Mezzomo, M.P. & Stefanello, S., 2015. Impact of a tannin extract on digestibility, ruminal fermentation and duodenal flow of amino acids in steers fed maize silage and concentrate containing soybean meal or canola meal as protein source. J. Agric. Sci. 153, 943–953.

Calsamiglia, S., Ferret, A., Reynolds, C.K., Kristensen, N.B. & Van Vuuren, A.M., 2010. Strategies for optimizing nitrogen use by ruminants. Animal 4, 1184–1196.

Chadare, F.J., Linnemann, R., Hounhouigan, J.D., Nout, M.J.R. & Van Boekel, M. J.S., 2008. Baobab food products: a review on their composition and nutritional value. Crit. Rev. Food Sci. Nutr. 49, 254–74.

Changadeya, W., Ambali, Aggrey, J.D., Nyirenda, J.C., Chagunda, Mizeck G. G. & Kaunda, E., 2012. Genetic diversity and population structure of Malawi Zebu cattle. Int. J. Phys. Soc. Sci. 2, 59–81.

Chen, X.B. & Gomes, M.J., 1992. Estimation of microbial protein supply to sheep and cattle based on urinary excretion of purine derivatives - an overview of the technical details. Rowett Res. Institute, Bucksburn, Aberdeen AB2 9SB, UK 1–19.

Cohen-Zinder, M., Leibovich, H., Vaknin, Y., Sagi, G., Shabtay, A., Ben-Meir, Y., Nikbachat, M., Portnik, Y., Yishay, M. & Miron, J., 2016. Effect of feeding lactating cows with ensiled mixture of *Moringa oleifera*, wheat hay and molasses, on digestibility and efficiency of milk production. Anim. Feed Sci. Technol. 211, 75–83.

Detmann, E., Valente, É.E.L., Batista, E.D. & Huhtanen, P., 2014. An evaluation of the performance and efficiency of nitrogen utilization in cattle fed tropical grass pastures with supplementation. Livest. Sci. 162, 141–153.

Dzanja, J., Kapondamgaga, P. &Tchale, H., 2013. Value Chain Analysis of Beef in Central and Southern Malawi (Case Studies of Lilongwe and Chikhwawa Districts). Intl.J. Soc. Phys. Sci. 4, 92–103.

FAOSTAT, 2014. Production data on live animals: Malawi. Food and Agriculture Organisation, Rome Italy.

Goering, H.K. & Van Soest, P.J., 1970. Forage fiber analysis. Agric. Handbook. 1–19.

Grainger, C., Clarke, T., Auldist, M.J., Beauchemin, K.A., McGinn, S.M., Waghorn, G.C. & Eckard, R.J., 2009. Potential use of *Acacia mearnsii* condensed tannins to reduce methane emissions and nitrogen excretion from grazing dairy cows. Can. J. Anim. Sci. 89, 241–251.

IPCC, 2007. Climate Change 2007: Impacts, adaptation and vulnerability. Intergovernmental Panel on Climate Change.

Khanyile, M., Ndou, S.P. & Chimonyo, M., 2014. Influence of *Acacia tortilis* leaf meal-based diets on growth performance of pigs. Livest. Sci. 167, 211–218.

Kuyah, S., Sileshi, G.W., Njoloma, J., Mng'omba, S. & Neufeldt, H., 2014. Estimating aboveground tree biomass in three different miombo woodlands and associated land use systems in Malawi. Biom. Bioe. 66, 214–222.

Madzimure, J., Musimurimwa, C., Chivandi, E., Gwiriri, L. & Mamhare, E., 2011. Milk yield and quality in Guernsey cows fed cottonseed cake-based diets partially substituted with baobab (*Adansonia digitata* L.) seed cake. Trop. Anim. Health Prod. 43, 77–82.

Makkar, H.P.S., 2003. Effects and fate of tannins in ruminant animals, adaptation to tannins, and strategies to overcome detrimental effects of feeding tannin-rich feeds. Small Rumin. Res. 49, 241–256.

Mapiye, C., Chimonyo, M., Dzama, K., Strydom, P.E., Muchenje, V. & Marufu, M.C., 2009. Nutritional status, growth performance and carcass characteristics of Nguni steers supplemented with *Acacia karroo* leaf-meal. Livest. Sci. 126, 206–214.

Mapiye, C., Chimonyo, M., Marufu, M.C. & Dzama, K., 2011. Utility of *Acacia karroo* for beef production in Southern African smallholder farming systems: A review. Anim. Feed Sci. Technol. 164, 135–146.

Mlambo, V. & Mapiye, C., 2015. Towards household food and nutrition security in semi-arid areas: What role for condensed tannin-rich ruminant feedstuffs? Food Res. Int. 76, 953–961.

Moore, K.J. & Jung, H.G., 2001. Lignin and fibre digestion. J. Range Manage. 54, 420-430

Mtimuni, J.P., 2013. Forages and feed resources, in: Smallholder Dairy Production in Malawi: Current Status and Future Solutions, Scoping Papers: Optimizing Smallholder Dairying.

Orlandi, T., Kozloski, G. V., Alves, T.P., Mesquita, F.R. & Ávila, S.C., 2015. Digestibility, ruminal fermentation and duodenal flux of amino acids in steers fed grass forage plus concentrate containing increasing levels of Acacia mearnsii tannin extract. Anim. Feed Sci. Technol. 210, 37–45.

Osman, M.A., 2004. Chemical and nutrient analysis of baobab (*Adansonia digitata*) fruit and seed protein solubility. Plant Foods Hum. Nutr. 59, 29–33.

Owen, E., Smith, T. & Makkar, H., 2012. Successes and failures with animal nutrition practices and technologies in developing countries: A synthesis of an FAO e-conference. Anim. Feed Sci. Technol. 174, 211–226.

Phesatcha, K. & Wanapat, M., 2017. Tropical legume supplementation influences microbial protein synthesis and rumen ecology. J. Anim. Physiol. Anim. Nutr. 101, 552–562.

Porter, L. J., Hrstich, L. N. & Chan, B.G., 1985. The conversion of procyanidins and prodelphinidins to cyanidin and delphinidin. Phytochem. 25, 223–230.

Proll, J., Petzke, K.J., Ezeagu, I.E. & Metges, C.C., 1998. Low nutritional quality of unconventional tropical crop seeds in rats. J. Nutr. 128, 2014–2022.

Rubanza, C.D.K., Shem, M.N., Bakengesa, S.S., Ichinohe, T. & Fujihara, T., 2007. Effects of *Acacia nilotica, A. polyacantha* and *Leucaena leucocephala* leaf meal supplementation on performance of Small East African goats fed native pasture hay basal forages. Small Rumin. Res. 70, 165–173.

Schalla, A., Meyer, L., Meyer, Z., Onetti, S., Schultz, A. & Goeser, J., 2012. Hot topic: apparent total-tract nutrient digestibilities measured commercially using 120-hour *in vitro* indigestible neutral detergent fiber as a marker are related to commercial dairy cattle performance. J. Dairy Sci. 95, 5109–14.

Valadares, R.F.D., Broderick, G.A., Valadares, S.C. & Clayton, M.K., 1999. Effect of replacing alfalfa silage with high moisture corn on ruminal protein synthesis estimated from excretion of total purine derivatives. J. Dairy Sci. 82, 2686–2696.

World Bank, 2016. Malawi Economic Monitor, May 2016: Absorbing Shocks, Building Resilience. World Bank, Lilongwe, Malawi. World Bank.

Zampaligré, N., Dossa, L.H. & Schlecht, E., 2013. Contribution of browse to ruminant nutrition across three agro-ecological zones of Burkina Faso. J. Arid Environ. 95, 55–64.

Chapter 6: Prediction of dry matter intake and average daily gain of Malawi Zebu steers fed rangeland-based diets using different nutritional computer models

Abstract

The objective of the present study was to evaluate the Beef Cattle Nutrient Requirements Model (BCNRM) and Large Ruminant Nutrition System (LRNS) predictions for dry matter intake (DMI) and average daily gain (ADG) of Malawi Zebu steers fed rangeland-based diets. The models were evaluated using data collected from 30 Malawi Zebu steers that were fed diets containing rangeland hay and maize bran with either *Vachellia polyacantha* leaf-meal, baobab seed meal (*Adansonia digitata*) or soybean meal (*Glycine max*) as the main protein sources under feedlot conditions. The BCNRM was more accurate and precise in predicting the DMI (r^2 = 0.95; mean bias, MB = 2.5%; mean square prediction error, MSPE = 0.16; and concordant correlation coefficient, CCC = 0.96) than the LRNS (r^2 = 0.79; MB = 11%; MSPE = 0.19; CCC = 0.82). Similarly, BCNRM was more accurate and precise in forecasting ADG (r^2 = 0.87; MB = 10%; MSPE = 0.029; CCC = 0.75) than LRNS (r^2 = 68; MB = 24%; MSPE = 0.038; CCC = 0.33). The BCNRM could be better a model especially for predicting DMI of Malawi Zebu steers fed rangeland based diets under feedlot conditions. However, the LRNS prediction for DMI was acceptable.

Key words: Beef, cattle, feed intake, nutrient, rangeland, supplementation.

6.1 Introduction

Smallholder beef production in Malawi is practised on communal rangelands dominated by tropical C_4 grass species. Tropical C_4 grasses, exhibit nutritional constraints, including low levels of crude protein (CP) and high lignin content which reduce feed intake, digestibility and performance of the grazing animals (Detmann et al., 2014). However, stage of maturity of harvest is one of several factors that determine the CP and lignin content. For instance, the CP will be high and the lignin content low if C_4 grasses are harvested at the boot stage compared to close to senescence. Nonetheless, excess of energy relative to available CP in tropical grasses reduces efficiency of the utilisation of metabolisable energy and limits intake due to heat production from excess energy in the rumen (Poppi and McLennan, 1995; Illius and Jessop, 1996). It is therefore important to supplement tropical grasses with protein supplements. However, protein supplementation in high levels or supplementing with protein that is highly degradable (soluble protein content) relative to energy supply leads to N spillage/wastage as ammonia (Poppi and McLennan, 1995; Illius and Jessop, 1996). Therefore, accurate and precise protein supplementation programmes are, therefore, required to address these challenges posed by tropical grasses, and optimise feed intake and animal performance.

Overall, feed supplementation strategies for smallholder cattle production are often inaccurate and imprecise as they are usually targeted to meet the requirement of one nutrient, mainly protein, without considering balancing for other nutrients and accounting for environmental conditions and the dynamic state of nutrient requirements for the animal (Garg et al., 2013). It is important to offer balanced diets to animals because any imbalances, for example, when energy is the first limiting factor, proteins, vitamins, minerals will be utilized for energy generation until both energy and protein are deficient; and supplementation of energy alone will not improve animal performance and may in fact depress performance (NRC, 2000). Furthermore, often the mismatch between expected animal's performance and diets offered to animals when diets are even balanced for nutrients may be a result for not considering the animal and environmental factors when formulating and evaluating the diets (NRC, 2000). To improve accuracy and precision of nutrient supply, several nutritional models that incorporate feed chemical composition, the dynamic state of nutrient requirements, animal and environmental factors have been developed and are being continually improved (NRC, 2000; Fox et al., 2004; Tylutki et al., 2008; Tedeschi et al., 2014; Tedeschi et al., 2015; Tedeschi and Fox, 2016).

There are several models available including the Beef Cattle Nutrient Requirements Model (BCNRM; National Academies of Sciences, Engineering and Medicine, 2016), Ruminant Nutrition System (RNS; Tedeschi and Fox, 2016) and Large Ruminant Nutritional Systems (LRNS; Fox et al., 2004; Tedeschi et al., 2014). All these models are based on the Cornell Net Carbohydrate Protein System (CNCPS; Tedeschi et al., 2015). The CNCPS based models consider basic principles of rumen function, microbial growth, feed digestion and passage, animal physiology and environmental conditions (Fox et al., 2004) which theoretically allow their application in various environmental conditions and management systems, different breeds and feeds. However, it would be important to compare the two models since the BCNRM, formerly NRC 2000 model, and LRNS have similar features except that BCNRM adjusts for differences in breed when computing maintenance energy requirement while LRNS, based on CNCPS, does not adjust for breed (Fox et al., 2004) which could affect their predictions of *Bos indicus* such as Malawi Zebu. Furthermore, there are inconsistent reports on models about their application in different production environments (Molina et al., 2004; Zhao et al., 2008; Du et al., 2010; Morenz et al., 2012; Parsons et al., 2012). Their application in a new production environment, therefore, may require prior evaluation and possible adjustments for optimization. The objective of this study was, therefore, to evaluate Large Ruminant Nutrition System (LRNS) and Beef Cattle Nutrient Requirement Model (BCNRM) predictions for dry matter intake and average daily gain of Malawi Zebu steers fed rangeland-based diets in feedlot conditions.

6.2 Material and Methods

The data used in this study was obtained from a feeding trial in Chapter 5. Briefly, the feeding trial involved thirty 29-months old Malawi Zebu steers that weighed (mean ± SD) 182 ± 21.4 kg at the beginning of the trial and 230 ± 21 kg at the end. The care and handling of animals for the feeding trial was approved by the Research Ethics Committee, Animal Care and Use of Stellenbosch University (Stellenbosch, South Africa; Protocol Number: SU-ACUD14-00075). During the feeding trial, the steers (10/ treatment) were randomly allocated to three diets made up of rangeland hay, maize bran (hominy chop) with either baobab seed meal, *Vachellia polyacantha* leaf-meal or soybean meal (control) as protein supplements. The steers were individually housed in pens over for a period of 120 days at the Beef Unit of the Department of Animal Science, Lilongwe University of Agriculture and Natural Resources (Lilongwe, Malawi). Diets were formulated using the Large Ruminant Nutrition System (LRNS) v.1.0.33: (http://www.nutritionmodels.com/lrns.html). Diets were offered ad libitum as total mixed rations.

Table 6.1 Chemical composition (g/kg DM) of feed ingredients used to evaluate the models

Chemical	Soybean	Baobab seed	Hominy chop	*V. polyacantha* leaf-meal	Grass hay
DM	92.6	90.6	90.4	89.8	90.1
CP	35.6	33	12.1	19.3	8.5
Crude fat	17.5	20.4	8.3	3.4	1.4
Ash	5.0	6.6	4.9	7.0	8.0
aNDFom	25.7	18.9	25.1	34.2	71.6
ADFom	13.1	15.9	7.6	25.2	40.4
ADL	1.9	5.4	1.5	14.0	5.1
Starch	13.4	11.9	25.5	4.9	5.4
In vitro starch (7 h)	96.5	69.9	58.5	51.1	100
In vitro NDF (30 h)	82.9	59.8	72.5	11.6	35.3
Total polyphenols	-	3.2	-	57.0	-
Total tannins	-	1.5	-	51.2	-
Condensed tannins	-	3.2		22.9	-
P	4.24	1.22	6.27	1.08	2.33
Ca	1.93	3.87	0.35	19.7	3.29
K	1.77	18.7	9.35	8.08	18.0
Mg	2.21	5.82	2.65	2.13	2.35
S[1]	2.45	2.67	1.11	1.52	3.44
Zn[1]	43.5	60.7	62.3	7.11	27.8
Cu[1]	11.0	22.7	5.43	3.26	5.72
Mn[1]	28.8	24.6	18.8	28.8	23.7
Fe[1]	201	117	275	286	190
Se[1]	0.06	0.19	0.08	0.16	0.07

mg/kg DM[1]; DM= dry matter; CP= crude protein; aNDFom = amylase treated neutral detergent fibre exclusive of ash; ADFom= acid detergent fibre exclusion of ash.

6.2.1 Model inputs

6.2.1.1 Feed nutrient composition

Feed compositions used for evaluating the models were analysed according to specifications of Licitra et al. (1996). *In vitro* digestibility of starch and aNDFom was analyzed according to

Goering and Van Soest (1970) by incubating the feed samples for 7 and 30 hrs, respectively. The starch and aNDFom values from the *in vitro* digestibility were used to come up with fractional rates of digestion of starch and aNDFom for the feedstuffs (Table 5.3) according to Sniffen et al. (2009). For detailed chemical analyses, refer to Section 4.2.2 in Chapter 4.

6.2.1.2 Animal and environment inputs

As required by these models, animal and environmental descriptions were collected before dietary formulations (Table 5.4). The data descriptors for Malawi zebu included DMI, ADG, body condition score (BCS), age, frame size and mature weight. The forecast weather data the duration of the experimental period (July to November 2016) was obtained from Kamuzu International Airport, Lilongwe in Malawi. This included temperature, rainfall, air relative humidity and wind speed.

Table 5.2 The kinetic digestibility rate (%/ hr) of feedstuffs used for evaluating the models

Feedstuff	Starch digestibility rate	NDF digestibility rate
Soybean meal	47.9	9.45
Baobab seed meal	17.2	9.04
Maize bran	12.6	7.21
Vachellia leaf-meal	10.2	4.30
Grass hay (tropical)	3.72	2.13

Table 5. 3 Animal type and environment inputs

Item	Description		
Diets	Vachellia	Baobab	Soybean
Number of animals	10	10	10
Breed	Malawi Zebu	Malawi Zebu	Malawi Zebu
Breeding	Straight	Straight	Straight
Frame size	Small	Small	Small
Age in months	29	29	29
Body condition score (1-9)	3	3	3
Initial mean weight, kg	182	182	182
Mean mature weight, kg	298	298	298
Days in growth period	120	120	120
Animal type	Steer	Steer	Steer
Average daily gain, kg/ day	0.73	1.01	0.88
Environment			
Mean day temperature	26 ºC	26 ºC	26 ºC
Mean night temperature	11 ºC	11ºC	11 ºC
Humidity, %	31	31	31
Wind speed, km/ h	18	18	18
Cattle coat condition	No mud	No mud	No mud
Housing type	Pen (4.65-9.29 m^2)	Pen (4.65-9.29 m^2)	Pen (4.65-9.29 m^2)

6.2.2 Model predictions

The BCNRM- and LNRS-predicted DMI and ADG were generated for each animal based on the diet offered during the feeding trial. To achieve this, all the model information used for the diet formulation (model inputs) was not changed except for the information on individual animal's initial weight and final weight for both models. Precisely, the diets for feed steers in the feeding trial were formulated using the LRNS using the same model inputs described in 6.2.1. The DMI required (DMR) to achieve the observed ADG (oADG) was based of 2.5% of body livebody weight for both models. The predicted ADG (pADG) was estimated from the observed DMI so that DMI and DMR and oADG and pADG could be compared. Level two solutions were used for both models

6.2.3 Model adequacy evaluations

The data were analyzed in Microsoft Excel 2016 and SAS (SAS Institute Inc. Cary. NC. USA). A student t-test was used to evaluate the differences between observed and the predicted values. The models' prediction precision and accuracy were evaluated using the model assessment methods described by Tedeschi (2006) including mean bias, mean square prediction error (MSPE) and Lin's concordance correlation coefficient (CCC; Lin, 1989). The MSPE was decomposed to estimate the error due to central tendency (mean bias), regression (systematic bias), and random variation. A small mean bias, MSPE and CCC close to unitary show model's good accuracy and precision (Tedeschi, 2006). Regression analysis of observed and model-predicted values was conducted to establish total variation explained by the model. The paired t-test of the mean of difference of observed and model-predicted values was performed.

6.3 Results

6.3.1 Dry matter intake

Figure 6.1 shows a graph of the observed dry matter intake plotted against model-predicted dry matter intake (DMI) of the Beef Cattle Nutrient Requirements Model (BCNRM) and the Large Ruminant Nutritional System (LRNS), respectively. Both models had slopes and trajectories for DMI that were similar to the ideal straight-line Y = X (BCNRM; P = 0.1489 and LRNS; P = 0.5509). Furthermore, the model assessments for accuracy and precision of the two models in predicting DMI are summarized in Table 6.4. The results of paired t-test showed that the predicted DMI for both models were similar (P > 0.05) to the observed values. The BCNRM predicted the DMI of Malawi Zebu steers with greater precision (r^2 of 0.95) than LRNS (r^2 = 0.79; Table 6.5). The BCNRM predicted DMI with a smaller mean bias than LRNS (Table 5.5). Furthermore, the BCNRM was more accurate (low MSPE) than LRNS (high MSPE). Based on concordant correlation coefficient (CCC) which accounts for both model accuracy and precision, the BCNRM predicted DMI with more accuracy and precision (high CCC which was close to 1) than LRNS (medium CCC).

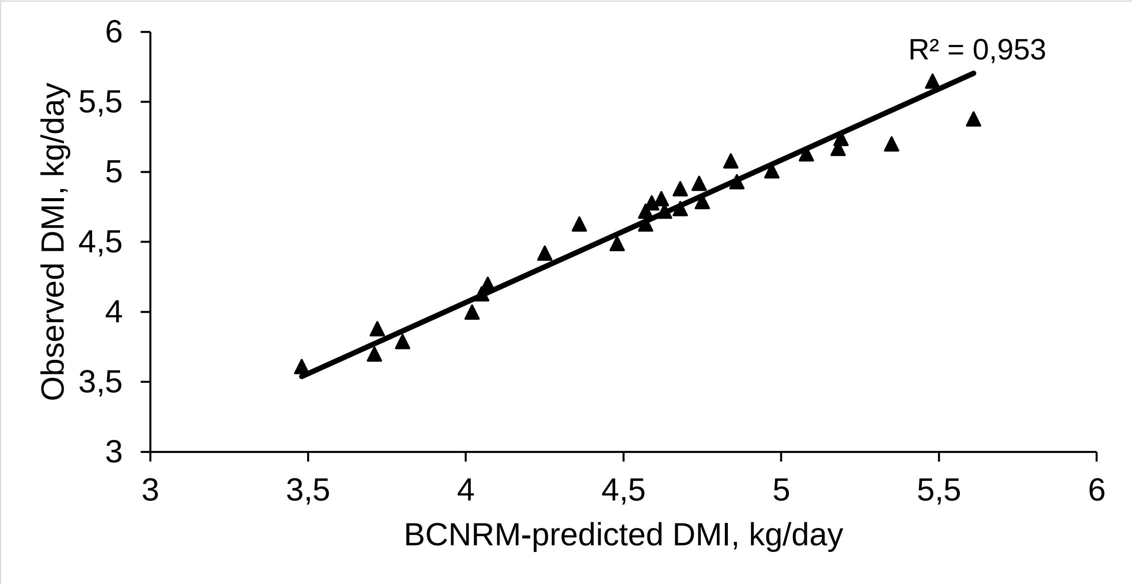
6.3.2 Average daily gain

Figure 6.2 shows the relationship between observed and model predicted average daily gain (ADG) for both models. The slope for both models was similar to 1 (P > 0.05). The t-test analysis showed that there was no difference between the model predicted and observed ADG values for BCNRM and LRNS models, respectively (P > 0.05). Table 6.4 summarises the adequacy assessments of models for precision and accuracy in predicting ADG. The BCNRM was more precise as it explained 87% of the total variation in the observed ADG than LRNS model that accounted only for 68%. Furthermore, the BCNRM predicted ADG with a smaller mean bias than LRNS (Table 6.4). The BCNRM was more accurate than LRNS in predicting the ADG (MSPE of 0.03 versus 0.04). However, the results of CCC (Table 5.4) showed that BCNRM had moderate precision and accuracy while LRNS was imprecise and inaccurate when predicting the ADG of Malawi Zebu fed rangeland diets.

Table 6.4: Model fit comparison between observed and predicted DMI and ADG of Beef Cattle Nutrient Requirement Model and Large Ruminant Nutrition System

Model fitness method	Nutritional Models			
	BCNRM		LRNS	
	DMI	ADG	DMI	ADG
Observed mean, kg/day	4.67±0.53	0.70±0.15	4.99±0.47	0.72±0.14
Predicted mean, kg/day	4.54±0.57	0.63±0.12	5.52±0.25	0.55±0.08
R-squared (r^2)	0.96	0.87	0.79	0.68
Mean bias, kg	-0.16	-0.07	0.53	0.17
Mean bias, %	-2.5	-10	11	-24
MSEP, kg/day	0.16	0.029	0.19	0.037
Concordance correlation coefficient	0.96	0.75	0.82	0.33
Error of the central tendency	0.007	0.005	0.023	0.030
Systematic error	0.021	0.023	0.005	0.001
Random error	0.130	0.001	0.150	0.006

DMI= Dry matter intake; ADG=Average daily gain; MSPE= Mean square predication error



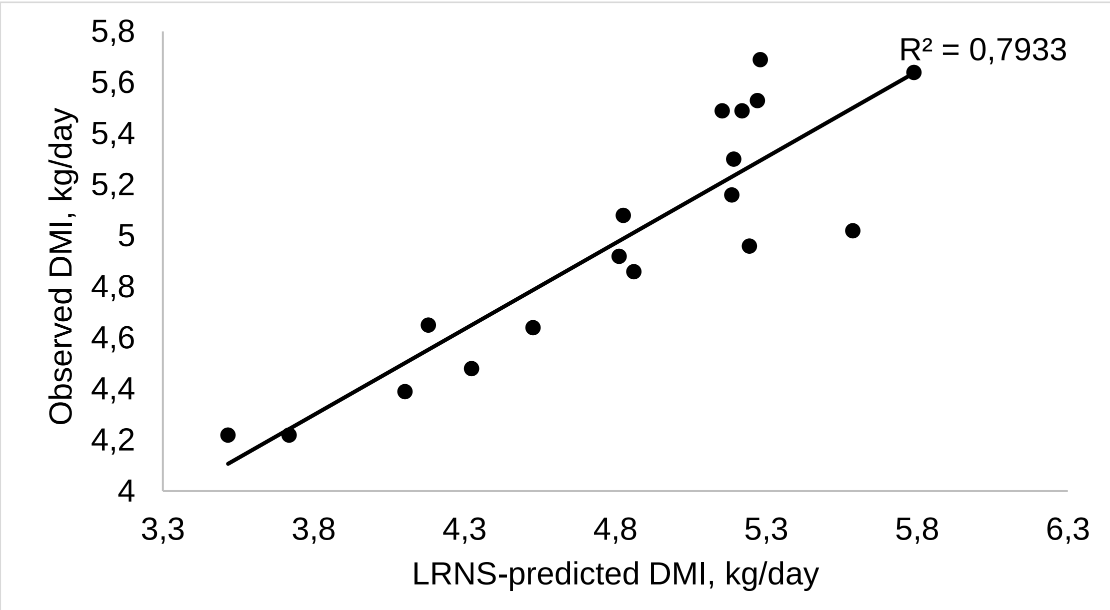


Figure 6.1. The relationship between the observed daily DMI and the BCNRM- and LRNS-predicted intake

.

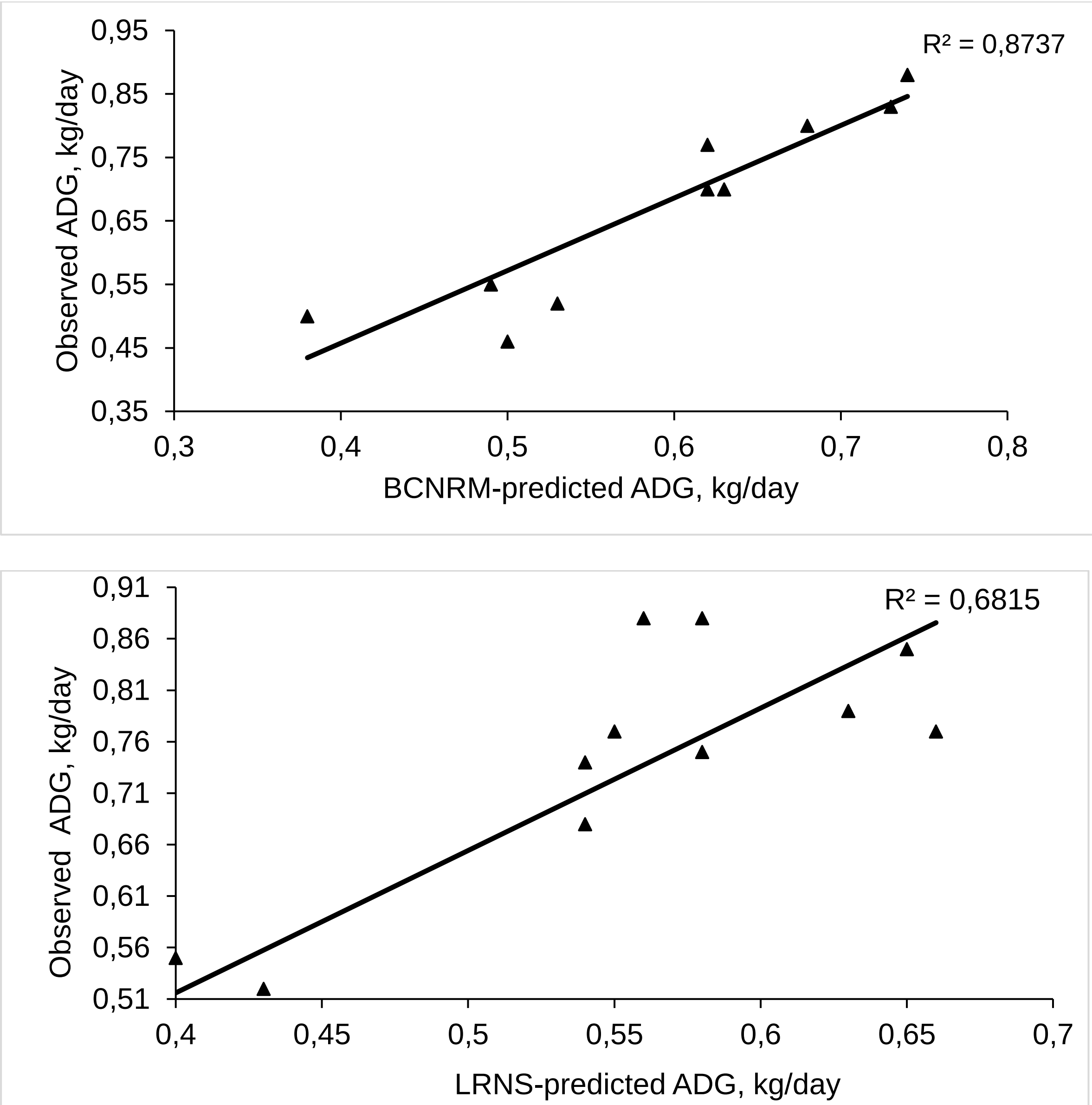


Figure 6.2 The relationship between the observed ADG and the BCNRM- and LRNS predicted ADG

6.4 Discussion

The BCNRM performed better than LRNS in predicting the DMI of Malawi Zebu cattle fed rangeland-based diets given the higher r^2, small mean bias, low MSPE and greater CCC close to unitary (Tedeschi, 2006). In fact, the BCNRM, formerly NRC 2000 Model, showed the best fit for the data DMI and ADG of Malawi Zebu cattle since it explained 95% and 87% of the total variation of the in the observed DMI and ADG, respectively, compared to the LRNS that explained 79% and 68%, respectively. The results could be attributed to the way two models computed the maintenance energy requirement for the animals where the BCNRM reduced the energy requirement by 10% while LRNS did not adjust for the breed (Fox et al., 2004). Therefore, the LRNS might have wrongly extrapolated the performance of Malawi zebu. Maintenance (NEm) requirements is the first limiting factor influencing the animal performance as energy available for performance depends on the proportion of energy consumed that must be used for meeting NEm (Fox et al., 2004).

In general, reports on use of the CNCPS and/or LRNS to predict performance of *Bos indicus* or other breeds show a limitation similar to what was observed in this study. For example, Zhao et al. (2008) reported that the CNCPS v5 (Fox 2004) also which the LRNS is based explained 83% of the observed DMI for local beef breeds in China under the Chinese production environments. Parsons et al. (2012) reported poor LRNS predictions (both level solutions 1 and 2) for DMI of Vietnamese cattle under Vietnamese conditions (r^2 of 0.39 and 0.63) and larger mean biases and 70% for level 1 solution and 86% for level 2 solutions for ADG. Lana et al. (1998) reported that CNCPS accounted for 72% of the variation in ADG for Nellore (the most common Zebu breed) in Brazil.

The differences observed in this study between the predictions of the two models agree with Tedeschi et al. (2014) who observed that, although nutrition computer models share similar assumptions and calculations, they may differ in conceptual and structural foundations characteristic to their intended purposes might result in differences. The differences might be more pronounced in the new environment which the other model was not adjusted for.

Nonetheless, the results reported in the study were from a small dataset and over a limited study period with limited changes in environmental conditions, therefore, further studies are warranted.

6.5 Conclusion

The BCNRM was more acceptable model than LRNS for predicting DMI and ADG of Malawi Zebu steers fed rangeland based diets under confined conditions under Malawian conditions. However, future studies should consider use of a large dataset since the information generated in the current study was based on a small dataset.

6.6 References

Detmann, E., Valente, É.E.L., Batista, E.D. & Huhtanen, P., 2014. An evaluation of the performance and efficiency of nitrogen utilization in cattle fed tropical grass pastures with supplementation. Livest. Sci. 162, 141–153.

Du, J., Liang, Y., Xin, H., Xue, F., Zhao, J., Ren, L. & Meng, Q., 2010. Evaluation of dry matter intake and average daily gain predicted by the Cornell Net Carbohydrate and Protein System in crossbred growing bulls kept in a traditionally confined feeding system in China. Asian-Aust. J. Anim. Sci. 23, 1445–1454.

Fox, D., Tedeschi, L.., Tylutki, T., Russell, J.., Van Amburgh, M., Chase, L., Pell, A.N. & Overton, T., 2004. The Cornell Net Carbohydrate and Protein System model for evaluating herd nutrition and nutrient excretion. Anim. Feed Sci. Technol. 112, 29–78.

Garg, M.R., Sherasia, P.L., Bhanderi, B.M., Phondba, B.T., Shelke, S.K., Makkar & H.P.S., 2013. Effects of feeding nutritionally balanced rations on animal productivity, feed conversion efficiency, feed nitrogen use efficiency, rumen microbial protein supply, parasitic load, immunity and enteric methane emissions of milking animals under field conditions. Anim. Feed Sci. Technol. 179, 24-35.

Goering, H.K. & Van Soest, P.J., 1970. Forage fiber analysis. Agric. Handbook. pp 1–19.

Illius, A.W. & Jessop, N.S., 1996. Metabolic constraints on voluntary intake in ruminants. J. Anim. Sci. 74, 3052–3062.

Lanna, D.P.D., Fox, D.G., Boin, C., Traxler, M.J. & Barry, M., 1996. Validation of the Cornell Net Carbohydrate and Protein System estimates of nutrient requirements of growing and lactating zebu germplasm in tropical conditions. J. Animal Sci. 74 (Suppl. 1), 287.

Licitra, G., Hernandez, T.M. & Van Soest, P.J., 1996. Standardization of procedures for nitrogen fractionation of ruminant feeds. Anim. Feed Sci. Technol. 57, 347–358.

Lin, L.I.K., 1989. A concordance correlation coefficient to evaluate reproducibility. Biom. 45, 255–268.

Molina, D., Matamoros, I., Almeida, Z., Tedeschi, L. & Pell, A.N., 2004. Evaluation of the dry matter intake predictions of the Cornell Net Carbohydrate and Protein System with Holstein and dual-purpose lactating cattle in the tropics. Anim. Feed Sci. Technol. 114, 261–278

Morenz, M.J.F., da Silva, J.F.C., Aroeira, M. L.J., Deresz, F., Vásquez, H.M., Lopes, F.C. F., Paciullo, D.S.C. & Tedeschi L. O., 2012. Evaluation of the Cornell Net Carbohydrate and Protein System model on the prediction of dry matter intake and milk production of grazing crossbred cows. R. Bras. Zootec. 41, 398-406

National Academies of Sciences, Engineering, and Medicine. 2016. Nutrient Requirements of Beef Cattle. (8th Ed.). Nutrient requirements of domestic animals. National Academy Press, Washington, DC.

NRC, 2000. Nutrient Requirements of Beef Cattle: Seventh Revised Edition. Update 2000 Washington, DC: The National Academies Press.

Parsons, D., Van, N.H. Malau-Aduli, A.E.O., Ba, N.X., Phung, L.P., Peter A. Lane, P.A., Ngoan, L.D. & Tedeschi, L.O., 2012. Evaluation of a nutrition model in predicting performance of Vietnamese Cattle Asian-Aust. J. Anim. Sci. 25, 1237 – 1247.

Poppi, D.P., McLennan, S.R., 1995. Protein and energy utilization by ruminants at pasture. J. Anim. Sci. 73, 278–290.

Sniffen, C.J.M., & de Ondarza, W.R., 2009. Interpreting and implementing starch digestibility information in the field. Proc. the Cornell Nutr. Conf. pp 148

Tedeschi, L.O., 2006. Assessment of the adequacy of mathematical models. Agric. Syst. 89, 225–247.

Tedeschi, L. O., Cavalcanti, L. F. L., Fonseca, M. A., Herrero, M. & Thornton, P. K., 2014. The evolution and evaluation of dairy cattle models for predicting milk production: An agricultural model intercomparison and improvement project (AgMIP) for livestock. Anim. Prod. Sci. 54, 2052–2067.

Tedeschi, L.O., Fox, D.G., Fonseca, M.A., Cavalcanti, L.F.L., 2015. Models of protein and amino acid requirements for cattle. Rev. Bras. Zootec. 44, 109–132.

Tedeschi, L. O., and D. G. Fox. 2016. The Ruminant Nutrition System: An Applied Model for Predicting Nutrient Requirements and Feed Utilization in Ruminants. XanEdu, Acton, MA.

Tylutki, T.P., Fox, D.G., Durbal, V.M., Tedeschi, L.O., Russell, J.B., Van Amburgh, M.E., Overton, T.R., Chase, L.E. & Pell, N., 2008. Cornell Net Carbohydrate and Protein System: A model for precision feeding of dairy cattle. Anim. Feed Sci. Technol. 143, 174–202.

Zhao, J.S., Zhou, Z.M., Ren, L.P., Xiong, Y.Q., Du, J.P., Meng, Q.X., 2008. Evaluation of dry matter intake and daily weight gain predictions of the Cornell Net Carbohydrate and Protein System with local breeds of beef cattle in China. Anim. Feed Sci. Technol. 142, 231–246

Chapter 7: Carcass attributes and physicochemical meat quality characteristics of Malawi Zebu steers fed diets containing rangeland-based protein sources

Abstract

This study evaluated the effects of feeding Malawi steers with diets containing baobab (*Adansonia digitata*) seed meal and white thorn tree (*Vachellia polyacantha)* leaf-meal as alternative protein sources to soybean meal on carcass attributes and physico-chemical meat quality characteristics. Thirty individually penned Malawi Zebu steers, weighing 182 ± 21.4 kg and 29 months old, were randomly allocated to three diets for 120 days. The diets consisted of rangeland hay and maize bran with either baobab seed meal, *V. polyacantha* leaf-meal or soybean meal (control) as the major protein source. At day 120, all animals were slaughtered and the *Longissimus thoracic et lumborum* muscle from left side was removed for objective colour, drip and cooking loss, water-holding capacity Warner-Blatzler shear force and nutrient composition. Soybean-fed animals had the heaviest (P<0.05) slaughter weight followed by baobab-fed and Vachellia-fed animals. The carcass weight for baobab- and soybean-fed animals were similar (P>0.05). Vachellia-fed cattle had the highest (P<0.05) muscle ultimate pH, followed by baobab-fed steers, whereas soybean-fed steers had the lowest muscle pH. Feeding baobab and Vachellia diets resulted in *l. lumborum* muscle with higher (P<0.05) water-holding capacity and lower cooking loss than the soybean diet. Intramuscular fat, zinc and manganese contents were higher (P<0.05) *l. lumborum* muscle from steers fed the baobab compared to Vachellia and soybean diets. Meat (*l. lumborum* muscle) from soybean-fed steers had a brighter (P<0.05) red color (higher L* values) than meat from baobab- and Vachellia-fed steers. Beef from steers fed the Vachellia diet had the most stable colour (lowest hue angle

value) during retail display compared to the rest. Overall, the diets containing baobab seed meal and *V. polyacantha* leaf-meal improved meat quality of Malawi Zebu steers.

Keywords: baobab seed meal, beef cattle, *Vachellia polyacantha* leaf-meal, meat quality, soybean meal

7.1 Introduction

Beef is the second most consumed meat in Sub-Saharan Africa (SSA); estimated at 33% of the total meat consumption with poultry, sheep/ goat and pork estimated at 36%, 19% and 12% respectively (Organisation for Economic Co-operation and Development; OECD, 2016). Consumption patterns of meat in SSA reflect cultural and religious preferences, level of income, as well as the dominance of extensive, rangeland-based production systems, with cattle grazing on communal pasture a common occurrence (OECD, 2016). Beef production per livestock unit on communal rangelands, however, remains below the global average, suggesting that significant productivity gains could be realized (OECD, 2016).

Beef production on communal rangelands is hindered by the low-quality tropical natural grasses especially during the dry season (Mapiye et al., 2011). When harvested/grazed at later stages of maturity, tropical grasses have a low protein and high lignin content, which reduce their digestibility, and could consequently compromise animal performance (Detmann, et al., 2014). It is, therefore, important to provide protein supplements to ensure optimal animal performance on rangelands. In a recent study we conducted (Chapter 5), we observed that feeding Malawi Zebu steers with baobab seed meal (a rangeland protein source) improved DMI, ADG and reduced production costs.

Regardless of the region, cultural background and income, consumers show a clear willingness to pay for beef that has high eating quality (Polkinghorme and Thompson, 2010). Besides quality, consumers also seek nutritious foods with health-promoting functions such as bioactive nutrients like certain fatty acids (De Smet and Vossen, 2016). In general, the inclusion of tanniferous feeds such as Vachellia leaf-meal is reported to improve beef nutritional's composition, fatty acid profile and colour stability (Mapiye et al., 2010). Although baobab seed meal could support animal performance at the same level as soybean meal (Chapter 5), there is limited information on the effects of its dietary inclusion on beef carcass and meat quality attributes. On the other hand, there is also limited information on the meat quality characteristics of Malawi Zebu. Therefore, the objective of this study was to evaluate the effects of feeding diets containing baobab seed meal and *V. polyacantha* leaf-meal as alternative protein sources to soybean meal on carcass and physicochemical attributes of Malawi Zebu steers.

7.2 Materials and Methods

7.2.1 Location of study, experimental design, treatments and animals

The experimental design, treatments and animals were as previously described in Chapter 5

7.2.2 Chemical analyses of experimental diets

Refer to Section 4.2.2 in Chapter 4

7.2.3 Slaughter and carcass attribute measurements

On day 120 of the trial, all steers were weighed and transported to a commercial abattoir (Kanengo Abattoir, Lilongwe, Malawi; GPS coordinates: 13º 54' 24.3S 33º 47'18.7 E) for slaughter. The animals were slaughtered according to the commercial abattoir practices. The carcasses were inspected, split into left and right halves. The pH and temperature were measured at approximately 45 minutes post-mortem on the right half in the M. *longissimus thoracic et lumborum* muscle using a Crison pH 25 hand-held portable pH meter with an automatic temperature adjuster (Lasec Pty Ltd, Cape Town, South Africa). Furthermore, the back-fat thickness was measured 5 cm laterally from the mid-line cut between the 10^{th} and 11^{th} ribs. The carcasses were weighed and chilled for approximately 24 hours at 4 ºC. After chilling, pH was recorded again at the same anatomical position as used for the 45 mins post-mortem pH. Cold carcass weight was estimated as 2% of the warm carcass weight according to the abattoir's practice. Dressing percentage was estimated by dividing the hot carcass weight by the final live weight and multiply the result by 100. The carcasses were graded using the Malawi Grading System (Malawi Meat and Products Act, 1985) by a qualified government meat grader. Briefly, the major criteria for Malawian grading system are age (dentition), cold carcass weight and fat colour, with a top grade reserved for animals with not more than six permanent teeth; cold carcass weight of above 180 kg which is covered in white or creamy fat.

7.2.4 Sampling and physical meat quality measurements

Approximately 24 hours after slaughter, steaks from the *Longissimus thoracic et lumborum* (LTL) muscle were excised from the left side of the carcasses. Each steak was further cut into two portions. One portion was immediately sliced (~10 mm thick) for colour stability evaluation during 8-d retail display. The remaining portion was analyzed for drip loss, cooking loss, water-holding capacity and Warner-Bratzler shear force.

7.2.5 Drip loss and water-holding capacity

Drip loss was determined by suspending pre-weighed steaks in individual plastic bags (Needham and Hoffman, 2015). Briefly a small hole was made in the corner of the steak through which a green wire (50 cm in length) was attached. The piece of steak was then suspended in an inflated plastic bag, without touching the sides of the bag at any stage. The bag was suspended in the fridge (4 °C) for 24 hours. The meat was then removed from the bag and gently blotted dry using a paper towel and weighed. Drip loss percentage was calculated using the following equation:

Drip loss = [(weight before suspension – weight after suspension)/weight before suspension] × 100.

The determination of water holding capacity using the filter pressing method of Grau and Hamm (1953) was performed as described by North et al. (2016). Each beef sample, weighing 0.5 g, was finely chopped and pressed onto filter paper between two Perspex plates (pressure: 588N). The photographs of the pressed samples on the filter paper were taken from the same camera settings. The ImageJ software (National Institute of Mental Health, Bethesda, Maryland, USA) was used to calculate the area of purge (outer circle) and meat (inner circle) on photographs. The water holding capacity was calculated as the difference between the outer and inner circle area divided by outer circle area multiplied by 100.

7.2.6 Proximate and mineral composition

Moisture, ash, and protein determination (Kjeldahl Method) were according to AOAC International (2002) methods. Total fat was determined by extracting the fat using a chloroform/methanol (2:1; v/v) solution (Lee et al., 1996). Nutritionally important microminerals in beef: Fe, Zn, Cu and Mn (Mulvihill, 2014), were analyzed using 0.5 g of defatted and dry samples. The samples were ashed at 550°C for 6 h. The ash was solubilized in concentrated nitric acid. Five ml of 6 M HCl were added to the samples before analysis using an Atomic Absorption Spectrophotometer (Varian SpectrAA 20, Agilent Technologies).

7.2.7 Cooking loss and warner-Bratzler shear force

Steaks were sliced (10 mm thickness), weighed, placed in thin-walled plastic bags marked with permanent marker, and boiled at 80 ºC in a water-bath for an hour (North et al., 2016). After boiling, the samples were removed from the water-bath. Water that had accumulated in the bags during the boiling was removed before the samples were cooled in an ice slurry. The steaks were taken from the bag, gently blotted dry using a paper towel and weighed. Cooking loss was calculated by subtracting the weight after cooking from the weight before cooking. The difference was then divided by the weight before cooking, and the result multiplied by 100. The cooked meat samples from cooking loss analysis were used for the determination of Warner-Bratzler shear force (WBSF). Six circular cores (diameter = 12.7 mm) were bored using a core borer with the fibre direction parallel to a long dimension of at least 30 mm at right angles to the fibre axis. The cores were sheared by means of a Warner-Bratzler shear attachment fitted to an electronic scale with a load cell of 2 kN with the blade moving at a crosshead speed of 3.33 mm/s.

7.2.8 Beef colour stability during the refrigerated conditions

Measurements of colour stability during retail display were done by modifying the procedure of Neethling et al. (2016). Nine steak slices (2.5 cm thick) were cut from the LTL of each steer. The steaks were packaged in polystyrene trays (three slices per tray) and cling-wrapped in low-density polyethylene (LDPE) film. Thereafter, steaks were stored in an aerobic refrigerated environment to simulate a retail display for colour stability assessment. The packed steaks were stored for 0, 3 and 7 days at 4°C. The cold room was continuously illuminated by white fluorescent lights L58W/640, Energy Saver, 4600 Lumen. Instrumental colour measurements were made using a calibrated Colour Guide 45°/0° colorimeter (Model 6801, BYK-Gardner, Geretsried, Germany) equipped with an 11-mm aperture, illuminant D65, and 10° observer angle. Prior to colour measurement, the LDPE film wrap was removed and colour was measured directly on the surface of the steaks perpendicular to the muscle fibre direction. Three measurements were taken on each steak. Blooming was carried out for 30 min prior to colour measurement according to King et al. (2010).

7.2.9 Statistical analyses

All data were analyzed in SAS 9.4 (SAS Institute, Cary, NC, USA). The data were inspected for normality using the Shapro-Wilk test. Outliers were identified using the studentized residual analysis. Data were analyzed using the PROC GLM procedure, but the colour stability measurements which were analyzed using PROC MIXED procedure with time of storage fitted as repeated measures and animal (diet) as subject; a first-order autoregressive covariance structure was used since it produced the lowest Akaike Information Criterion (AIC). The Kenwood-Rogers method was used for approximation of degrees of freedom for the fixed effects. Pairwise difference was used for separating means. Significance was declared at P <

0.05 and trends at $0.05 < P \leq 0.10$. The following statistical models were used for analysis of the carcass attributes:

General linear model,

$$Y_{ij} = \mu + \beta_i + \varepsilon_{ij}$$

Where,

Y_{ij} = dependent response;

μ = overall mean;

β_i = fixed effect of the ith diet i = baobab, *Vachellia*, soybean diets and;

εij = random error.

Mixed model

$$Y_{ij} = \mu + \beta_i + \lambda(\beta_i) + \tau_j + \beta_i\tau_j + \varepsilon_{ijk}$$

Where, Y_{ijk}= colour measurement;

β_i= fixed effect of the diet;

$\lambda(\beta_i)$=animal within diet as a random effect;

τ_j=time of storage;

$\beta_i\tau_j$=interaction between diet and time of storage; and

ε_{ijk}= random error

7.3 Results

7.3.1 Carcass characteristics

Steers fed the soybean and baobab diets had higher (P < 0.05) slaughter weights than animals fed the *Vachellia* diet had the lightest slaughter weights (Table 7.1). Both the hot and cold carcass weights and subcutaneous fat thickness for the baobab-fed and soybean-fed animals were similar (P > 0.05), but both were greater (P < 0.05) than for the *Vachellia*-fed steers. Steers fed the Vachellia and baobab diets had carcasses with higher (P < 0.05) ultimate temperature than steers fed the soybean diet. Diet had no effect (P>0.05) on the dressing percentage. All the carcasses were graded as Standard.

Table 7.1 Carcass characteristics of Malawi zebu steers fed with diets containing soybean meal, baobab seed meal and *Vachellia polyacantha* a leaf-meal

	Diets[1]				
Variable	Soybean	Baobab	Vachellia	SEM	*P*-value
Final body weight, kg	241[a]	239[a]	211[b]	5.8	<.0001
Hot carcass weight	121[a]	122[a]	105[b]	3.8	<.0001
Cold carcass weight	119[a]	118[a]	103[b]	3.51	<.0001
Dressing percentage	50.4	50.9	49.9	0.72	0.8569
Fat thickness, mm	4.83[a]	5.12[a]	2.69[b]	0.55	<.0001
Temperature $_{initial}$, °C	31.6	32.1	31.7	0.58	0.6474
Temperature $_{ultimate}$, °C	13.8[a]	13.6[a]	13.0[b]	0.20	0.0025
pH $_{initial}$, 45 min	6.57	6.59	6.64	0.06	0.5321
pH $_{ultimate}$, 24h	5.77[b]	6.09[a]	6.22[a]	0.13	0.0155

[abc]Means within a row with different superscript letters differ (P< 0.05).

[1]Soybean = soybean meal + maize bran + rangeland hay; Baobab = baobab seed meal + maize bran + rangeland hay; Vachellia = *Vachellia polyacantha* leaf-meal + maize bran + rangeland hay.

7.3.2 Physicochemical meat quality characteristics

The LTL muscle from steers fed the baobab and Vachellia diets had lower ($P < 0.05$) drip and cooking losses than the LTL of steers fed the soybean diet (Table 7.2). The highest ($P < 0.05$) WHC was measured in LTL muscle from animals consuming the baobab diet, whereas the lowest WHC was reported in LTL muscle from steers fed the soybean diets. Warner-Blatzler shear force (WBSF) of the LTL muscle was not affected by diet (Table 7.2). Only LTL lightness values (L*) differed cross the diets among the colour parameters measured 24 h post-mortem (Table 7.2). The L* values of LTL muscle from baobab- and Vachellia-fed steers did not differ ($P > 0.05$); however, they and were darker than that of Soybean-fed steers.

Table 7.2 Physical meat quality attributes of *Longissimus thoracic et lumborum* of Malawi Zebu steers fed diets containing the rangeland-based protein sources

	Diet[1]				
Variable	Soybean	Baobab	Vachellia	SEM	P-value
Drip loss, %	2.02[a]	1.58[b]	1.57[b]	0.166	0.0001
Cooking loss, %	40.9[a]	38.9[b]	38.8[b]	1.06	0.0148
Water-holding capacity, %	57.6[c]	61.4[a]	59.8[a]	2.11	0.0062
WBSF, kg	4.20	3.72	3.89	0.54	0.6481
Colour, 24 hr post-mortem					
*L**	39.6[a]	36.4[b]	34.7[b]	1.76	0.0273
a*	12.6	12.5	11.9	0.52	0.4297
b*	7.73	7.70	7.23	0.52	0.5409
Hue angle	30.1	29.4	28.3	1.93	0.6586
Chroma	15.2	14.8	14.6	0.70	0.6180

[abc]Means within a row with different superscript letters differ ($P< 0.05$).
[1]Soybean = soybean meal + maize bran + rangeland hay; Baobab = baobab seed meal + maize bran + rangeland hay; Vachellia = *Vachellia polyacantha* leaf-meal + maize bran + rangeland hay.

7.3.3 Proximate and selected mineral composition

The LTL muscle from steers fed Vachellia- and Baobab had similar moisture content ($P > 0.05$), which was higher ($P < 0.05$) than the moisture content of LTL muscle from Soybean-fed steers (Table 7.3). Steers on the baobab diet had beef LTL with higher the IMF, zinc and manganese content of LTL muscle was higher ($P < 0.05$) for steers fed the baobab compared to Vachellia and Soybean diets.

Table 7.3 Proximate and selected micromineral composition of *Longissimus thoracic et lumborum* from Malawi zebu steers fed rangeland based diets

		Diet[1]			
Nutrient	Soybean	Baobab	Vachellia	SEM	P-value
Proximate composition, %					
Moisture	72.2^{a}	73.9^{b}	73.4^{b}	0.65	0.0191
Protein	22.3	21.5	21.1	1.02	0.4302
Intramuscular Fat	1.80^{b}	2.52^{a}	1.78^{b}	0.28	0.0379
Ash	1.20	1.24	1.28	0.16	0.8693
Micromineral, mg/100g					
Cu	0.06	0.07	0.06	0.02	0.7488
Zn	1.90^{b}	2.83^{a}	2.01^{b}	0.33	0.0352
Fe	7.41	6.17	6.13	2.09	0.8005
Mn	0.02^{b}	0.04^{a}	0.01^{b}	0.01	0.0433

[abc]Means within a row with different superscript letters differ ($P< 0.05$).
[1]Soybean = soybean meal + maize bran + rangeland hay; Baobab = baobab seed meal + maize bran + rangeland hay; Vachellia = *Vachellia polyacantha* leaf-meal + maize bran + rangeland hay.

7.3.4 Beef colour stability during refrigerated storage conditions

All colour measurements of the LTL steaks were influenced by time of storage (Table 7.4; P < 0.05). In general, L* declined steadily over time while a*, b* and chroma showed a sustained increase over time before declining. The hue angle showed an increasing trend over time. Diet had a significant effect (P < 0.05) on all LTL colour measurements except for chroma during the retail display (Table 7.5). However, there was no interactive effect of diet and time of storage on any of the colour parameters during storage (P > 0.05).

Table 7.4 Objective colour of *thoracic longissimus et lumborum* muscle from steers fed diets containing Baobab seed meal, *Vachellia polyacantha* and Soybean over 8-day of retail display.

Variable	Day			SEM	P-value	
	0	3	7		Day	Day*Diet
*L**	36.0^{a}	34.5^{b}	33.3^{c}	0.40	<.0001	0.2504
a*	12.1^{b}	13.5^{a}	11.2^{b}	0.39	<.0001	0.9725
b*	6.89^{c}	9.74^{a}	8.44^{b}	0.39	<.0001	0.6933
Hue angle	29.3^{c}	34.9^{b}	36.4^{a}	1.18	<.0001	0.1302
Chroma	14.1^{c}	17.7^{a}	14.3^{b}	0.59	<.0001	0.8031

^{abc}Means in a row bearing different superscript letters differ (p< 0.05).

Table 7.5 Overall objective colour of *thoracic longissimus et lumborum* muscle from Malawi zebu steers fed diets containing soybean meal, baobab seed meal and *Vachellia polyacantha* leaf-meal over 8-day retail display

	Diet[1]				P-value		
Variable	Soybean	Baobab	Vachellia	SEM	Diet	Time	Diet*Time
*L**	36.4^{a}	35.0^{a}	32.3^{b}	1.36	0.0215	<.0001	0.2504
a*	13.1^{a}	12.3^{ab}	11.4^{b}	0.69	0.0426	<.0001	0.9725
b*	9.4^{a}	7.9^{b}	7.7^{b}	0.57	0.0087	<.0001	0.6933
Hue angle	40.6^{a}	36.2^{b}	30.2^{c}	1.74	0.0053	<.0001	0.1302
Chroma	15.3	15.1	15.8	0.62	0.7013	<.0001	0.8031

[abc]Means within a row with different superscript letters differ ($P< 0.05$).

7.4 Discussion

The inferior slaughter, warm and cold carcass weights reported for steers on the Vachellia diet could be attributed to their low DMI and ADG, which was associated with the low starch, high lignin and tannin content in the diet as discussed in Chapter 6. The low starch, high lignin and tannin content may have reduced rumen fermentation, thereby reducing nutrient supply to animals. The higher carcass ultimate temperatures observed in steers fed diets containing soybean meal and baobab seed meal than those fed *V. polyacantha* leaf-meal could be ascribed to the high carcass weights reported for the former diets as it is known that fatter and more bulky animals take longer to cool down (Warris, 2010).

The highest LTL ultimate pH and lower L* values from steers fed the Vachellia diet could be related to the low energy content in the muscle at the point of slaughter. This low muscle energy could be due to the low starch, high tannin and lignin contents possibly reducing ruminal fermentation and, thus, glucose supply and accumulation of glycogen reserves in the muscle at slaughter. Acidification of muscle post-mortem is chiefly influenced by the level of glycogen available in the carcass, which determines the extent of lactic acid production (Warris, 2010). Prioli et al. (2000) also observed that lambs fed tannin-rich diets had carcasses with high ultimate pH and this was attributed to a low dietary energy supply due to the interference of tannins with ruminal fermentation, which had a negative effect on carcass glycogen status.

The higher carcass ultimate pH and low L* values observed in steers fed diets containing *V. polyacantha* than soybean meal leaf-meal may be partly ascribed to the lower ADG and lighter carcass weights observed for the former diet. In similar studies, Mapiye et al. (2013) and Młynek and Guliński (2007) ascribed differences in meat quality attributes of steers that had different growth rates to differences in muscle fibre type composition. In general, slower growth rates result in animals with a higher composition of type I compared to type II muscle fibres (Młynek and Guliński, 2007). Type I muscle fibres are red in colour, have high oxidative capacity, and are lower in glycogen content and glycolytic enzyme activity (Klont, Brocks, and Eikelenboom, 1998). Consequently, lactic acid production is decreased and muscle acidification slows down, which result in meat with a high pH and darker colour (Młynek and Guliński, 2007). Alternatively, lighter carcass weights observed for the steers fed the diet containing *V. polycantha* likely resulted in faster loin cooling rates, which in turn yielded meat with a higher pH and darker (low L*) colour than those fed soybeans. The LTL muscle from steers fed the diets containing *V. polyacantha* could be classified as DFD (dark firm and dry); a phenomenon associated with low muscle glycogen stores immediately before death. All the other physical quality attributes (low drip loss and L*, high WHC and pH) as depicted in Table

7.4 are typical of DFD meat. The LTL muscle from steers fed the Baobab seeds could also have been classified as DFD when the classical definition of muscle ultimate pH > 6.0 is used as the determining parameter; however, the phenomenon was not as prominent as in the Vachellia diet fed steers.

The higher ultimate pH in the baobab- compared to the soybean-fed animals had no immediate reason as it the animals had similar growth performances. This could may be related to vitamin C levels, which have been reported to be much higher in baobab seed than soybean containing over 30 g/kg DM (Assogbadjo et al., 2012). Vitamin C promotes ruminal production of acetic acid, which is non-gluconeogenic, over propionic acid, which is gluconeogenic (Tagliapietra et al., 2013). An increase in acetic acid production may have then limited glycogen storage in the body. However, to the best of my knowledge, there is no information on the effect of feeding baobab seed meal to ruminants on carcass attributes. Therefore, future studies should determine the level of vitamin C in baobab and its effect on ruminal fermentation and muscle glycogen accumulation and pH.

The higher drip loss and lower WHC of the beef from the steers fed the soybean compared to the baobab and Vachellia diets could be related to a low ultimate pH observed in the carcasses of steers on soybean diet. The lower pH is close to the iso-electric point of muscle protein, which might have caused protein denaturation and, thus, reduced ability to bind water molecules that increases drip loss (Huff-Lonergan and Lonergan, 2005; Warris, 2010; Puolanne, 2017). The higher cooking loss for LTL muscle from steers fed soybean compared to baobab and Vachellia diets could be also be related a low pH, as previously discussed.

Although WBSF values of the LTL found in this study for Malawi Zebu steers did not differ significantly across diets, the values were all below the ≤4.4 kg threshold used to denote tenderness (Howard et al., 2013). Despite being rated tender, the animals were graded as Standard, which is three levels lower than the top grade. The tender meat was most probably a result of their age at slaughter, which was less than six permanent teeth. The animals were penalized because of their low carcass weights, which were too low to achieve the second top Malawian beef grade of 142 kg carcass weight. Malawi Zebu are a small-framed and slow-growing breed and can hardly achieve a 180-kg cold carcass weight required for the top grades at an age younger than 36 months (Nkhonjera et al., 1988). The weight of a carcass does not give an indication of beef palatability (Polkinghorne and Thompson, 2010). Therefore, incorporation of criteria related to beef palatability is recommended in the Malawi Grading System.

Although the moisture contents in the LTL muscle from steers fed the different diets differed possibly due to differences in pH as described earlier (Table 7.4), these differences were small and, thus, could be of little biological significance. However, the high intramuscular fat, zinc and manganese content in the LTL muscle of the Baobab-fed steers could be because of the high content of fat, zinc and manganese in the baobab diet which would have resulted in high intake of these nutrients. Beef rich in minerals such as zinc and iron could be used in formulating diets for children to increase intake of these minerals, which are commonly deficient in the human populations in most developing countries including Malawi (Mulvihill, 2014).

Despite the fact diet had an influence on L*, a*, b* and hue angle during the refrigerated storage conditions, attention should be paid to the changes in the hue angle (Table 7.4). Hue angle (arctangle) concurrently measures an increase in yellowness (b* value) and a decrease in redness (a*), which gives an accurate picture of meat discolouration (Jerónimo et al., 2012). The results in the present study showed that beef from steers fed the Vachellia diet had the highest resistance to discolouration (low hue angle values) during the retail display, which could be attributed to the impact of tannins on discolouration during storage. These findings agree with reports by Jerónimo et al. (2012) who observed lower hue angle values in meat from lambs fed grape seed extract diets compared to lambs fed a control diet (without grape extract). Although they do not get absorbed into the blood stream of animal because of their large size, tannins might undergo depolymerization and catabolism, which break down into smaller molecules that in turn are absorbed and have an anti-oxidant capacity, thereby stabilizing meat colour (Luciano et al., 2009). On the other hand, the sustained increase in chroma from d 0 to 3 of retail display before declining across diets could be attributed to the high forage inclusion level in all the diets. Forages contain high levels of antioxidant vitamins (α-tocopherol and β-carotene), which improves beef colour stability during refrigerated storage (Suman et al 2014).

7.5 Conclusion

Feeding steers diets containing baobab seed meal and V. polyacantha leaf-meal resulted in DFD meat. Nevertheless, the diet containing baobab seed-meal caused higher WHC, lower drip and cooking losses, lower fat and mineral composition. The Vachellia diet improved the colour stability of LTH muscle during retail display. Unfortunately, the grading system used penalized these Malawi Zebu steers (inherently small-sized cattle breed) fed with rangeland diets even when the animals were young and achieved acceptable instrumental tenderness. This calls for an in-depth analysis of the shortcomings of the criteria of the current Malawi grading system by comparing it to the carcass grading /classification systems applied in other countries in southern Africa. This will enable us to make recommendations on the possible changes that could be made to ensure that the small framed indigenous breeds typically found in small-holder farms in southern Africa are evaluated in a fair manner.

7.6 References

AOAC International, 2002. Official methods of analysis of AOAC International. 17th Ed. AOAC International, Gaithersburg, MD.

Assogbadjo, A. E., Chadare, F. J., Kakaï, R. G., Fandohan, B. & Baidu-Forson, J. J. (2012). Variation in biochemical composition of baobab (*Adansonia digitata*) pulp, leaves and seeds in relation to soil types and tree provenances. Agric., Ecosy. Environ, 157, 94–99.

De Smet, S. & Vossen, E. (2016). Meat: The balance between nutrition and health. A review. Meat Sci. 120, 145–156.

Detmann, E., Valente, É. E. L., Batista, E. D. & Huhtanen, P., 2014. An evaluation of the performance and efficiency of nitrogen utilization in cattle fed tropical grass pastures with supplementation. Liv. Sci. 162, 141–153.

Grau, R. & Hamm, R. 1953. Eine einfache Methode sur Bestimmung der Wasserbindung in Muskel. Naturwissenschaften 40, 29.

Howard, S.T., Woerner, D.R., Scanga, J.A., Van Overbeke, D.L., Mafi, G.G., Igo, J.L. & Belk, K.E., 2013. North american beef tenderness survey 2011-2012: Benchmarking tenderness and sample shipping procedures. J. Anim. Sci. 91, 5981–5988.

Huff-Lonergan, E. & Lonergan, S. M., 2005. Mechanisms of water-holding capacity of meat: The role of postmortem biochemical and structural changes. Meat Sci. 71, 194–204.

Jerónimo, E., Alfaia, C.M.M., Alves, S.P., Dentinho, M.T.P., Prates, J.A.M., Vasta, V. & Bessa, R.J.B., 2012. Effect of dietary grape seed extract and *Cistus ladanifer* L. in combination with vegetable oil supplementation on lamb meat quality. Meat Sci. 92, 841-847.

King, D.A., Shackelford, S.D. & Wheeler, T.L., 2011. Relative contributions of animal and muscle effects to variation in beef lean color stability. J. Anim. Sci. 89, 1434–1451.

Klont, R.E., Brocks, L. & Eikelenboom, G., 1998. Muscle fibre type and meat quality. Meat. Sci. 49, 219–S229.

Lee, C.M., Trevino, B. & Chaiyawat, M. 1996. A simple and rapid solvent extraction method for determining total lipids in fish tissue. J. AOAC Int. 79, 487-92.

Luciano, G., Monahan, F.J., Vasta, V., Biondi, L., Lanza, M. & Priolo, A., 2009. Dietary tannins improve lamb meat colour stability. Meat Sci. 81, 120–225.

Malawi Meat and Meat Products, 1985. Grading of beef carcasses. Laws of the Republic of Malawi 67:02.

Mapekula, M., Mapiye, C. & Chimonyo, M., 2011. Changes in Metabolites Concentration in Nguni and Crossbred Calves on Natural Pasture. Asian-Aust. J. Anim. Sci. 24, 1569–1576.

Mapiye, C., Chimonyo, M., Marufu, M.C. & Dzama, K., 2011. Utility of *Acacia karroo* for beef production in Southern African smallholder farming systems: A review. Anim. Feed Sci. Technol. 164, 135–146.

Mapiye, C., Turner, T.D., Rolland, D.C., Basarab, J.A., Baron, V.S., McAllister, T.A., Block, H.C., Uttaro, B., Aalhus, J.L. & Dugan, M.E.R., 2013. Adipose tissue and muscle fatty acid profiles of steers fed red clover silage with and without flaxseed. Liv. Sci. 151, 11–20.

Mulvihill, B., 2014. Micronutrients in meat. Encyc. of Meat Sci. 2nd Ed. Vol.2, pp 124-129. Elselvier.

Młynek, K. & Guliński, P., 2007. The effect of growth rate and age at slaughter on dressing percentage and colour, pH48 and microstructure of longissimus dorsi muscle in Black-and-White (BW) bulls vs commercial crossbreds of BW with beef breeds. Animl. Sci. Papers and Reports. 25, 65–71.

Needham, T. & Hoffman, L. C., 2015. Physical meat quality and chemical composition of the *Longissimus thoracis* of entire and immunocastrated pigs fed varying dietary protein levels with and without ractopamine hydrochloride. Meat Sci. 110, 101–108.

Neethling, N. E., Suman, S. P., Sigge, G. O. & Hoffman, L. C., 2016. Muscle-specific colour stability of blesbok (*Damaliscus pygargus phillipsi*) meat. Meat Sci. 119, 69–79.

Nkhonjera, L., Agymang, K. & Butterworth, M.H., 1988. Performance of cattle stall-fed for beef in Malawi. Trop. Anim Health Prod. 20, 155-60.

North, M. K., Frylinck, L. & Hoffman, L. C., 2016. The changes in springbok (*Antidorcas marsupialis*) *Longissimus thoracis et lumborum* and *Biceps femoris* muscles during the rigour period. Meat Sci. 112, 24–30.

OECD (Organisation for Economic Co-operation and Development), and Food and Agriculture Organization of the United Nations (FAO). 2016. OECD-FAO Agricultural Outlook 2016-2025. http://doi.org/10.1787/agr_outlook-2016-en

Polkinghorne, R. J. & Thompson, J. M., 2010. Meat standards and grading. A world view. Meat Sci. 86, 227–235.

Priolo, A., Waghorn, G. C., Lanza, M., Biondi, L. & Pennisi, P. 2000. Polyethylene glycol as a means for reducing the impact of condensed tannins in carob pulp: Effects on lamb growth performance and meat quality. J. Anim. Sci. 78, 810–816.

Puolanne, E., 2017. Developments in our understanding of water holding capacity in meat. In: New aspects of meat quality from genes to ethics. P.P. Purslow (Ed). pp167-190. W.P. Woodhead, Elselvier, UK.

Suman, S. P., Hunt, M. C., Nair, M. N. & Rentfrow, G., 2014. Improving beef color stability: Practical strategies and underlying mechanisms. Meat Sci. 98, 490–504.

Tagliapietra, F., Cattani, M., Hansen, H. H., Bittante, G. & Schiavon, S., 2013. High doses of vitamin E and vitamin C influence *in vitro* rumen microbial activity. Anim. Feed Sci. Technol. 183, 210–214.

Warris, P. 2010. Meat Science. An introductory text. 2nd Ed. CABI, UK.

Chapter 8: Evaluation of shortcomings of selected beef carcass grading and classification systems in southern Africa

(Part of this chapter was published in the *South African Journal of Animal Science,* see Appendix B)

Abstract

Southern Africa is home to over 64 million cattle, of which 75% are raised on natural pasture in smallholder farming areas. Indigenous cattle breeds Bos indicus (zebu), B. taurus africanus (Sanga type) and their crosses with B. taurus (European and British) are the most dominant. Despite their dominance, indigenous cattle breeds in smallholder farming areas are marketed through informal markets, and their contribution to formal national economies is therefore limited. This is partly because the current beef carcass grading and classification systems used in the region value inappropriately carcasses from slow-growing indigenous cattle breeds that are ideally suited to being marketed off natural pasture. The existing systems use carcass yield and quality attributes, but do not predict eating quality at the consumer level. Moreover, the principal criteria used to estimate carcass yield and quality, namely age, fat cover and conformation, are assessed indirectly and subjectively. The aim of the current review is to give an overview of the beef carcass grading and classification systems in Southern Africa and analyse their shortcomings in valuing carcasses from indigenous breeds and local production systems. In addition, the review highlights opportunities for improving these systems in Southern Africa and makes recommendations towards developing a regional beef carcass classification system.

Key words: beef, carcass grading and classification, indigenous cattle, smallholder farming.

8.1 Introduction

Southern Africa is the southernmost region of the African continent geopolitically, comprising twelve mainland countries (Angola, Botswana, Democratic Republic of Congo, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe) and three island ones (Madagascar, Mauritius and Seychelles), located between latitudes 4° to 35° south and longitudes 12° to 58° east (FAO, 2007). These 15 countries make up a regional economic body known as the Southern African Development Community (SADC). The region is home to over 64 million cattle, of which 75% are kept under smallholder farming systems that rely on natural pasture (SADC, 2012). Natural pastureland constitutes over 60% of the region's total land area (FAO, 2007). Indigenous *Bos indicus* (zebu) and *B. taurus africanus* (Sanga) and their nondescript crosses with exotic *B. taurus* (European and British) are the dominant cattle breeds (Strydom, 2008). Indigenous cattle are slow-growing and ideally suited to being marketed off natural pasture (Strydom et al., 2015). Natural pasture-fed indigenous cattle often achieve the required levels of finish at lighter weights and older age than early maturing exotic breeds, which are suitably finished on grain. Such older and lighter carcasses from indigenous cattle fetch low prices in formal markets. This is mainly because grading and classification systems in formal markets favour heavy carcasses from young animals, which are usually obtained from grain-fed exotic breeds (Strydom et al., 2015; Webb, 2015).

Grading and classification systems are used in the beef industry to describe the quality and yield of a carcass to ensure consistent meat quality and consumer satisfaction (Allen, 2014; Aalhus et al., 2014). The terms 'grading' and 'classification' do not have the same meaning. On the one hand, grading refers to the placing of different values on several carcass attributes and using combinations of these attributes to develop a grade that relates to meat quality for pricing purposes, depending on the market and requirements of traders and consumers (Allen, 2014). On the other hand, carcass classification refers to the sorting of carcasses with similar attributes into classes based on certain criteria to guide those involved in the production, trading, and consumption of carcasses (Aalhus et al., 2014). Overall, in carcass classification the emphasis is on providing the beef industry and consumers with a choice of types of carcasses in terms of carcass composition and physical attributes, while there is no indication of perceived quality, as is provided in a grading system (Strydom, 2011; Webb, 2015).

Beef carcass grading and classification systems used in Southern Africa are becoming less useful because of considerable increases in variation in their categories (Strydom et al., 2015), mainly because of differences among cattle breeds and production systems, and the use of modern feedstuffs and growth-enhancing technologies (Strydom, 2011). Furthermore, these systems do not always include eating quality standards, particularly beef palatability (Webb, 2015). Most systems in southern Africa (Strydom, 2011; Webb, 2015) and the world at large (Polkinghorne and Thompson, 2010) are indicators of cattle finishing or fatness and meat yield rather than beef palatability at consumer level. Moreover, most of the descriptive terms used in the current systems are vague, subjective and sometimes meaningless. Consequently, there is growing interest in Southern Africa in establishing systems that correspond with the diverse beef breeds and production systems, and are in tune with local consumer preferences. The current review summarizes grading and classification systems used in Southern Africa, examines their strengths and weaknesses in valuing carcasses of indigenous breeds finished off pasture, and makes recommendations for the development of an inclusive classification system for the region.

8.2 Beef production and marketing systems in Southern Africa

Beef production in Southern African countries is divided into commercial (freehold) and smallholder (traditional) sectors (Naziri et al., 2015; Soji et al., 2015). The commercial sub-sector is well developed, capital intensive, and export oriented (Cabrera et al., 2010). Commercial beef production is stratified into extensive (ranching) and intensive (feedlot) systems, with herd sizes varying between 1000 and 30000 cattle, although a few feedlot systems have larger numbers of cattle at any one period, made up mostly of British and European breeds and their crosses with indigenous breeds (Strydom, 2008; Ransom, 2011; Haasbroek, 2013). Pure indigenous cattle breeds are shunned by feedlots because they often fail to meet feedlot induction specifications for weight, fatness, age, and frame score (Strydom, 2008). Except for South Africa, feedlot systems in Southern African countries are not fully developed, and beef is mostly derived from cattle finished off natural pasture (Ransom, 2011; Dzanja et al., 2013; Maciel et al., 2015). In South Africa, feedlot beef production accounts for over 80% of the national beef value chain, and parallels some developed countries (Webb and Erasmus, 2013). Weaner producers in Southern Africa in general supply steers or bulls to feedlots at six to twelve months, with induction weights between 180 and 250 kg (Strydom, 2008). These steers or bulls are then finished on a high-energy grain-based diet for 60 to 150 days. Alternatively, steers are backgrounded on natural pasture or forage-based diets for one to three years before entering the feedlot (Webb and Erasmus, 2013).

Smallholder beef production is subdivided into small-scale (subsistence-cum-commercial) and communal (subsistence) systems (Naziri et al., 2015; Soji et al., 2015). Natural pasture is the major feed resource for cattle in the smallholder sector (Mapiye et al., 2009). Cattle are usually offered for sale at three years or older on an ad hoc basis (Ransom, 2011; Soji et al., 2015). A large proportion of the cattle kept in smallholder areas are tropical indigenous breeds and their nondescript crosses with exotic breeds (Strydom, 2008). The major indigenous cattle breeds in Southern Africa are *Bos indicus* (zebu) (e.g. Angoni and Malawi zebu) and *B. taurus africanus* (Sanga type) (e.g. Afrikaner, Mashona, Nguni, Tuli and Tswana). Zebu cattle are found mostly north-east of the Zambezi River (Malawi, Mozambique and Zambia). Sanga cattle are found predominately to the south of the Zambezi in Angola, Botswana, Namibia, South Africa and Zimbabwe.

The parallelism exhibited in beef production systems in Southern Africa is also evident in beef marketing (Marandure et al., 2016). The commercial sector sells its beef through formal markets, while the smallholder sector sells through informal (unlicensed) markets. In formal markets, cattle are marketed through abattoirs to wholesalers, retailers, processors, and specialized butcheries (Soji et al., 2015). At the abattoir, quality assurance schemes, including carcass grading and classification systems, are used to determine meat prices. In the informal markets, cattle are marketed directly from farmer to farmer or to local butcheries, speculators, and auctioneers (Musemwa et al., 2010). Here, the prices are determined visually, based on frame size and live weight. Under current grading and classification systems in Southern Africa, indigenous cattle breeds, especially those finished off natural pasture, often fail to achieve the best classes and grades owing to their light weight, lack of subcutaneous fat, and old age (Strydom et al., 2015). Light and old animals fetch lower prices per kilogram in the formal sector (Soji et al., 2015). This drives smallholder farmers away from marketing indigenous cattle through formal markets. Interestingly, there is a segment of beef consumers in Southern Africa that prefer older animals finished off pasture, especially among black African communities (Thompson et al., 2010; Ransom, 2011). Furthermore, a number of ventures in Southern Africa that are funded by governments and development agents seek to promote beef production from indigenous breeds in the smallholder sector. The success of these programmes hinges on the development of a new classification system that can offer best rewards for older animals finished off pasture. A clear description of important carcass and meat traits is therefore the first step towards improved beef production in the region. It is therefore crucial to reform current grading and classification systems to promote slow-growing indigenous cattle marketed off natural pasture. This could be done by marketing pasture- and grain-finished beef separately as unique products in the same classification system to cater for different consumer preferences. This could create an opportunity for smallholder farmers to gain a share of lucrative formal markets, which are currently dominated by young feedlot-finished carcasses from exotic breeds produced by commercial farmers.

8.3 Selected beef carcass grading and classification systems in Southern Africa

The origins and evolution of the major grading and classification systems of the world, including Australian Meat Standards (MSA), Canadian beef grading system, EUROP classification system, Japanese grading standards, and United States Department of Agriculture (USDA) grading system are well published (Allen, 2014; Polkinghorne and Thompson, 2010). The majority of grading and classification systems in Southern Africa (Table 8.1), like other developing countries, apply similar schemes to or derivatives of the world's major systems (Allen, 2014). The grading and classification schemes in Southern African countries emphasize carcass maturity (age), fat cover and conformation (Malawi Meat & Meat Products Act, 1985; South African Meat Industry Company; SAMIC, 2006; Botswana Livestock & Meat Industries, 2007; Zimbabwean Carcass Classification and Grading Regulations, 2016). With the exception of South Africa and Namibia, information describing beef carcass grading and classification schemes in Southern African countries is limited. The principal grading and classification criteria used in selected Southern African countries are summarized in Table 8.1.

Table 8.1: Principal components of beef carcass grading and classification schemes in selected countries in Southern Africa

Country	Botswana	Malawi	Namibia and SA*	Zimbabwe
Grading or classification unit	Carcass	Carcass	Carcass	Carcass
Classification system	-	-	Yes	Yes
Grading system	Yes	Yes	-	-
Attributes appraised on the slaughter floor	Carcass weight Dentition Fat cover Conformation Carcass bruising	Carcass weight Dentition Gender	Carcass weight Dentition Gender Fat cover Conformation Carcass bruising	Carcass weight Dentition Gender Fat cover Conformation Carcass bruising Bone ossification
Attributes appraised on the chilled carcass	Fat colour	Cold carcass weight Conformation Marbling score Fat cover Fat colour Bone ossification Carcass bruising		

South Africa*

Grading and classification systems in Southern Africa are applied voluntarily in licensed registered slaughter facilities. Despite carcass grading and classification being applied on this basis, most retailers and wholesalers prefer classified meat as a guarantee of product quality, in line with consumer demands (Strydom et al., 2015).

Botswana uses a grading system to distinguish beef carcasses, which are graded into hierarchical quality grades of prime, super, first, second, third, fourth and canning. Grading is based on carcass maturity (dentition), and subjective scores of degree of subcutaneous fat distribution, conformation, bruising, fat cover and colour (Botswana Livestock and Meat Industries, 2007). Beef carcasses showing signs of staginess, over-fatness, and bruising may be graded one or more grades lower than the one for which they would have qualified. Prime grade is placed on carcases of either sex with no more than two permanent incisors of good conformation with uniform light fat cover and white fat. Super grade is obtained from animals of either sex with no more than four permanent incisors, of good conformation with uniform light fat cover, and white fat. Carcasses with no more than four permanent incisors, but patchy fat cover, or those with five to eight permanent incisors, of good conformation with uniform light fat cover and white or creamy fat, are ranked first grade. The carcasses of either sex with up to eight permanent incisors, of fair conformation with uniform light fat cover, and fat of any normal colour, are assigned to second grade. Third grade is given to carcasses of any sex and age, of poor conformation and no fat cover. Fourth grade is placed on carcasses of any sex and age of very poor conformation and patchy or no fat cover. Canning grade is given to carcasses of any sex and age of very poor conformation with oedema.

Similarly to Botswana, Malawi uses a grading system. The criteria in Malawi are carcass maturity (dentition and bone ossification), cold carcass weight, fat cover, fat colour, marbling, conformation, bruising and gender (Malawi Meat and Meat Products Act, 1985). The Malawian grading system divides carcass maturity into two age groups: zero–six permanent incisors, and more than six. Bone ossification, an additional criterion used to assess carcass maturity, is determined visually by the presence or absence of ossification in the spinal process of the lumbar region of carcasses with more than six permanent incisors. Marbling at the twelfth rib is scored visually into three classes: liberal, fair and poor. Beef carcasses are graded into five quality grades of choice, prime, standard, commercial, and inferior. Choice grade is placed on carcasses derived from steers or heifers with not more than six permanent incisors and weighing not less than 180 kg (cold carcass weight). In addition, choice grade carcasses must have a good conformation with plump, well-fleshed quarters, an even covering of firm white or creamy-white fat, well-developed kidney and channel fat, and a liberal distribution of marbling at the point of quartering. The carcasses must be free from objectionable bruises and taint, and be bright and sound in condition. Carcasses of young bulls qualify for choice grade if they have no permanent incisors and meet all other requirements of that grade. Prime grade is assigned to carcasses derived from steers or heifers with seven–eight permanent incisors, which do not show any pronounced ossification of the spinal processes in the lumbar region, and weighing not less than 146.25 kg cold carcass weight after 24 hours' refrigeration. The quarters must be plump and well fleshed, but the development of internal and external fat may be somewhat less than in the choice grade. The carcasses must have a fair distribution of marbling at the point of quartering (twelfth rib). Carcasses must be free from objectionable bruises and taint, and be bright and sound in condition. Standard grade is given to carcasses from steers, cows, and bulls of any age, moderately fleshed, and covered with fat, except for bulls. Bulls should be well covered with fat. Commercial grade is given to carcasses harvested from steers, cows and bulls of any age, fairly fleshed, and covered with some fat. Inferior grade is given to steers, cows and bulls below the standard grade. The use of quality grade names such as 'inferior' in the current grading system may have negative connotations tor retailers and consumers. Use of non-discriminatory terms such as 'canning' and 'manufacturing' grade, as adopted in the Botswana grading system, which corresponds to the Malawian inferior grade, may be more appropriate.

Namibia and South Africa use a classification system to describe beef carcasses. Owing to their common geopolitical history, Namibia and South Africa have the same carcass classification system (SAMIC, 2016). According to South African Government Notice No. 38431 of 2015 and the Meat Board Namibia, beef carcasses are classified based on age, fat cover, conformation, carcass damage and gender (Table 8.2). However, age and fat cover are the major criteria (Strydom, 2011). Age is categorised into four classes, as shown in Table 8.2. Beef bulls in age classes B and C are marked 'MD' to distinguish them from young beef bulls in A and AB classes. Fat cover is assessed objectively through subcutaneous backfat depth measured 5 cm laterally from the mid-line cut on the ninth rib, and carcasses are assigned to one of seven classes as shown in Table 8.2. Conformation is classified into five classes, while carcass damage is categorized into three classes (Table 8.2).

Table 8.2: South African and Namibian beef carcass classification system

Classification	Description
Age	
0 permanent incisors	A
1–2 permanent incisors	AB
3–6 permanent incisors	B
>6 permanent incisors	C
Fat cover	
0	No fat (0 mm fat thickness)
1	Very lean (0.1–0.9 mm fat thickness)
2	Lean (1.0–3.0 mm fat thickness)
3	Medium (>3.0–≤5.0 mm fat thickness)
4	Fat (5.0–≤7.0 mm fat thickness)
5	Very fat (>7.0–≤10.0 mm fat thickness)
6	Excessively fat (>10 mm fat thickness)
Conformation	
1	Very flat
2	Flat
3	Medium
4	Round
5	Very round
Carcass damage	
1	Slight
2	Moderate
3	Severe
Gender	
Only beef bulls in age class B and C are marked ‘MD’	

The Zimbabwean beef industry moved recently from a carcass grading system to a new carcass classification system (Zimbabwean Carcass Classification and Grading Regulations, 2016). Under the new system, beef carcasses are classified based on maturity (age), fat cover, conformation, gender and bruising (Table 8.3). In terms of age, carcasses are categorized into three classes (Table 8.3) according to the number of erupted permanent incisor teeth in young cattle and the degree of spinal ossification in carcasses of full-mouth cattle. Fat cover is assessed objectively through subcutaneous backfat depth measured 5 cm laterally from the midline cut between 10th and 11th ribs and carcasses are allotted to one of five classes as shown in Table 3. Carcass conformation is divided visually into five classes (Table 8.3). Carcasses of male cattle that show the development of secondary male sex characteristics, and signs of late castration are marked with a code 'MD'. Carcass bruising classification is done by estimating the trimmed meat weight loss as a percentage of carcass weight. Damage is categorised into four classes (Table 8.3). Calf carcasses are classified according to age and weight and codified 'CALF'. Calf carcass conformation and damage are classified as for mature cattle carcasses

Table 8.3: Zimbabwean beef carcass classification system

Classification	Description
Age	
0–2 permanent incisors	A
3–6 permanent incisors	B
7–8 permanent incisors	C
Fat cover	
0	No measurable fat (0 mm fat thickness)
1	Slight fat cover (1–2 mm fat thickness)
2	Medium fat cover (3–6 mm fat thickness)
3	Slightly over fat 7–12 mm fat thickness)
4	Excessive fat cover (>13 mm fat thickness)
Conformation	
1	Very flat
2	Flat
3	Medium
4	Round
5	Very round
Gender	
Only beef bulls in Age Class B and C are marked 'MD'	
Bruising	
1	The code is shown on one side to indicate that the other side is unbruised
2	The code appears on both sides indicating that bruising is <2% of the carcass weight
3	The code indicates that both sides were trimmed by >2% of the carcass weight
4	The code denotes trimming caused by abscesses, infected wounds and injections

8.4 Shortcomings of the current beef carcass grading and classification systems in Southern Africa

Overall, grading and classification systems in Southern Africa use similar criteria, which emphasize animal age, fat cover and conformation. They also use carcass yield and quality attributes to infer beef palatability. Fisher (2007) noted that it is confusing to infer beef palatability when yield and quality attributes are used in grading and classification systems. Thus minimizing the concurrent use of beef yield and quality attributes when valuing carcasses in current systems could be worthwhile. Alternatively, ideas could be borrowed from the USDA system, which has separate grading systems for quality and yield, or the EUROP beef classification, which focuses on yield. It may also be important to modify current systems in the region, to adapt existing systems or to develop new ones to estimate the value of carcasses.

Current systems in Southern Africa use age as determined by dentition and bone ossification as the primary basis for predicting beef tenderness. Consumers' willingness to pay premiums for beef with guaranteed tenderness is well documented (Verbeke et al., 2010; Reicks et al., 2011). As a result, the primary emphasis of most global carcass grading and classification systems is on guaranteeing beef of consistent tenderness in and across grades or classes. Progression in animal age is generally associated with decreased meat tenderness, which is triggered by the increased concentration of insoluble collagen (Warris, 2010). Meat from younger animals has more soluble collagen, and consequently is more tender than that of older animals (Warris, 2010). Namibia, South Africa, Botswana, and Zimbabwe place desirable grades and classes on carcasses from young animals (0–2 permanent incisors). In Malawi, carcasses with up to six incisors are considered for top beef quality grades. Similar carcases from six-toothed animals are put in low or inferior classes and grades in systems that emphasize young animals. It has emerged that such systems that emphasize young animals do not accurately predict the beef tenderness of slow-growing African indigenous cattle with three to six incisors that are often finished off pasture (Strydom, 2011). Contrary to the proven trend that tenderness declines with age from 0–2-toothed, through 3–6-toothed, to 7–8 toothed cattle for grain-finished animals (Warris, 2010), 3–6-toothed pasture-finished cattle have been reported to have more tender beef than 0–2-toothed pastured animals (Strydom, 2011). The tougher meat reported for 0–2-toothed pastured animals could be related to poor conditioned small carcasses that reflect poor growth rates (Strydom, 2011), which could be addressed by improving pasture condition. Shackelford et al. (1994) and Perry and Thompson (2005) reported more tender meat for faster growing animals in the same group, which Shackleford et al. (1994) related to lower calpastatin activities, and consequently better ageing ability of muscle.

Besides age and production systems, differences in tenderness could be caused by other pre-slaughter factors, including differences between cattle breeds (genetic), pre-slaughter stress and growth-enhancing technologies (Strydom et al., 2015; Frylinck et al., 2015). Variation in tenderness at shelf level is also a function of the amount of ageing of meat (Polkinghorne and Thompson, 2010), among other post-abattoir practices that are not covered by any classification system, including electrical stimulation and hanging. These factors affect accuracy of use of age for predicting tenderness. Inclusion of these factors in a classification could accurately describe the final product and provide accurate information to consumers (Webb, 2015). Use of dentition as the only proxy for beef tenderness does not accurately describe the attribute when breed, growth promotants and post-mortem manipulations are considered. Even when this system is regarded as unbiased, it fails to support large-scale production requirements as it is tedious, costly and time consuming (Craigie et al., 2012). It is also questionable whether consumers see the classification and, if they do, whether they understand what it means. Breed, ecotype, growth promotants and post-slaughter manipulations, however, have never been considered in grading and classification systems in Southern Africa. Owing to a significant level of crossbreeding in the region, breed factor may be difficult to describe in these systems, but could be viable for indigenous cattle breeds finished off natural pasture (Strydom et al., 2015). Generally, 0–2-toothed young cattle from feedlot are implanted or dosed with hormonal growth promotants and beta-agonists, which affect meat tenderness negatively (Strydom et al., 2011; Frylinck et al., 2015). Consequently, young cattle do not show differences in meat tenderness in low connective tissue muscles compared with older grass-fed cattle (Crosley et al., 1994; Thompson et al., 2010; Strydom et al., 2015). Research to determine better criteria for predicting tenderness than age are therefore important. These could include the use of proteomics (Moloto et al., 2015), visual observation of structural properties (Modika et al., 2015), measurement of the hump (*Rhomboideus* muscle), which is linked to the *B. indicus* breeds and their genetic deposition to higher levels of calpastatin (Strydom et al., 2016) and building models to explain differences and use them to develop technologies to standardize meat tenderness (Frylinck et al., 2015).

There are contrasting positions over what constitutes the optimal level of beef carcass fatness among Southern African countries. Countries such as Botswana, Namibia, and South Africa prefer low carcass fatness, while Malawi and Zimbabwe prefer fatter carcases. Botswana’s preference for low carcass fatness is probably influenced by its long participation in international beef trade

(Ransom, 2011) characterized by a decline in proportions of consumers preferring fat beef cuts (Ngapo and Dransfield, 2006). South Africa's push for beef carcasses with low fat is possibly driven by socio-economic factors, including an increasing population of consumers with high disposable incomes that seek healthier foods (Schönfeldt et al., 2016). Contradictory fatness preferences have implications for the grading and classification of indigenous cattle finished off natural pasture. In Botswana, Namibia, and South Africa, indigenous cattle finished off natural pasture would be desirable because of their lean carcasses. In contrast, in Malawi and Zimbabwe, beef from such animals would be less preferred. Instead of valuing beef based on fat content alone, recent evidence calls for the grading and classification to be based on content and fatty acid composition (Mapiye *et al*., 2012; De Smet and Vossen, 2016). Although the practicality of measuring fatty acids may be an obstacle, near-infrared spectroscopy (NIRS) online technology (Prieto et al., 2013) could be used in high-throughput abattoirs. Such information could be particularly important for health-conscious consumers. Carcass fat content and fatty acid composition affect organoleptic properties (i.e. juiciness, flavour and tenderness) and healthfulness of beef (O'Quinn et al., 2012). Therefore, new carcass grading and classification systems must consider valuing beef in terms of content and fatty acid composition without compromising organoleptic quality or healthfulness.

Another shortcoming is that carcasses from indigenous cattle finished off natural pasture receive poor conformation classes or inferior grades. In fact, carcasses from indigenous cattle do not compete favourably with those derived from exotic breeds owing to their inherent small and compact bodies (Soji et al., 2015). In addition, conformation in the region is assessed subjectively using visual scores of body shape profiles. Overall, current grading and classification systems in

Southern Africa indicate that there are numerous combinations of age, fat and conformation classes in which carcasses can be classified or graded. In South Africa for example only 5 to 10% of the carcass classification system is used effectively, notably classes A2, A3, AB2, AB3, while small proportions of carcasses are classified in other categories (Webb, 2015). This phenomenon arises partly because most of the cattle traded in the formal market come from feedlots and are therefore young and have good subcutaneous fat cover. There is also evidence of increased variation in carcass grading and classification categories. This is attributed to differences between cattle breeds, different animal production systems, and the use of modern feedstuffs and growth-enhancing technologies (Webb, 2015). The wide range of grading and classification criteria and variations in categories might be predisposing factors for dissatisfaction among stakeholders in the meat production-to-consumption continuum since they may not be capable of embracing diverse breeds and production characteristics and their influence on beef palatability.

In the current systems, carcass weight may be considered at the same level as age in terms of inappropriate description of carcasses from indigenous cattle. Indigenous cattle are not preferred in the feedlot system because they are slow growing, have light bodyweight and small frames (Strydom, 2008). In general, feedlots target fast-growing, medium- to late-maturing breeds with heavy weight and large frames. In South African feedlots for example beef cattle are fed to an average target slaughter weight of 300–450 kg, which give target average carcass weights of 180–250 kg (Haasbroek, 2013; SAFA, 2015; Strydom, 2008). It is almost impossible for indigenous breeds to achieve an average carcass weight of 180–260 kg when they are less than 36 months old (0–2 toothed). Typically, indigenous cattle are kept longer in the feedlot or marketed at an older age if finished off natural pasture to gain more weight (Strydom, 2008). Indigenous cattle become less profitable when kept for a long period in the feedlot as they mature early, thus gain less weight, and deposit more fat. With the current drive towards heavier carcasses in South Africa, this is going to become an even bigger problem and indigenous cattle may become less suitable for meeting market demand. In terms of grading and classification, Malawi is probably the only country in Southern Africa that grades carcasses based on weight, in which carcasses (>180 kg) are preferred. Age categories in Malawian grading systems were probably crafted to suit the slow-growing small-framed Malawian zebu (Dzanja et al., 2013), which are ready for slaughter off natural pasture at the age of 36 to 48 months (Butterworth and McNitt, 1994). Unfortunately, by the time the indigenous breeds are finished, they have 7–8 permanent incisors and qualify for choice or prime grades (Nkhonjera et al., 1988).

Carcass fat colour is one of the criteria that are used in Malawian and Botswanan grading systems. Carcasses covered with white fat are valued more than those covered with yellow or creamy fat. The motivation for discriminating against yellow fat was probably aimed at promoting feedlot beef production to meet increased domestic demand for beef and beef products (Ransom, 2011). However, there is not sufficient local evidence that consumers prefer white fat to yellow fat in Southern Africa. In fact, yellow or creamy fat colour in a healthy bovine is a result of a high intake of carotene and is characteristic of carcasses from pasture-raised cattle (Dunne et al., 2009). Negative discrimination of carcasses based on yellow fat does not favour indigenous cattle. In fact, a positive discrimination of yellow fat should be promoted because beef from pasture-finished animals has many human health benefits (Van Elswyk and McNeill, 2014; Scollan et al., 2014). It is thus important to describe fat colour appropriately in future carcass classification systems. It may also be relevant to distinguish between pasture-and grain-fed animals, especially when other quality characteristics are considered, such as meat fatty acid composition, flavour, juiciness, and aroma. Overall, there are great challenges and opportunities for the Southern African beef industry, which is under pressure to improve production efficiency while maintaining or improving quality traits desired by consumers. At the same time, opportunities to enter new world markets are expanding and these markets come with different consumer expectations.

8.5 Opportunities for improving beef carcass grading and classification systems in Southern Africa

The use of subjective methods in grading and classification systems for assessing the value of beef carcasses is often the cause of distrust among players in the meat industry globally (Craigie et al., 2012). Use of manual inspection is not reliable because it is difficult to demonstrate objectivity as long as human classifiers are involved (Allen, 2014). In addition, some systems have sophisticated standards, training, certification and audit processes, which improve the objectivity of manual grading and classification. It is against this background that high-technology solutions are being sought to use machine vision for quality, timely assessment and accurate valuation of agro-based products (Alfatni et al., 2013). There is an opportunity to improve the prediction of meat quality characteristics, and obtain additional value from mature carcasses through advanced machine-based technologies such as grade cameras, dual energy X-ray absorptiometry and spectroscopic methods, including NIRS, Raman spectroscopy, and hyperspectral imaging (Aalhus et al., 2014). Meanwhile, video image analysis (VIA) and hyperspectral imaging, which uses a combination of VIA and NIRS, are becoming popular in meat classification systems (Konda et al., 2015). In VIA, digital video images of carcass sides or cuts are taken and processed in software to generate output variables, which are then evaluated for their relationship to meat quality attributes (Vote et al., 2003). The best opportunities for improving computer vision solutions lie in hyperspectral imaging (HIS), which provides additional information about meat composition and structure. HSI, coupled with multivariate analyses, could be used for rapid and accurate prediction of meat quality parameters such as colour, tenderness, marbling, water-holding capacity, drip loss and pH (Cheng et al., 2015). In addition, HSI could be used in classification and discrimination of muscle types (Cheng et al., 2015). Robust NIRS online technology for predicting the content and composition of fatty acids, represents another opportunity (Prieto et al., 2013). The future incorporation of this technology into automated grading and classification and data collection systems will allow the possibility of health-conscious marketing, beyond grass-finishing value chains (Aalhus et al., 2014). Therefore, advanced technologies could be used as augmentation tools for objective valuation and standardization of beef carcasses in Southern Africa. Advanced technologies such as HSI might be more important to high-throughput abattoirs than low-throughput ones. Low throughput abattoirs may work towards implementing small cost-effective grade cameras and VIA systems, which use a camera with special lighting to photograph and estimate carcass traits such as fat thickness. However, in any regional structure, all abattoirs should use the same classification system, and the cost of more modern technologies may be a limiting factor for the introduction of such systems.

Biotechnological tools that are applicable to meat production include analysis of single nucleotide polymorphisms (SNPs), proteomics and metabolomics. These tools identify biomarkers (genes, proteins, and metabolites), whose expression level or abundance is associated with a phenotype of interest, such as the quality of meat (Hocquette et al., 2014). SNP biomarkers are used to predict meat quality attributes from birth, while protein and metabolite biomarkers are used to predict meat quality after slaughter (Picard et al., 2015). Gene and protein expression profiling of bovine muscles has revealed that the expression level of many genes and the abundance of many proteins could be indicators of muscle mass, tenderness, flavour and marbling of meat (Viegas et al., 2014). Therefore, genomic, proteomic and metabolomic approaches could be used to value beef carcasses and meat cuts for specific markets. Markers for beef tenderness are now well known, including those of African indigenous cattle. For example, Moloto et al. (2015) showed protein expression changes in response to ageing associated with beef tenderness in Nguni cattle. The major gap in Southern Africa's carcass classification is lack of accurate criteria for describing beef quality attributes, especially tenderness. Proteome and metabolite-based markers could fill the gap. Although these approaches are expensive and require highly skilled technical expertise, the advance of rapid methods through collaboration with developed countries could be feasibly be implemented in Southern African high-throughput slaughterhouses in the short to midterm.

Overall, consumers in Southern Africa have limited understanding of the use and significance of beef grading and classification systems (Vermeulen et al., 2015; Schönfeldt et al., 2016). This is probably because these systems are more producer than consumer centred (Vermeulen et al., 2015). Knowledge of physical meat traits such as tenderness, fat cover and conformation, which are emphasized in current Southern African systems, gives limited information to consumers about expected eating quality compared with the ageing period, feeding regime (grass versus grain and use of growth promotants) and even the slaughter process (Vermeulen et al., 2015). Stakeholders (i.e. education and research institutions, health professionals, policy makers, consumer associations, animal protection societies, and the media) must educate producers, retailers and consumers and help them to understand production, quality, safety, and ethical issues related to beef production and the importance of beef grading and classification systems. Carcass grading and classification schemes constructed according to consumer preferences easily achieve wide acceptance in any beef industry (Polkinghorne and Thompson, 2010). It is also crucial to re-align the current grading and classification systems with consumer preferences.

Perceptions of and expectations about beef quality and eating experience are not the same among consumers, even from the same country (Olivier et al., 2009). In Southern Africa in general, white African consumers prefer more tender beef, while black African consumers, particularly those that live in rural areas, prefer beef that is chewy, flavoursome and juicier (Thompson et al., 2010; Ransom, 2011). Consumer decisions to purchase beef are influenced by appearance characteristics (muscle, fat and bone ratio, colour of lean and fat, and lack of defects). The eating quality of the cooked meat (flavour, juiciness, tenderness) (Smith et al., 2008) influences subsequent purchases. In most cases, consumers concentrate on flavour to ultimately establish when beef tenderness is acceptable to them (Aalhus et al., 2014). Thus, flavour is a decisive sensory trait that affects consumer satisfaction in beef. Although cattle finished off natural pasture may not have a perceived superior value based on the existing grading and classification systems, they may have other quality attributes that are of value to the consumer – such as flavour – that are not considered in these systems. This creates an opportunity to include meat eating quality as a supplementary grouping to mainstream carcass classification systems (Matthews, 2016). The same line of reasoning was adopted by Polkinghorne et al. (2008) when they developed the MSA beef grading system, which seems to hold most potential for implementation in South Africa.

Unlike existing beef grading and classification systems in Southern Africa, which use a carcass as the basic unit, the MSA system predicts consumer satisfaction from a cooked meal for each cut of the carcass (Polkinghorme and Thompson, 2010). The system considers pre-slaughter and post-slaughter factors to attain a palatability score (Polkinghorme et al., 2008). Pre-slaughter factors include breed, weight for age and growth rate, hormonal growth implants, fatness, marbling, gender, stress and management practices. Post-slaughter practices include pH and temperature paths, hanging, ageing, and cooking method. Overall, the MSA scheme is less about carcass description and more about quality assurance and conditions in the abattoir. Thompson et al. (2010) tested the MSA system in South Africa, and found that beef from indigenous cattle classified using this system met consumer eating quality expectations on the same level as that from exotic breeds. More importantly, Thompson et al. (2010) noted that while the increased connective tissue toughness from older indigenous animals was a problem with grilling, it was suited to the slow cooking methods commonly used by black African communities. These authors reported that beef cuts from the older lighter indigenous cattle finished off pasture and prepared with slow cooking methods were preferred by black African consumers. Based on these considerations, the opportunity to develop a flavour niche market might be achieved by utilizing indigenous breeds owing to their slow-growing and exposure to natural pasture. As a result of its success when tested locally, the MSA quality system has been considered for use in South Africa (Strydom et al., 2015).

Although beef value lies in the eye, mouth and mind of the consumer (Aalhus et al., 2014), at present producers in Southern Africa are rewarded by carcass grade or class instead of eating quality. Southern Africa is experiencing rapid urbanization and consumers with high disposable income are willing to pay for credence and measureable quality differences (Schönfeldt et al., 2016). Credence quality traits refer to beef quality attributes that cannot be evaluated under normal circumstances by the average consumer, becoming a matter of faith and trust in the information (Grunert et al., 2004). Credence quality is important to consumers in terms of rising concerns about health, safety, origin, animal welfare and sustainability (Warriss, 2010). In South Africa for example affluent consumers are demanding healthier animal foods produced in a sustainable manner with higher standards of animal welfare (Schönfeldt et al., 2016). The expanding middle-class consumers, with a high affinity for animal-based protein sources, are increasingly emulating this type of behaviour, with less affluent consumers expected to follow suit in the near future (Marandure et al., 2016).

The major health concern about beef is consumption of high proportions of saturated fatty acids and trans-fatty acids, which have been associated with cardiovascular disease, diabetes, and several cancers (Mitchell et al., 2012; De Smet and Vossen, 2016; Ruiz-Núñez et al., 2016). However, consuming beef from grass-fed animals could reduce these risks as it contains human health beneficial fatty acids (e.g. vaccenic acid, rumenic acid, omega-3 fatty acids), β-carotene, and α-tocopherol in greater proportions than grain-fed beef (Daley et al., 2010; Van Elswyk and McNeill, 2014; Scollan et al., 2014). Until now, natural pasture finished animals have been imprecisely and non-verifiably identified in the current system through the presence of yellow fat and their market potential is not being realized. Smallholder farmers raising cattle on natural pasture, who are currently disadvantaged by grading and classification systems, may benefit from classification or labelling and niche marketing of natural pasture-fed beef.

Another concern regarding consumption of beef is safety, which is centred on the use of non-forage feed supplements, acaricides, anthelmintics and growth promotants, including hormones and antibiotics (Dunshea et al., 2014). These chemicals are linked to the risk of cancers, worm and microbial resistance to antibiotics, among other undesirable issues (Warris, 2010). Under natural pasture-based production systems in Southern Africa, indigenous beef cattle are produced with minimal or no use of biocides (Muchenje et al., 2008; Mapiye et al., 2011). Globally, information about hormones, antibiotics, traceability-enabled and bovine spongiform encephalopathy (BSE) tested beef have been associated with willingness to pay a premium for meat (Viegas et al., 2014). However, current grading and classification systems do not distinguish between beef production that are enhanced with chemicals (e.g. growth enhancing technologies) and naturally produced beef. Where the information is provided through labelling, it is a question of faith and trust (Viegas et al., 2014). Therefore, efforts should be made in Southern African carcass classification and meat labelling schemes to distinguish between growth promotant-based beef and natural beef, which again may promote smallholder natural pasture-based beef production systems.

Humanely raised and slaughtered beef is another trend that is focused on a segment of consumers that are ready to pay a premium for meat that has been produced under prescribed standards (Aalhus et al., 2014). Current research shows that stress-free livestock that are allowed to express their natural behaviour are healthier (Horgan and Gavinelli, 2006), thus more productive in terms of quantity and quality. Development of on-package labelling for certified animal welfare standards throughout the production process could be crucial. However, as Webster (2001) notes, even though producers are responsible for providing animal welfare, there are costs associated with implementing higher animal welfare standards, such as those related to training farm staff, and adapting farm activities to appropriate standards (Viegas et al., 2014). Another problem is that, to date, there is no single definition of 'humane meat'. In addition, it would be particularly difficult for smallholder producers to certify humane beef, and easier for large commercial producers. Thus humane certified labelling of beef may prove a disadvantage to smallholder producers. However, the main idea behind the humane meat movement is that people will continue to eat meat for the foreseeable future, but farming practices deemed to be inhumane could be eliminated (Freeman, 2010). In addition to animal welfare, some consumers are worried about the consequences of beef production on the environment and the economic status, social life and cultural heritage of producers (Tallontire et al., 2001). Research should contribute to effective and informative labelling of animal welfare information on products to enhance informed decision making, transparency, and eventually the likelihood of consumers choosing animal welfare-enhanced beef products.

Overall, beef healthfulness, safety, animal welfare and sustainability are often jointly produced. Extensive natural pasture-based production systems of indigenous cattle breeds are often considered more sustainable in terms of carbon sequestration, utilization of unproductive land and conversion of fibre to food, and provide higher standards of animal welfare, each linked to healthier, safer and more flavoursome beef (Marandure et al., 2016). Nguni cattle for example, owing to their adaptability (i.e. drought and heat tolerant, disease and parasite resistant), can be raised on natural pastures with little or no acaricides and anthelmintics, and no growth enhancers, and produce safe health-promoting high-quality beef (Muchenje *et al*., 2008; Mapiye et al., 2011). A combination of indicators related to beef nutritional and sensory quality, environmental sustainability considerations (e.g. carbon footprint, water footprint, animal welfare, ecological biodiversity), economic efficiency (i.e. income of farmers and of other stakeholders of the supply chain, and rural development) and producers' social sustainability (e.g. gender equity, social life and cultural heritage) would allow prediction of the overall quality of beef, mainly for consumers, but also for stakeholders in the supply chain (Van Ittersum et al., 2007; Hocquette et al., 2014). Credence quality attribute information could be indicated on meat through an on-package labelling system. A clear labelling system may be used as a mechanism for differentiation to enable heterogeneous consumers to purchase traits they desire. It could be important to assess whether the price premium consumers are willing to pay for these beef credence attributes is sufficient to offset production costs. Research to identify segmentation variables and corresponding consumer segments is warranted because there are probably niche markets for various combinations of credence quality attributes. Undertaking this segmentation based on socio-demographic profiles could help capitalize on consumers' heterogeneous preferences by showing new market opportunities for beef differentiation.

8.6 Towards a regional carcass classification system

Carcass grading and classification systems in Southern Africa, like other global classification systems, are limited in that they can describe only those attributes that are measurable or detectable on the day of slaughter or, at most, the day after (Strydom et al., 2015). In addition, most of the properties that are described or scored in a grading or classification system are indirect measurements of traits such as age, which is recorded as a number of permanent incisors, while fat and conformation are based only on visual appraisal of fat content and muscularity or edible yield, even when assessed by a trained classifier with photographic references (Webb, 2015). Nor do the current systems describe ultimate beef palatability, which is influenced mostly by post-abattoir practices. In addition, many of the descriptive terms used in the current grading and classification systems are vague, subjective, and sometimes meaningless. More importantly, current grading and classification systems in the region are faulted for their emphasis on younger and heavier carcasses from fast-growing exotic breeds, as opposed to older and lighter carcasses from slow-growing indigenous cattle that are ideally suited to being finished off natural pasture. It is essential to the system that the attributes that are evaluated during classification should reflect the interests of the people who want to trade in the product, and that the evaluation itself is totally consistent and repeatable. The deficiencies of current systems in describing the carcasses of indigenous cattle finished off natural pasture may be addressed through the development of a common carcass classification for the region. A common stand among countries in Southern Africa would go a long way towards pushing for standardization of the criteria that appropriately describe carcass yield and meat eating quality of indigenous and exotic cattle breeds under local production systems.

Suggestions to be considered in the common carcass classification would include a total regional movement from a grading system to a classification system. The ranking of beef in grading systems often gives the impression that beef with low palatability has no value, yet such carcasses may be ideal for manufacturing certain products and for other consumers (Fisher, 2007). In addition, beef that is considered of low palatability by grading systems may meet the requirements of certain ethnic groups. Unfortunately, peer-reviewed evidence is limited, but anecdotal evidence suggests that this may be applicable in Southern Africa and warrants further research. The current South African, Namibian and Zimbabwean beef carcass classification systems have quality ranking connotations in their classes (A, B and C). Owing to the use of preferred classes, the Namibian and South African classification systems are used as grading systems, which defeats the original purpose of a classification system. The proposed regional classification should not have quality connotations. Perhaps the classes would have to bear the SADC acronym like the EUROP classification system.

Agreement would have to be reached as to whether to use dentition and bone ossification or weight for age and growth rate, as in the MSA system, to assess carcass maturity. However, there is a poor relationship between shear force or sensory panel tenderness of the loin muscle and age classified according to dentition (Lawrence et al., 2001). Inconsistencies of shear force and sensory panel tenderness of the loin muscle and age classified according to dentition were shown in South African beef carcass classification when production system was considered (Strydom, 2011; Webb and Erasmus 2013). On the other hand, in systems that use the bone ossification method to assess carcass maturity, including the USDA grading system, mature cattle are classified more appropriately by including marbling to compensate for maturity deficiencies (Polkinghorne and Thompson, 2010). However, this trade-off would have to be considered carefully, since at present marbling is not considered in most grading and classification systems in the region.

The regional classification would have to predict the ultimate beef eating quality or experience. This could be achieved by modifying the MSA, as suggested by Strydom (2011). Marbling for example has to be revised to cut down on beef fat level if the MSA system is to be adopted. Although there are differences in fat preferences between and within countries, the common system could borrow this argument for cutting down fat levels, as high levels of fat in meat are perceived to be unhealthy. Strydom (2011) was cautious about adapting the South African classification system to the MSA, in spite of its inadequacy in defining the beef eating quality of indigenous and exotic breeds. This author argued that the MSA system is more expensive and requires higher technical skills, better organized infrastructure and improved traceability compared with the present systems. The starting point could be giving MSA licences to high-throughput abattoirs and those that are interested in exporting beef in Southern African member states, as suggested by Strydom (2011). Similarly, abattoirs that are interested in using advanced technologies for classifying carcasses would be encouraged to use of the objectivity and convenience of technology to support large-scale production.

It could be important to have a classification system that awards value to different types of production systems. Information about beef that may not be included in the classification system – including credence quality attributes and some post-slaughter treatments – should be conveyed to the consumer through an on-package labelling system. In practice, standard post-slaughter treatments would be defined from time to time. The label need only indicate deviations from this standard, as suggested by Price (1982). In Canada for example an alternative approach is used in which labelling at retail outlets incorporates best cooking practices for a particular cut in the label to assist consumers with limited cooking background (Canada Beef Inc., 2011). Labelling information would be vital to consumers, ensuring repeatability of eating quality, while the classification information would be crucial to people in the meat production-to-consumption continuum. A clear and adequate meat labelling system could improve consumer confidence, cultivate positive attitudes, and ensure that meat satisfies consumer expectations, demands and needs (Font-i-Furnols and Guerrero, 2014). Such labelling could increase the competitiveness and market share of beef from the region. Credence quality attribute claims and labelling systems are perceived as credible when they are supported by authorities that are trusted among the public (Ingenbleek and Immink 2010). Research should therefore provide objective methodologies to develop accurate indicators to predict credence quality traits of beef.

A common beef carcass classification system in the region would ensure easy trade facilitation between member states. In addition, it could facilitate international trade in which it is beneficial for member states to combine forces in search of better markets and to bargain collectively for improved trade terms and conditions. A regional effort through a harmonized beef carcass classification system could help to conserve indigenous cattle genetic resources, which are rapidly being lost through crossbreeding and breed replacement. The use of a single system could help to foster technical cooperation in livestock production among member states. From a resource-based perspective, developing marketing strategies based on regional attributes may provide the smallholder beef sector with a competitive advantage (Haucap et al., 1997). By using a common regional classification system, marketers in member states would be able to exploit consumer associations and provide a product with a regional image. Together with specific beef product qualities, this image could create a unique identity for the regional beef products and in this way add value to beef (Steiner, 2004).

Despite the benefits, attempts to develop a common carcass classification system are often resisted owing to entrenched opinions and priorities between and within countries (Price, 1995). Development of a common classification for Southern Africa is likely to face challenges including wide differences among beef industries in technological advancement and consumer preferences.

However, a common carcass classification scheme might foster active cooperation among countries, thereby satisfying regional consumers and the international market (Polkinghorne and Thompson, 2010). To minimize resistance to such a system, it should be crafted in such a way that it is flexible and applicable to a variety of consumers and conditions. In Europe for example the EUROP system allows each country to expand or collapse the levels on a particular class (Fisher, 2007). Another option for minimizing resistance is to develop a basic regional classification system that could be used for price formation with supplementary descriptive systems to differentiate product quality. Such descriptive quality systems could be initiated and implemented by producers, abattoirs and retailers and audited by independent organisations. Certainly, the development of a unified carcass valuation system for the region could be a long and costly process for the beef industry. It could therefore be important to estimate the costs and benefits associated with development and implementation of the new system before a decision is made. That would give the beef industry an opportunity to establish a more flexible and less costly classification system.

8.7 Conclusions

Current beef carcass grading and classification systems in Southern Africa value indigenous cattle inappropriately, which are ideally suited to being marketed off natural pasture. In addition, the principal criteria used to estimate carcass yield and quality are measured indirectly and subjectively and do not predict beef palatability accurately. There are opportunities to improve the prediction of carcass yield and quality, including the use of biotechnology and machine-based technologies, and obtain additional value from carcasses of indigenous cattle breeds finished off pasture. There is also an opportunity to develop credence quality attribute-based niche markets that take advantage of the adaptability of indigenous breeds and benefits of natural pasture-based production systems. Establishing common consumer-centred beef carcass classification and labelling systems that accommodate diverse breeds and production systems in the region could satisfy local and international markets.

8.8 References

Aalhus, J.L., López-Campos, Ó., Prieto, N., Rodas-González, A., Dugan, M.E.R., Uttaro, B. & Juárez, M., 2014. Review: Canadian beef grading – Opportunities to identify carcass and meat quality traits valued by consumers. Can. J. Anim. Sci. 94, 545-556.

Alfatni, M.S.M., Shariff, A.R.M., Abdullah, M.Z., Marhaban, M.H.B. & Saaed, O.M.B., 2013. The application of internal grading system technologies for agricultural products – Review. J. Fd. Eng. 116, 703-725.

Allen, P., 2014. Beef carcass classification and grading. Encyc. Meat Sci. Elsevier.

Botswana Livestock and Meat Industries, 2007. Grading of carcasses regulations. Republic of Botswana.

Butterworth, M.H. & McNitt, J.I., 1994. The Malawi Zebu. Wrld Anim. Rev. Article No. 49.

Cabrera, R., Cochran, M., Dangelmayr, L., D'Aguilar, G., Gawande, K., Lee, J., Speir, I.S. & Weigand, C., 2010. African capacity building for meat exports: Lessons from the Namibian and Botswanan beef industries. Currents: Int. Trade Law J.19, 55-78.

Canada Beef Inc., 2011. Standard cooking instructions for Canadian beef cuts. http://bic3dev.boldinternet.com/pdf/Standard_Cooking_Instructions_EN.pdf. Retrieved 10 March 2017.

Cheng, W., Cheng, J. H., Sun, D. W. & Pu, H., 2015. Marbling analysis for evaluating meat quality: Methods and techniques. Compre. Rev. Fd. Sci. Fd. Safety. 14, 523-535.

Craigie, C.R., Navajas, E.A., Purchas, R.W., Maltin, C.A., Bünger, L., Hoskin, S.O. & Roehe, R., 2012. A review of the development and use of video image analysis (VIA) for beef carcass evaluation as an alternative to the current EUROP system and other subjective systems. Meat Sci. 92, 307-318.

Crosley, R.I., Heinze, P.H. & Naudé, R.T., 1994. The relationship between beef tenderness and age classification in the South African beef carcass classification system. Proc. 40th Int. Cong. Meat Sci. Technol., The Hague, Netherlands SIII.15, 34-35.

Daley, C.A., Abbot, A., Doyle, P.S., Nader, G.A. & Larson, S., 2010. A review of fatty acid profiles and antioxidant content in grass-fed and grain-fed beef. Nutri. J. 9, 1-12.

De Smet, S.D. & Vossen, E., 2016. Meat : The balance between nutrition and health. A review. Meat Sci. 120, 145–156.

Dunne, P.G., Monahan, F.J., O'Mara, F.P. & Moloney, A.P., 2009. Colour of bovine subcutaneous adipose tissue: A review of contributory factors, associations with carcass and meat quality and its potential utility in authentication of dietary history. Meat Sci. 81, 28-45.

Dunshea, F.R., D'Souza, D.N., Jensen, B.B. & Engberg, R.M., 2014. Use of antibiotics and growth promotants. Classification of carcasses. Ency. Meat Sci. Elsevier.

Dzanja. J., Kapondamgaga, P. & Tchale, H., 2013. Value chain analysis of beef in Central and Southern Malawi (case studies of Lilongwe and Chikhwawa districts). Int. J. Bus. Soc. Sci. 4, 92-102.

FAO, 2007. Subregional report on animal genetic resources: Southern Africa. Annex to The State of the World's Animal Genetic Resources, FAO. Rome.

Fisher, A., 2007. Beef carcass classification in the EU: A historical perspective. In: C. Lazzaroni, S. Gigli and D. Gabiña (Eds), Evaluation of carcass and meat quality in cattle and sheep. EAAP Publication No. 123, Wageningen Academic Publishers. The Netherlands. pp. 19-30.

Font-i-Furnols, M. & Guerrero, L., 2014. Consumer preference, behavior and perception about meat and meat products: An overview. Meat Sci. 98, 361-371.

Freeman, C.P., 2010. Framing animal rights in the 'Go Veg' campaigns of US animal rights organizations. Soc. and Anim. 18,163-182.

Frylinck, L., O'Neil, A., Du Toit, E., Strydom, P.E & Webb E.C. 2015. The beef tenderness model. S. Afr. J. Anim. Sci. 45 (3), 234-248.

Grunert, K.G., Bredahl, L. & Brunsø, K., 2004. Consumer perception of meat quality and implications for product development in the meat sector – a review. Meat Sci. 66, 259-272.

Haasbroek, F.E., 2013. The effect of essential oils and calcified marine algae as natural alternatives to ionophore antibiotics on performance of feedlot cattle. MSc thesis, Department of Animal and Wildlife Sciences, University of Pretoria, South Africa. pp. 1-87.

Haucap, J., Wey, C. & Barmbold, J.F., 1997. Location choice as a signal for product quality: The economics of 'Made in Germany', J. Inst. Theor. Econ. 153, 510-531.

Hocquette, J.F., Botreau, R., Legrand, I., Polkinghorne, R., Pethick, D.W., Lherm, M., Picard, B., Doreau M. & Terlouw E.M.C., 2014. Win–win strategies for high beef quality, consumer satisfaction, and farm efficiency, low environmental impacts and improved animal welfare. Anim. Prod. Sci. 54, 1537-1548.

Horgan, R. & Gavinelli, A., 2006. The expanding role of animal welfare within EU legislation and beyond. Liv. Sci. 103, 303-307.

Ingenbleek, P.T.M. & Immink, V.M., 2010. Managing conflicting stakeholder interests: An exploratory case analysis of the formulation of corporate social responsibility standards in the Netherlands. J. Publ. Policy Marketing. 29, 52-65.

Konda, G., Cluff, K., Samal, A., Calkins, C.R., Jones, D.D., Lorenzen, C.L. & Subbiah, J., 2015. Hyperspectral imaging of ribeye muscle on hanging beef carcasses for tenderness assessment. Comp Elect. Agric.116, 55-64.

Lawrence, T.E., Whatley, J.D., Montgomery, T.H., Perino, L.J. & Dikeman, M.E., 2001. Influence of dental carcass maturity classification on carcass traits and tenderness of longissimus steaks from commercially fed cattle. J. Anim. Sci. 79, 2092-2096.

Maciel, S., Amimo, J., Martins, M., Okeyo, A.M., Scholtz, M.M. & Neser, F.W.C., 2013. Feedlot performance of the Nguni ecotypes in southern Mozambique. Liv. Res. R. Dev. 25, 111.

Malawi Meat and Meat Products Act, 1985. Grading of beef carcasses. Chapter 67:02. Laws of the Republic of Malawi.

Mapiye, C., Chimonyo, M., Marufu, M.C. & Dzama, K., 2011. Utility of *Acacia karroo* for beef production in Southern African smallholder farming systems: A review. Anim. Feed Sci. Tech. 164, 135-146.

Mapiye, C., Chimonyo, M., Dzama, K., Raats, J.G. & Mapekula, M., 2009. Opportunities for improving Nguni cattle production in the smallholder farming systems of South Africa. Liv. Sci. 124, 196-204.

Mapiye, C., Aldai, N., Turner, T.D., Aalhus, J.L., Rolland, D.C., Kramer, J.K.G. & Dugan, M.E.R., 2012. The labile lipid fraction of meat: From perceived disease and waste to health and opportunity. Meat Sci. 92, 210-220.

Marandure, T., Mapiye, C., Makombe, G., Nengovhela, B. Strydom, P., Muchenje, V. & Dzama K., 2016. Beef traders' and consumers' perceptions on the development of a natural pasture-fed beef brand by smallholder cattle producers in South Africa. Afr. J. Range Forage Sci. 33, 207-214.

Matthews, K., 2016. How does the UK meat industry meet consumer expectations? In: Proc. of Aldam Stockman's Sch. Progr., South Africa.

Mitchell, P.L., Karakach, T.K., Currie, D.L. & McLeod, R.S., 2012. t-10, c-12 CLA dietary supplementation inhibits atherosclerotic lesion development despite adverse cardiovascular and hepatic metabolic marker profiles. PLoS ONE. 7, 1-11.

Modika, K.Y., Frylinck, L., Moloto, K.W., Strydom, P.E., Heinze, P.H. & Webb, E.C. 2015. Visual evaluation of beef tenderness by using surface structural observations and its relationship to meat colour. S. Afr. J. Anim. Sci. 45, 255-262.

Moloto, K.W., Frylinck, L., Strydom, P.E. & Koorsen, G., 2015. Proteomics approach as a new way to predict tenderness as compared to classical South African Beef Carcass Classification System. S. Afr. J. Anim. Sci. 45, 249-254.

Muchenje, V., Dzama, K., Chimonyo, M., Raats, J.G. & Strydom, P.E., 2008. Meat quality of Nguni, Bonsmara and Aberdeen Angus steers raised on natural pasture in the Eastern Cape, South Africa. Meat Sci. 79, 20-28.

Musemwa, L., Mushunje, A., Chimonyo, M. & Mapiye, C., 2010. Low cattle market off-take rates in communal production systems of South Africa: Causes and mitigation strategies. J. Sust. Dev. Afr. 12, 5.

Naziri, D., Rich, K.M. & Bennett, B., 2015. Would a commodity-based trade approach improve market access for Africa? A case study of the potential of beef exports from communal areas of Namibia. Dev. Policy Rev. 33, 195–219.

Ngapo, T.M. & Dransfield, E., 2006. British consumers preferred fatness levels in beef : Surveys from 1955, 1982 and 2002. Food Qual. Prefer. 17, 412-417.

Nkhonjera, L., Agymang, K. & Butterworth, M.H., 1988. Performance of cattle stall-fed for beef in Malawi. Trop. Anim Health Prod. 20, 155-60.

O'Quinn, T.G., Brooks, J.C., Polkinghorne, R.J., Garmyn, A.J., Johnson, B. J., Starkey, J.D. & Miller, M. F. 2012. Consumer assessment of beef strip loin steaks of varying fat levels. J. Anim. Sci. 90, 626-634.

Olivier, M.A., Nute, G.R., Font-i-Furnols, M., San Julian, M., Campo, M.M., Sanudo, D., Caneque, V., Guerrero, L., Alvarez, I., Diaz, M.T., Branscheid, W., Wicke, M. & Montossi, F., 2006. Eating quality of beef, from different production systems, assessed by German, Spanish and British consumers, Meat Sci. 74, 435-442.

Perry, D. & Thompson, J.M., 2005. The effect of growth rate during back grounding and finishing on meat quality traits in beef cattle. Meat Sci. 69, 691-702.

Picard, B., Lebret, B., Cassar-Malek, I., Liaubet, L., Berri, C., Le Bihan-Duval, E., Hocquette, J.F. & G. Renand, G., 2015. Recent advances in omic technologies for meat quality management. Meat Sci. 109, 18-26.

Polkinghorne, R.J. & Thompson, J.M., 2010. Meat standards and grading – A world view. Meat Sci. 86, 227–235.

Polkinghorne, R., Thompson, J.M., Watson, R., Gee, A. & Porter, M., 2008. Evolution of the Meat Standards Australia (MSA) beef grading system. Aus. J. Exp. Agric. 48, 1351-1359.

Price, M.A., 1982. Meat carcass grading in the future. Can. J. Anim. Sci. 62:3-13.

Price, M.A., 1995. Development of grading and carcass systems. In: M. Jones (Ed). Quality and grading of carcass of meat animals. CRC Press, Boca Raton. pp. 174-195.

Prieto, N., Dugan, M.E.R., Lopez-Campos, O., Aalhus, J. L. & Uttaro, B., 2013. At line prediction of PUFA and biohydrogenation intermediates in perirenal and subcutaneous fat from cattle fed sunflower or flaxseed by near infrared spectroscopy. Meat Sci. 94, 27-33.

Ransom, E., 2011. Botswana's beef global commodity chain: Explaining the resistance to change. J. Rural Stud. 27, 431-439.

Reicks, A.L., Brooks, J.C., Garmyn, A.J., Thompson, L.D., Lyford, C.L. & Miller, M.F., 2011. Demographics and beef preferences affect consumer motivation for purchasing fresh beef steaks and roasts. Meat Sci. 87, 403-411.

Ruiz-Núñez, B., Dijck-Brouwer, D.A.J. & Muskiet, F.A.J., 2016. The relation of saturated fatty acids with low-grade inflammation and cardiovascular disease. J. Nutr. Biochem. 36, 1-20.

SADC. 2012. Livestock Production. Southern African Development Community. http://www.sadc.int/themes/agriculture-food-security/livestock-production/. Retrieved 19 June 2016.

SAFA, 2016. Beef market indicators. South African Feedlot Association. http://www.safeedlot.co.za/index.asp?Content=151. Accessed 30 June 2016

Schönfeldt, H.C., Pretorius, B. & Vermueulen, H., 2016. Expectations of different consumer market segments in South Africa. In: Proc. of Aldam Stockman's Sch. Progr., South Africa.

Scollan, N.D., Dannenberger, D., Nuernberg, K., Richardson, I., MacKintosh, S., Hocquette, J.F. & Moloney, A. P., 2014. Enhancing the nutritional and health value of beef lipids and their relationship with meat quality. Meat Sci. 97, 384-94.

Shackelford, S.D., Koohmaraie, M., Cundiff, L.V., Gregory, K.E., Rohrer, G.A. & Savell, J.W., 1994. Heritabilities and phenotypic and genetic correlations for bovine post rigor calpastatin activity intramuscular fat content, Warner–Bratzler shear force, retail product yield and growth rate. J. Anim. Sci. 72, 857-863.

Smith, G., Tatum, J.D. & Belk, K.E., 2008. International perspective : characterisation of United States Department of Agriculture and Meat Standards Australia systems for assessing beef quality. Aus. J. Exp. Agri. 48, 1465-1480.

Soji, Z., Chikwanda, D., Chikwanda, A.T., Jaja, I.F., Mushonga, B. & Muchenje, V., 2015. Relevance of the formal red meat classification system to the South African informal livestock sector. S. Afr. J. Anim. Sci. 45, 263-277.

South African Meat Industry company (SAMIC), 2006. Classification of red meat. www.samic.co.za. Retrieved 12 July 2014.

Steiner, B., 2004. French wines on the decline? Econometric evidence from Britain. J. Agri. Econ. 55, 267-288.

Strydom, P.E., 2008. Do indigenous Southern African cattle breeds have the right genetics for commercial production of quality meat? Meat Sci. 80, 86-93.

Strydom, P.E., 2011. Quality related principles of the South African beef classification system in relation to grading and classification systems of the world. S. Afr. J. of Anim. Sci. 41, 177-193.

Strydom, P.E., Lühl, J., Kahl, C. & Hoffman, L.C. (2016). Comparison of shear force tenderness, drip and cooking loss, and ultimate muscle pH of the loin muscle among grass-fed steers of four major beef crosses slaughtered in Namibia. S. Afr. J. Anim. Sci. 46, 348-359.

Strydom, P.E., Frylinck, L., Van Heerden, S.M., Hope-Jones, M., Hugo, A., Webb, E., Moholisa, E., Liebenberg, B.E. & Sehoole, O.C., 2015. Sources of variation in quality of South African beef: Case studies in relation to the Red Meat Classification System. S. Afr. J. Anim. Sci. 45, 289-301.

Tallontire, A., Rentsendorj, E. & Blowfield M., 2001. Ethical consumers and ethical trade: a review of current literature. Policy Series 12. Natural Resources Institute, Chatham, UK.

Thompson, J., Polkinghorne, R., Gee, A., Motiang, D., Strydom, P., Mashau, M, Ng'ambi, J., deKock, R. & Burrow, H., 2010. Beef palatability in the Republic of South Africa: Implications for niche-marketing strategies. The Australian Centre for International Agricultural Research (ACIAR). The Commonwealth of Australia, Australia.

Van Elswyk, M.E. & McNeill, S.H., 2014. Impact of grass/forage feeding versus grain finishing on beef nutrients and sensory quality: The U.S. experience. Meat Sci. 96, 535-540.

Van Ittersum, K., Meulenberg, M.T.G, Van Trijp, H.C.M. & Candel, M.J.J.M., 2007. Consumers' appreciation of regional certification labels: A pan-European Study. J. Agric. Econ. 58, 1-23

Verbeke, W., Wezemael, L. Van, Barcellos, M.D.D. & Ku, J.O., 2010. European beef consumers' interest in a beef eating-quality guarantee: Insights from a qualitative study in four EU countries. Appetite, 54, 289-296.

Vermeulen, H, Schönfeldt, H.C. & Pretorius, B., 2015. A consumer perspective of the South African red meat classification system. S. Afr. J. Anim. Sci. 45, 339-354.

Viegas, I., Nunes, L.C., Madureira, L., Fontes, M.A. & Santos, J.L., 2014. Beef credence attributes: Implications of substitution effects on consumers' WTP. J. Agric. Econ. 65, 600-615.

Vote, D.J., Belk, K.E., Tatum, J.D., Scanga, J.A. & Smith G.C., 2003. Online prediction of beef tenderness using a computer vision system equipped with a BeefCam module. J. Anim. Sci. 81, 457-465.

Warris, P., 2010. Meat science. An introductory text. 2nd edition. CABI, UK.

Webb, E.C., 2015. Description of carcass classification goals and the current situation in South Africa, S. Afr. J. Anim. Sci. 45, 229-233.

Webb, E.C. & Erasmus, L.J., 2013. The effect of production system and management practices on the quality of meat products from ruminant livestock. S. Afr. J. Anim. Sci. 43, 413-423.

Webster A.J.F., 2001. Farm animal welfare: The five freedoms and free market. Vet. J. 161, 229-237.

Zimbabwean Carcass Classification Regulations. 2016. Agricultural product marketing (livestock) (carcass classification) regulations. Republic of Zimbabwe.

Chapter 9: General discussion, conclusion and recommendations

9.1 General discussion

The general hypothesis tested was that applying different strategies that address the climate-change related challenges could improve beef production in the smallholder areas in Malawi. Protein supplementation strategies involving underutilized rangeland-based protein sources might serve as drought adaptation and mitigation strategies for resource-poor farmers under the changing climatic conditions (Khanyile et al., 2014). To develop suitable adaptation and mitigation strategies to enhance farmers' capacity to adapt to climate change, it is highly recommended to understand local information on vulnerabilities, coping strategies, constraints and opportunities (Thornton et al., 2009).

The hypothesis tested under Chapter 3 was that socio-economic factors have no influence on farmers' perceptions of the impacts of climate change on beef production and there were no potential protein sources for use during drought periods in Malawi. Generally, all the farmers were aware of the impacts of climate change on beef production including deterioration of grazing rangelands, which results in poor reproductive and production performance. Nevertheless, farmers' perceptions were influenced more by the biophysical factors such as agro-ecological zone when compared to socio-economic factors. Farmers had limited options to mitigate the impacts of climate change on beef production. One of the major mitigation strategies was the use of exotic leguminous trees as a protein source for animals. Farmers also mentioned that their animals consumed oilseed from *A. digitata* and leaves from trees such as *V. polyacantha* and *D.*

kilimandscharicus in the dry season when grass was sparsely available. The nutritional composition of these indigenous browse legume trees in Malawi has, however, not been investigated.

It was hypothesized in Chapter 4 that rangeland-based protein sources (i.e., *A. digitata*, *V. polyacantha* and *D. kilimandscharicus* identified in Chapter 3) have similar nutrient composition and *in vitro* digestibility across the growing seasons. The Baobab seed had lower CP content than soybean but had higher mineral composition than soybeans regardless of growing season. Although *V. polyacantha* had the highest tannin levels, its CP content meets the minimum of requirements of 110-130 g/kg DM required by growing beef cattle (NRC, 1996). However, the information about feed's nutrient ability to meet animal requirements must be accompanied by information regarding the animal intake for the feed.

In Chapter 5, it was hypothesized that there are no differences in total tract nutrient digestibility, microbial nitrogen supply, growth performance and gross margins of Malawi Zebu steers fed diets containing Baobab seed meal, V. *polyacantha* leaf-meal and soybean meal. Steers fed baobab seed and soybean meal based diets had similar nutrient digestibility, DMI and ADG but these were higher than measured for steers fed a *V. polyacantha* leaf-meal based diet. The lack of differences in nutrient digestibility between steers fed diets containing baobab seed meal and soybean meal could be attributed to CP which was isonitrogenous and a small difference of NDF in the two diets. High protein and energy promote the availability of energy in the rumen, which increases the production of volatile fatty acids, thereby increasing animal growth (Calsamiglia et el., 2010). The low nutrient digestibility, DMI and ADG for steers fed the *V. polyacantha* leaf-meal based diet could be related to the high tannin content (Makkar, 2003). The high inclusion level of *V. polyacantha* leaf-meal in this study, was aimed at establishing animal performance when fed as the only source of protein in finishing beef cattle diets (Mlambo and Mapiye, 2015). The highest gross margin for baobab-fed steers was a result of the higher total revenue and lower production cost compared to the other dietary treatments. Although, Vachellia-fed steers had a lower production cost than baobab-fed steers, the low ADG resulted in animals of low weights, thereby reducing the total revenue. While feeding animals with rangeland-based protein sources reduced production costs and improved animal performance, especially for the baobab diet, it was important to evaluate their effects on meat quality characteristics.

The hypothesis studied in Chapter 6 was that it is possible to predict dry matter intake and average daily gain of Malawi Zebu steers fed with rangeland-based diets under feedlot conditions in the Malawian environment using the Beef Cattle Nutrient Requirements Model (BCNRM) and Large Ruminant Nutritional System (LRNS). The BCNRM model had better predictions of DMI and ADG of Malawi Zebu steers than the LNRS model. These findings agree with those of Tedeschi et al. (2014) that, although nutrition computer models share similar assumptions and calculations, they may differ in conceptual and structural foundations characteristic to their intended purposes.

The hypothesis examined in Chapter 7 was that there are no differences in carcass and meat quality characteristics between steers fed baobab seed meal and *V. polyacantha* leaf meal-based diets and steers fed a soybean meal-based diet. The carcass weights and fat thickness for the baobab- and soybean-fed steers were similar but both were heavier than that for Vachellia-fed steers. Carcasses from the Vachellia- and baobab-fed steers had higher ultimate meat pH (typical of the DFD phenomenon) than soybean-fed steers. The highest ultimate carcass pH in the animals on the Vachellia diet may have been related to the low starch content in the diet, which may have resulted in low muscle glycogen stores at the point of slaughter. However, the reason for a higher ultimate pH in the baobab-fed steers than the soybean-fed animals was not immediate. It could however may be related to vitamin C which is reported to be much higher in baobab seed (over 30 g/kg DM) than in soybean (Assogbadjo et al., 2012). High doses of Vitamin C has some effects on rumen fermentation which promotes acetic acid, which is non-gluconeogenic, over propionic acid, which is gluconeogenic (Tagliapietra et al., 2013) and this might limit glycogen storage in the body. All steers were downgraded because of their low weights (< 142 kg), even though they were young (less not more than six permanent incisors). The criterion needed for top grades under the Malawian Grading System and elsewhere is typically linked to carcass weight. Therefore, the use of carcass weight as a grading criterion in the Malawi Grading system should be revised as it penalizes youthful carcasses from inherently small-sized indigenous Malawi Zebu (Changadeya et al., 2012).

Beef from animals fed diets containing baobab seed meal and *V. polyacantha* leaf-meal had higher WHC, lower drip and cooking loss than from animals fed soybean-based diets which is a characteristic of dark cuts caused by high pH which maintains high electrostatic net charge of the myofibrillar protein to bind to water. All the diets produced LTL steaks with acceptable tenderness

(< 4.4 kg). The high intramuscular fat, zinc and manganese contents in the LTL muscle from baobab-fed steers could be due to the high content of fat, zinc and manganese in the baobab diet, which resulted in a high intake of these nutrients. Steers fed the Vachellia diet had LTL muscle with limited browning during retail display, which was attributed to the absorption of tannin metabolites that have antioxidant properties. Based on results from this study, there is potential for use of baobab seed as a protein supplement for beef production. However, to enhance adoption of strategies aimed at equipping smallholder beef producers to deal with climate change related feed shortages, it is also important to align carcass classification and grading systems that discriminate against smallholder beef production associated with small-framed indigenous cattle breeds.

Chapter 8 hypothesized that beef carcass classification and grading systems in southern Africa inappropriately classify and/or grade carcasses from indigenous cattle. Indigenous cattle are small-sized breeds that have evolved to adapt to low quality forage and heat stress under tropical or subtropical climates and reach targeted market weights at an advanced age. As a result, the small-framed breeds produce less tender meat compared to exotic breeds that are typically fed high grain diets (Strydom, 2008). Under the current carcass evaluation systems, it is not possible for slow growing indigenous animals finished on low quality forages to attain top classes/grades when the latter are based on carcass weights. However, there is evidence that ethnic consumers (black Africans in rural areas) who have raised these animals for many generations prefer beef that is less tender (Ransom, 2011; Thompson et al., 2010). On other hand, with improved nutrition, indigenous animals can potentially achieve comparable meat quality to British/Continental European breeds (Strydom, 2008). Therefore, use of an objective beef evaluation system that closely predicts beef palatability could improve acceptability of their use in diverse production systems.

9.2 Conclusions

Farmers identified *A. digitata* seeds, *V. polyacantha* and *D. kilimandscharicus* as abundantly available rangeland-based protein sources. Although Baobab seed had lower CP content than Soybean meal, had a better mineral profile than soybean meal. The *V. polycantha* and *D. kilimandscharicus* also exhibited similar chemical composition except polyphenols, which were higher in *V. polyacantha*. The BCNRM was better a nutritional model than LRNS for predicting DMI and ADG of Zebu steers fed rangeland based diets under feedlot conditions in Malawian conditions. Feeding steers with a diet containing baobab seed meal improved nutrient digestibility and growth performance and gross margins. Steers fed the *Vachellia* and baobab diets had DFD meat. The Vachellia diet reduced discolouration of beef during refrigerated storage conditions over eight days. Current beef carcass classification and grading systems in southern Africa do not encourage the improvement of smallholder beef production associated with indigenous cattle finished on rangeland-based diets under the climatic changing environments. However, opportunities exist to improve the prediction of carcass yield and quality including machine-based technologies and establishing of a common consumer-centred beef carcass classification system that accommodate diverse breeds and production systems.

9.3 Conclusions

Farmers identified *A. digitata* seeds, *V. polyacantha* and *D. kilimandscharicus* as abundantly available rangeland-based protein sources. Although Baobab seed had lower CP content than Soybean meal, had a better mineral profile than soybean meal. The *V. polycantha* and *D. kilimandscharicus* also exhibited similar chemical composition except polyphenols, which were higher in *V. polyacantha*. The BCNRM was better a nutritional model than LRNS for predicting DMI and ADG of Zebu steers fed rangeland based diets under feedlot conditions in Malawian conditions. Feeding steers with a diet containing baobab seed meal improved nutrient digestibility and growth performance and gross margins. Steers fed the *Vachellia* and baobab diets had DFD meat. The Vachellia diet reduced discolouration of beef during refrigerated storage conditions over eight days. Current beef carcass classification and grading systems in southern Africa do not encourage the improvement of smallholder beef production associated with indigenous cattle finished on rangeland-based diets under the climatic changing environments. However, opportunities exist to improve the prediction of carcass yield and quality including machine-based technologies and establishing of a common consumer-centred beef carcass classification system that accommodate diverse breeds and production systems.

9.4 Recommendations

1. Further research is needed to determine the optimal inclusion level of baobab seed meal and *V. polyacantha* in diets for beef cattle as it is widely distributed and abundant in Malawi making it an ideal feed supplement for smallholder farmers.

2. The current study used a small dataset to evaluate the application of mathematical nutritional models to formulate rangeland diets; further studies involving large datasets are warranted.
3. Further research on establishing a classification system that best describes carcasses from indigenous animals commensurate with meat eating quality preferences of their ethnic consumers is warranted.
4. To improve animal productivity of beef cattle and adapt to climate change, smallholder farmers should adopt feeding strategies that are climate change tolerant such as use of rangeland based protein sources.
5. To improve beef production in smallholder farming systems and adaptation to climate change it is important to formulate policies that simultaneously promote improved beef production and indigenous animals.

9.4 References

Assogbadjo, A. E., Chadare, F. J., Kakaï, R. G., Fandohan, B. & Baidu-Forson, J. J., 2012. Variation in biochemical composition of baobab (*Adansonia digitata*) pulp, leaves and seeds in relation to soil types and tree provenances. Agric. Ecosys. Environ. 157, 94–99.

Calsamiglia, S., Ferret, A., Reynolds, C. K., Kristensen, N. B. & van Vuuren, A. M. 2010. Strategies for optimizing nitrogen use by ruminants. Anim. 4, 1184–1196.

Changadeya, W., Ambali, A., Nyirenda, J., Chagunda, M. & Kaunda, E., 2012. Genetic diversity and population structure of Malawi Zebu cattle. Int. J. of Phys. Soc. Sci. 2, 59–81.

Franzel, S., Carsan, S., Lukuyu, B., Sinja, J. & Wambugu, C., 2014. Fodder trees for improving livestock productivity and smallholder livelihoods in Africa. Curr. Opin. Environ. Sustan. 6, 98–103.

Howard, S. T., Woerner, D. R., Scanga, J. A., Van Overbeke, D. L., Mafi, G. G., Igo, J. L. & Belk, K. E., 2013. North american beef tenderness survey 2011-2012: Benchmarking tenderness and sample shipping procedures. J. Anim. Sci. 91, 5981–5988.

Khanyile, M., Ndou, S.P., Chimonyo, M., 2014. Influence of *Acacia tortilis* leaf meal-based diets on growth performance of pigs. Livest. Sci. 167, 211–218.

Makkar, H. P. S., 2003. Effects and fate of tannins in ruminant animals, adaptation to tannins, and strategies to overcome detrimental effects of feeding tannin-rich feeds. Small Rum. Res. 49, 241–256.

Mlambo, V. & Mapiye, C., 2015. Towards household food and nutrition security in semi-arid areas: What role for condensed tannin-rich ruminant feedstuffs? Food Res. Int. 76, 953-961.

NRC, 1996. National Research Council Nutrient Requirements for Beef Cattle. 7th Ed. National Academy Press, Washingston DC, USA

Polkinghorne, R. J. & Thompson, J. M., 2010. Meat standards and grading. A world view. Meat Sci. 86, 227–235.

Ransom, E., 2011. Botswana's beef global commodity chain: Explaining the resistance to change. J. Rural Stud. 27, 431-439.

Strydom, P. E., 2008. Do indigenous Southern African cattle breeds have the right genetics for commercial production of quality meat? Meat Sci. 80, 86–93.

Tagliapietra, F., Cattani, M., Hansen, H. H., Bittante, G. & Schiavon, S., 2013. High doses of vitamin E and vitamin C influence *in vitro* rumen microbial activity. Anim. Feed Sci.

Technol. 183, 210-214.

Tedeschi, L. O., Cavalcanti, L. F. L., Fonseca, M. A., Herrero, M. & Thornton, P. K., 2014. The evolution and evaluation of dairy cattle models for predicting milk production: An agricultural model intercomparison and improvement project (AgMIP) for livestock. Anim. Prod. Sci. 54, 2052–2067.

Thompson, J., Polkinghorne, R., Gee, A., Motiang, D., Strydom, P., Mashau, M, Ng'ambi, J., deKock, R. & Burrow, H., 2010. Beef palatability in the Republic of South Africa: Implications for niche-marketing strategies. The Australian Centre for International Agricultural Research (ACIAR). The Commonwealth of Australia, Australia.

Thornton, P. K., van de Steeg, J., Notenbaert, A. & Herrero, M. 2009. The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. Agric. Syst. 101, 113–127.

Appendix A

The baseline survey questionnaire on determinants of farmers' perceptions on impacts of climate change on beef production

A. General information

1. Gender of head of household M☐ F☐
2. Age of head of household < 30☐ 31-45☐ 30-50☐ 46-60☐ >60☐
3. Highest level of education No formal education ☐ Primary ☐ Secondary ☐ Tertiary☐
4. What is your principal occupation?_______________________________________
5. What are your sources of income? (Tick first column as appropriate and rank 1 as the most important source of income)

Source	Amount raised in past 12 months	Rank
Crops		
Livestock		
Salary/wages		
Pension		
Other (specify)		

6. What crops did you grow last season growing? (Rank 1 as the most commonly grown crop)

Crop	Rank	Area (ha)	Purpose of production	
			Consumption	Sale

7. What type of livestock species do you keep? (Rank 1 as the most important livestock species)

Species	Cattle/breed	Goats	Sheep	Chickens	Pigs	Other (specify)
Number						
Rank						

8. What breeds do you have?

Breed	Malawi zebu	Brahman	Crossbreeds	Other……………………
Number				

9. What is the herd composition of your cattle herd?

Class	Number
Calves	
Heifers	
Steers	
Cows	

Oxen	
Bulls	

10. Why do you keep cattle? (Tick one or more) (Rank 1 as the most common use)

Use	Rank	Use	Rank
Meat		Sales	
Milk		Status	
Draught power		Dowry	
Manure		Ceremonies	
Skin		Other (specify)	

11. How much land do you own (ha) ________________
12. How much land is arable (ha)? ________________
13. How much land is used for grazing or pasture cultivation (ha)________________
14. Is grazing communal? Yes☐ No☐

B. IMPACTS OF CLIMATE CHANGE

1. Has the temprature been changing over the past 20 years? ☐No change ☐ decreasing ☐ increasing
2. Has the rainfall been changing over the past 20 years? ☐No change ☐ decreasing ☐ increasing
3. What has occurrence of long dry spells/droughts been like over the past 20 years? ☐ Frequent ☐ Less frequent ☐ Rare
4. What has occurrence of floods been like over the past 20 years? ☐ Frequent ☐ Less frequent ☐ Rare

C. Direct effects of climate change

a) Rangeland biomass availability, quality, and grazing pattern of cattle

1. How have the impacts of climate change affected rangeland biomass supply of your cattle for over the past 20 years? ☐No effect ☐ decreased ☐ increased
2. How have the impacts of climate change affected the availability palatable rangeland grasses for your cattle for over the past 20 years? ☐No effect ☐ decreased ☐ increased
3. How have the impacts of climate change affected the rangeland palatable grass species composition for over the past 20 years? ☐No effect ☐ decreased ☐ increased
4. If climate change has resulted into reduced palatable grass species composition, what are the prevalent grass species now? ____
5. If climate change has resulted into reduced species composition, what species have declined?____
6. How has been bush encroachment in the rangelands for over the past 20 years? ☐None ☐ Increased
7. What are the prevalent bush encroaching species?____
8. How have the impacts of climate change affected the grazing patterns for over the past 20 years? ☐ increased overgrazing ☐ decreased overgrazing ☐ No change
9. What are sources of drinking water for your cattle______________________________
10. How have the impacts of climate change affected the availability drinking water in those sources for your cattle for over the past 20 years?
11. How has climate change affected quality of ☐No effect ☐ decreased ☐ increased

b) Cattle production and product quality of beef

1. How have the impacts of climate change affected feed intake of your cattle for over the past 20 years? ☐No effect ☐ decreased ☐ increased
2. How have the impacts of climate change affected the number of your cattle herd for over the past 20 years? ☐ No effect ☐ decreased ☐ increased
3. How have the impacts of climate change affected the growth of your cattle herd for over the past 20 years? ☐ No effect ☐ decreased ☐ increased
4. How have the impacts of climate change affected the carcass yield of your cattle herd for over the past 20 years? ☐No effect ☐ decreased ☐ increased
5. How have the impacts of climate change affected the meat quality (e.g. flavour, fat cover) of your cattle slaughtered from your herd for over the past 20 years? ☐No effect ☐ decreased ☐ increased
6. How have the impacts of climate change affected the milk yield of your cattle herd for over the past 20 years? ☐No effect ☐ decreased ☐ increased

7. How have the impacts of climate change affected the quality of milk of cows in your cattle herd for over the past 20 years? ☐No effect ☐ decreased ☐ increased
8. How have the impacts of climate change affected the body conditions of your cattle herd for over the past 20 years? ☐No effect ☐ decreased ☐ increased

c) Reproduction
1. How long is the age at first calving of heifers in your herd?________________________
2. How have the impacts of climate affected the age at first calving of heifers in your cattle herd for over the past 20 years? ☐No effect ☐ decreased ☐ increased
3. How have the impacts of climate change affected the calving rate of cows in your cattle herd for over the past 20 years? ☐No effect ☐ decreased ☐ increased
4. How long is the calving interval of cows in your herd?________________________
5. How have the impacts of climate change affected the calving interval cows in your herd for over the past 20 years? ☐No effect ☐ decreased ☐ increased
6. How many calves have died in your herd for the pasts twelve months?_________
7. How have the impacts of climate change affected the calf mortality in your herd for over the past 20 years? ☐ No effect ☐ decreased ☐ increased
8. How long is the reproductive life of cows in your cattle herd?_____________
9. How many calves does a single cow calved down its entire reproductive life?_______________
10. How have the impacts of climate change affected the longevity of cows in herd for over the past 20 years? ☐ No effect ☐ decreased ☐ increased

d) Animal health
1. What are the most prevalent diseases of cattle in your herd?

____

2. How have the impacts of climate change affected the most prevalent cattle diseases in herd for over the past 20 years? ☐No effect ☐ decreased ☐ increased
3. How you experienced any strange cattle diseases in your herd for over the past 20 years? Yes☐ No☐
4. If yes, name the disease or its signs____
5. What are the most prevalent parasites of cattle in your herd?_______________

____

9. How have the impacts of climate change affected the prevalence of cattle parasites in herd for over the past 20 years? ☐No effect ☐ decreased ☐ increased
6. How many adult cattle have died in your herd for the pasts twelve months____
10. How have the impacts of climate change affected the adult cattle mortality in your herd for over the past 20 years? ☐No effect ☐ decreased ☐ increased
7. Do you experience cattle predation in your herd? Yes☐ No☐
8. If yes, what are the common predators that prey in your herd?____
11. How have the impacts of climate change affected the cattle predation in herd for over the past 20 years? ☐No effect ☐ decreased ☐ increased

e) Cattle of marketing
1. How many cattle have you slaughtered for sale or consumption for the past 5years?____
2. How many live cattle have you sold for the past 5 years?________________
3. How many of the total cattle sold were steers for the past 5 years?_________
4. How many of the total cattle sold were young bulls for the past 5 years? ________
5. How many of the total cattle sold were heifers for the past 5 years? ___________
6. How many of the total cattle sold were culled oxen for the past 5 years? ___________
7. How many of the total cattle sold were culled cows for the past 5 years? ____________
8. What is the average price for the live steer for the past 12 months? _______________
9. What is the average price for the live young bull for the past 12 months? ___________
10. What is the average price for the live culled oxen for the past 12 months? __________
11. What is the average price for the live culled bull for the past 12 months? ___________
12. What is the average price for the live culled cow for the past 12 months? ___________

13. How have the impacts of climate change affected the fluctuations of prices of cattle over the past 20 years? ☐ No effect ☐ decreased ☐ increased
14. What is your preferred marketing channel? ____________________________

f) Which of direct effects has had the greatest effect (rank them, 1 as the most important)

Cattle growth and meat quality	
Reproduction	
Animal health	
Marketing	

D. Indirect effects on animal production

1. How have the impacts of climate change affected the crop yields for over the past 20 years? ☐No effect ☐ decreased ☐ increased
2. How have the impacts of climate change affected the rangeland biomass for over the past 20 years? ☐No effect ☐ decreased ☐ increased
3. How have the impacts of climate change affected the proximity of grasslands to your farm for over the past 20 years? ☐No effect ☐ decreased ☐ increased
4. How have the impacts of climate change affected the rangeland biomass quality for over the past 20 years? ☐ No effect ☐ decreased ☐ increased
5. How have the impacts of climate change affected crop-livestock conflicts for grazing lands over the past 20 years? ☐ increased ☐ decreased ☐ No change
6. How have the impacts of climate change affected availability water sources for cattle for over the past 20 years? ☐No effect ☐ decreased ☐ increased
7. How have the impacts of climate change affected water quantities in available sources for cattle for over the past 20 years? ☐No effect ☐ decreased ☐ increased

E. BEEF CATTLE MANAGEMENT RESPONSES CLIMATIC CHANGE

Nutritional management	**Management responses**
Increasing grazing time	Yes☐ No☐
Adjusting the herd size to suit the grazing land and other feed resources	Yes☐ No☐
Reducing reliance on communal grazing rangelands by estabilishing own pastures	Yes☐ No☐
Practising rotational grazing	Yes☐ No☐
Providing suplementary feeds in dry season	Yes☐ No☐
Conserving feeds for dry season	Yes☐ No☐
Constructing dams/rainwater-harvest to improve water availability	Yes☐ No☐
Reproduction management	Yes☐ No☐
Reducing reliance on communal bulls owning own bulls to improve calving rates	Yes☐ No☐
Increasing bull: cow ratio to improve calving rates	Yes☐ No☐
Following appropriate mating and calving seasons	Yes☐ No☐
Selecting bulls with superior traits e.g. scrotal circumference to improve fertility	Yes☐ No☐
Crossbreeding with adaptable but improved breeds of cattle	Yes☐ No☐
Herd health management	
Regular dipping of animals	Yes☐ No☐
Routine deworming	Yes☐ No☐
Routine vaccination against common cattle diseases	Yes☐ No☐

Increasing consumption of veterinary services and drugs for improved herd health	Yes☐ No☐
Marketing	
Selling through formal market channels for improved returns	Yes☐ No☐
Selling animals before bad weather based on long term weather forecasts/ early warnings	Yes☐ No☐
Conditioning animals before sales	Yes☐ No☐
Community policing to reduce stock theft	Yes☐ No☐

F. Barriers to climate change responses

Barrier	Rank	Possible solution
Lack of climate change adaptation information		
Lack of capital to implement the adaptation strategies		
Lack of market access to support innovative approaches		
Lack of labour		

INDIGENOUS BROWSE SPECIES

What indigenous browse trees are browsed by cattle or goats in your area

Tree species	Tree or shrub	Palatability (both goats and cattle)	Availability (scarce, moderate or plentiful)	Where mostly found (wood land or farm land)

End.
Thank you!