

**EFFECT OF DIFFERENT MARINADES ON QUALITY
CHARACTERISTICS OF CHEVON JERKY**

BY

GIFTY MOORE ARTHUR

(10507201)

**THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD
OF MASTER OF PHILOSOPHY DEGREE IN ANIMAL SCIENCE**

JULY, 2017

DECLARATION

I hereby declare that this thesis which is submitted to the Department of Animal Science, College of Basic Applied Sciences, University of Ghana, for the award of Master of Philosophy in Animal Science degree is the result of my own investigation. This thesis has not been submitted or presented for another degree elsewhere, either in part or in whole, except for other people’s work which was duly cited and acknowledged.

STUDENT

NAME: GIFTY MOORE ARTHUR

SIGNATURE:.....

DATE:.....

SUPERVISOR

NAME: DR. S. OHENE – ADJEI

SIGNATURE:.....

DATE:.....

CO - SUPERVISOR

PROF ANNA. R. BARNES

.....

.....

DEDICATION

This work is dedicated to my son Jethro Nana Eduah Ansah, my husband Raymond Ansah, my parents Mr. George Edward Moore Arthur and Madam Bernice Eshun, my siblings James Moore Arthur, Mrs. Constance Irene Cofie and Mrs. Patience Bernette and lastly to my niece Princess Lisa Cofie.

ACKNOWLEDGEMENTS

I am very grateful to the Almighty God, the creator and designer for the wisdom and knowledge he has bestowed on me. Dr. S. Ohene - Adjei my supervisor also deserves special commendation for his priceless dedication and support geared towards this dissertation. I also wish to thank Prof. A. R. Barnes my co- supervisor, for the advice and proof reading. My profound gratitude goes to Dr. Patrick Arthur of the Department of Biochemistry for his support and advice. I will also wish to thank Dr. Raphael A. Ayizanga for his support, advice and encouragement. I will also like to acknowledge the entire staff of the Faculty of Agriculture, College of Basic and Applied Science, especially those in the Animal Science Department for their support, encouragement and guidance.

Finally, I will like to acknowledge Akua Kumi Yeboah, Mrs. Sarah Afia Addo, Madam Rebecca Otoo and Madam Esther Akomaning, Alex Addo, Gifty Zieme Bumbie, my fellow graduate students and my sensory panelists for the diverse ways in which they contributed to the success of this dissertation. It is my prayer that all your heart desires will be accomplished by God and he will crown all your effort with success.

TABLE OF CONTENTS

Declaration	i
Acknowledgements	iii
Table of contents	iv
List of tables	ix
List of figures	x
Abstract	xi
CHAPTER ONE.....	1
1.0 Introduction.....	1
1.1 Problem Statement	4
1.2 Objectives	5
1.3 Justification	5
1.4 Hypothesis	6
CHAPTER TWO.....	7
2.0 Literature Review	7
2.1 History of Jerky	7
2.2 Manufacturing Process	8
2.3 Marinade	9
2.3.1 Functionality of Marinades	10
2.4 Acidic Marinades	11
2.4.1 Tenderisation Action of Acidic Marinades in Meat.....	11
2.4.2 Antimicrobial Effect of Acidic Marinades	13

2.5	Enzymatic Marinades (Exogenous Proteolytic Enzymes).....	15
2.6	Papain.....	18
2.6.1	Myofibrillar and Connective Tissue Degradation by Papain.....	19
2.7	Marinating Techniques and Duration.....	20
2.7.1	Marinating Methods.....	20
2.7.2	Immersion.....	20
2.7.3	Multi-needle Injection Marinating.....	21
2.7.4	Vacuum or Manual Tumbling.....	22
2.8	Marinade Ingredient Functionality.....	23
2.8.1	Spices.....	23
2.8.2	Salt (sodium chloride).....	24
2.8.3	Soy Sauce.....	25
2.8.4.	Sweeteners.....	26
2.9	Preservation of Meat.....	27
2.9.1	Odka.....	29
2.9.2	Qwanta.....	29
2.9.3	Biltong.....	29
2.9.4	Kilishi.....	30
2.10	Drying of Meat.....	30
2.10.1	Methods of Drying Meat.....	31
2.10.2	Natural or Traditional Drying Method.....	32

2.10.3	Sun Drying	32
2.10.4	Solar Drying	32
2.11	Artificial Heat Source	33
2.11.1	Smoke House Drying	33
2.11.2	Oven Drying	34
2.11.3	Freeze Drying	34
2.12	Rehydration Rate	36
2.13	Microbiology of Meat and Meat Products	36
2.14	Food Safety Concerns of Jerky	37
2.15	Principles of Preservation of Shelf-Stable Dried Meat Products	39
2.16	Shelf-Stability and Hurdle Effect	40
2.17	Packaging	42
2.18	Eating Qualities of Meat	44
CHAPTER THREE		50
3.0	Materials and Methods	50
3.1	Experimental Design	50
3.2	Sample Preparation	50
3.2.1	Treatments	51
3.2.2	Marination	51
3.2.3	Drying	51
3.3	Measurement	52

3.3.1	pH Measurement	52
3.3.2	Sensory Evaluation.....	52
3.3.3.	Rehydration Ratio	53
3.3.4	Microbiological Analysis.....	54
3.4	Statistical Analysis	55
CHAPTER FOUR		56
4.0.	Results	56
4.1	Sensory Evaluation.....	56
4.1.1	Effect of Treatments on Chevon Jerky Tenderness	56
4.1.2	Effect of Treatments on Chevon Jerky Chewiness	59
4.1.3	Effect of Treatments on Chevon Jerky Juiciness	61
4.1.4	Effect of Treatments on Chevon Jerky Flavour	63
4.1.5	Effect of Treatment on Chevon Jerky Acceptability.....	65
4.2	Microbiological Evaluation	67
4.2.1	Effect of Treatment on Total Plate Count.....	68
4.2.2	Effect of Treatment on <i>E.coli</i>	69
4.2.3	Effect of Treatment on <i>Staphylococcus aureus</i>	69
4.2.4	Effect of Treatment on Yeast and mould.....	70
4.3	Moisture content (%).....	71
4.4	Rehydration Characteristics.....	73

CHAPTER FIVE.....	75
5.0 Discussion.....	75
5.1 Sensory Evaluations	75
5.2 Microbiological Evaluation	79
5.3 Moisture Content (%) (Drying curve).....	82
5.4 Rehydration Rate.....	85
CHAPTER SIX	87
6.0 Summary, Conclusions and Recommendations.....	87
6.1 Summary.....	87
6.2 Conclusions.....	90
6.3 Recommendations	90
References.....	91

LIST OF TABLES

Table 1: Enzymes Classified as “Generally Recognised As Safe” (GRAS) for Meat Tenderisation.....	18
Table 2: Treatments of chevon jerky with papain and vinegar at various concentration levels.....	51
Table 3: Frequency (%) of panelist’s response on tenderness scale of chevon jerky .	57
Table 4: Frequency (%) of panelist’s response on the effect of storage period on tenderness of chevon jerky.....	58
Table 5: Frequency (%) of panelist’s response on chewiness scale of chevon jerky..	59
Table 6: Frequency (%) of panelist’s response on the effect of storage period on chewiness of chevon jerky	60
Table 7: Frequency (%) of panelist’s response on juiciness scale of chevon jerky	61
Table 8: Frequency (%) of panelist’s response on the effect of storage period on juiciness of chevon jerky	62
Table 9: Frequency (%) of panelist’s response on flavour scale of chevon jerky	63
Table 10: Frequency (%) of panelist’s response on the effect of storage period on flavour of chevon jerky.....	64
Table 11: Frequency (%) of panelist’s response on acceptability scale of chevon jerky	65
Table 12: Frequency (%) of panelist’s response on the effect of storage period on acceptability of chevon jerky	66
Table 13: Effect of treatments on microbial count (log CFU/g meat sample) of vacuum packaged chevon jerky stored for 30d.....	67
Table 14: Effect of storage time on microbial count (log CFU/g meat sample) of vacuum packaged chevon jerky stored for 30d.....	68

LIST OF FIGURES

Figure 1: The effect of papain and vinegar on moisture content of chevon jerky during drying.....	71
Figure 2: Effect of treatments on rehydration on percent moisture content (%MC) of chevon jerky	73

ABSTRACT

This study was carried out to investigate the effect of different marinades on quality characteristics of chevon jerky. Chevon (Hindquarter muscle) was treated with marinades containing different levels of vinegar (0, 2.5% or 5% v/v) and papain (0, 0.004g/0.04gw/v). A 3x3 factorial design which composed of nine treatments with three replicates was used. Chevon was cut into 1.5cm x 1.5cm cubes and samples were marinated for 12h and dried in an oven for 10h at temperature of 65°C. Sensory and microbial characteristics, drying rate and rehydration ratio were determined. The samples for sensory analysis were vacuum packaged after drying and stored at room temperature. Due to the risk of mould growth on samples from treatments containing papain only (T2 and T3) after 15d of storage in a preliminary work, sensory evaluation was conducted on samples stored for 1d and 15d. Panelists were presented with randomly coded cooked samples and the tenderness, chewiness, juiciness; flavour and overall liking of the samples were evaluated using 8 point hedonic scale. The result of sensory properties showed that out of the nine treatments tested, papain (0.04g) was effective in tenderising the chevon jerky compared with all the other treatments. Samples were ranked as very tender to extremely tender while samples treated with vinegar (5%) was ranked as moderately tough to slightly tough. Samples from control (T1) obtained the highest acceptability score of 52.78% and was ranked as “very like to extremely like” whereas papain 0.004g +vinegar 2.5% (T5) was the least scored 38.88% and was ranked as “slightly like to moderately like”. No significant ($p > 0.05$) differences were observed among treatments for chewiness, juiciness and flavour. However, juiciness improved with longer storage time at 15d. Samples evaluated at 1d were rated as “extremely dry to very dry” (24.69%) but were ranked as “very juicy to extremely juicy” (24.08%) at 15d. Samples for microbial test

were also vacuum packaged and stored at room temperature. Additionally, microbial quality analysis was conducted at 1d, 15d and 30d of storage and the effects of the nine treatments on the growth of four different microbes (total plate count, *Staphylococcus aureus*, *E.coli*, yeast and mould) during storage were investigated. As storage period increased from 15 to 30d total plate count increased from 1.59 to 1.93log cfu/g, while *E.coli* count declined from 0.19 to 0.09log cfu/g. Additionally, *Staphylococcus* count decreased from 1.96 to 0.00log cfu/g and lastly as storage period progressed from 15d to 30d yeast and mould count declined from 1.17 to 0.30log cfu/g. Drying rate was determined by change in % moisture content per unit time during drying for 10h. The analysis showed that all the test samples recorded lower moisture content compared to that of the control (T1) after drying. Samples from vinegar (2.5%) recorded the least (1.71%) moisture content whereas the highest (3.61%) was observed in control (T1) samples. Rehydration studies were carried out on sample (1.5cm x 1.5cm) to distilled water ratio of 1:40 for 300min under ambient condition. As rehydration time progressed from time 0 to 300min there was an increase in weight among all test samples. Samples from control (T1) recorded the least moisture uptake of 9.83 whereas samples from vinegar 2.5% (T4) recorded the highest moisture uptake (19.94) after rehydration. Overall, the results of this study indicate that although overall likeness score favoured the control treatment, it is possible to improve meat toughness using papain to produce meat with acceptable sensory attribute than vinegar. Also, the drying process resulted in a jerky product with low moisture content which inhibited microbial growth; however, vinegar can be used in jerky production to add flavour to the product.

CHAPTER ONE

1.0 Introduction

Meat is an excellent source of many important nutrients; however, it is subject to high rate of deterioration. It is also an ideal environment for bacterial to thrive due to its high protein and moisture contents (Bhaisare *et al.*, 2014). Microbial deterioration of meat begins soon after exsanguinations. The quantity of spoilage microorganism present in fresh meat at the time of processing has an impact on product's shelf life. Bacteria, mould and yeast are the three common microorganisms found in meat. The moulds and yeast growing on meat are aerobic whereas bacteria thriving in meat could be aerobic, anaerobic or facultative (Jay *et la.*, 2008). Some additional organisms of concern affiliated with meat in general are *Salmonella*, *Escherichia coli*, *Staphylococcus aureus* etc (Romans *et al.*, 1994). Therefore, meat processing methods such as refrigeration, canning and drying aim at limiting microbial growth at the least, making it possible to extend shelf life and also introduces variety of meat products. The process of freezing may decrease the number of microorganisms during storage. However, some species of bacteria found during refrigerated storage such as *Pseudomonas*, *Brochothrix thermosphacta* and lactic acid bacteria (LAB) (*Lactobacillus*, *Carnobacterium*, and *Leuconosto*) etc can survive this process and resume growth (Labadie, 1999; Ellis and Goodacre, 2001; Pin, *et al.*, 2002). On the other hand most traditional products have relied on salting and drying as a means of meat preservation.

Jerky is a form of processed meat in which fresh meat is dried to prevent it from early deterioration. The meat may be cut into smaller pieces or minced and then mould into strips or put into narrow casings (Nummer *et al.*, 2004). Salt, spices or marinades are

used to inhibit microbial growth and to flavour the meat (USDA - FSIS, 2004). Jerky can be processed from basically any defatted meat such as beef, chicken, pork (Calicioglu *et al.*, 2003; Pegg *et al.*, 2006; Han *et al.*, 2007) and chevon.

Quality characteristics of meat products deteriorate due to microbial growth and rancidity of lipids in the course of storage (Aguirrezabal *et al.*, 2000). The intent of processing and preservation is to mitigate such processes to extend the shelf life of processed meat products. To attain stability, jerky is dehydrated to water activity 0.70 to 0.85 (Quintion *et al.*, 1997), without the need for refrigeration due to the control of the growth of bacteria at low water activity. However, despite the imposition of this hurdle (low water activity) in jerky manufacturing, the connection of jerky products with food borne disease outbreaks (CDC, 1995; Eidson *et al.*, 2000) has raised questions about their safety. In order to address this challenge, vinegar can be used to effectively control pathogens in jerky products (Calicioglu *et al.*, 2002a). Acetic acid (vinegar) is usually used in the meat manufacturing sectors as an organic chemical to decontaminate meat (Ricke, 2003). Acetic acid exerts its action based primarily on its acidifying influence. It manifests this acidifying action only in an undissociated form (Sofos *et al.*, 1998). Acetic acid efficacy in arresting development or destroying food pathogenic bacteria could differ among treatments based on the percentage of undissociated acid at a given pH. Generally, all products treated with organic acids could restrict microbes' development or existence; however the degree of their existence is based on the types of organism harboured in the meat and the kind and quantity of organic acid, especially its buffering capacity.

Whole muscle jerky is tough due to the low moisture content to prevent microbial growth. Some restructured jerky products have a tender texture yet high in fat and water activity, which induced lipid rancidity and microbial growth (Quinton *et al.*, 1997). On the other hand, whole muscle jerky can also be reconstituted in water to soften it; however, it is time consuming. According to Huffman *et al.* (1996) a very tender meat is considered as the most essential eating property by consumers. Researchers have shown that meat tenderness is chiefly linked with the structural firmness of myofibrillar and connective tissue proteins (Marsh and Leet, 1966; Nishimura *et al.*, 1995). Several methods, including mechanical tenderisation, elevated-temperature storage, calcium chloride injection, electrical stimulation, organic acids treatments and enzymatic tenderisation, have also been used to enhance meat tenderness (Moeller *et al.*, 1976; Savell *et al.*, 1981; Koohmaraie *et al.*, 1988; Koohmaraie, 1992; Hwang *et al.*, 2000). Jerky toughness can be altered by the application of enzymatic tenderisers such as papain and bromelain. Papain is an enzymatic protease with very broad specificities and degrades connective tissue and myofibrillar proteins, sometimes leading to excessive tenderisation and distortion of sensory attribute (texture) of product (Miller *et al.*, 1989). Chen *et al.* (2006) reported that papain tenderise meat within a short time and is superior because of safety issues such as pathogenicity, compared to the other procedures of meat tenderisation. Similarly, bromelain is an enzymatic protease that exists naturally in pineapple plant and has been applied broadly as a meat tenderiser (Omojasola *et al.*, 2008). However, Sullivan and Calkins (2010); Rawdkuen and Benjakul (2012) reported that papain is most effective in improving meat tenderness than bromelain. The two most often used enzymes in marinades are papain and bromelain.

A marinade is a sauce which is designed to flavour and tenderise meats. Additionally, they improve meat juiciness and also enhance protection and shelf life of processed meat products through inhibition of microbial development (Alvarado and McKee, 2007). The efficacy of most marinades is based on the ingredients that are used (organic acids, soy sauce, essential oils, salts, tenderisers and spices). Therefore, there is the need to explore the benefits of marinades to enhance meat quality. The Government of Ghana's policy is to increase small ruminant production and has supported 90 farmers in the Central, Western and Eastern regions with superior breeds of 650 sheep and 450 goats under the West Africa Agricultural Productivity Programme (WAAPP) (Ablordeppey and Osabutey, 2015). There is the possibility of a potential increase in chevon production and value addition will be required to improve marketability of the raw meat, therefore the need to introduce jerky as a form of meat preservation.

1.1 Problem Statement

Most animals slaughtered in Ghana for meat consumption are over aged and meat tenderness decreases as animals increase in age. The decreased tenderness is due to increase in collagen cross-linking which is regarded as the chief determinants of meat texture. Meat from over aged animals require longer cooking time for it to tenderise, chewing such meat is also difficult and it will as well require a longer digesting time. Since jerky is dried to a low water activity in order to inhibit microbial growth, one might anticipate that using whole muscle from over aged animals would result in very tough and coarse textured jerky. Additionally, despite the low water activity there have been several reports on the outbreak of food borne diseases connected with the consumption of snack meat products (CDC, 1995; Eidson *et al.*, 2000). Hence, this

has raised questions about their safety, since jerky is consumed without further cooking. There is a dearth of knowledge in the use and effect of acidic and enzymatic marinades in the meat processing industry.

1.2 Objectives

The general objective of this study is:

To evaluate the effect of acidic (vinegar) and enzymatic (papain) marinades on quality characteristics of chevon jerky (produced by oven drying).

The specific objectives are:

1. Evaluate the effect of the marinades on sensory characteristic of chevon jerky.
2. Compare the effect of the treatments on microbial characteristics and shelf life of chevon jerky during storage.

1.3 Justification

There is an ongoing programme by the Government of Ghana supporting farmers with improved breeds of sheep and goat, which is aimed at increasing small ruminant production in the country. With the possibility of a potential increase in chevon production, value addition will be required to improve marketability of the raw meat. Jerky manufacturing is simple and cheap way to dry fresh meat to prevent it from deteriorating. With regard to introduction of pathogens into meat through the use of non-meat ingredients, papain is superior compared to other bacterial derived enzymes used as meat tenderisers. Additionally, papain tenderise meat within a short time and is most often more effective compared to other enzymatic tenderisers such as bromelain, ficin and *B. subtilis* proteases. On the other hand, vinegar is an organic

acid which effectively control pathogens in meat products. Marinades enhance quality of meat products, therefore, there is the need to explore the benefits of marinades to produce jerky products with desired sensory quality and microbiologically safe.

1.4 Hypothesis

1. Addition of acidic and enzymatic marinades will improve microbial characteristics, sensory attributes and shelf life of chevon jerky.

CHAPTER TWO

2.0 Literature Review

2.1 History of Jerky

Around the year 1550s jerky was identified with the indigenous tribe (Quechua) from the Southern part of America and also previously from the Inca empire. They called meat that has been burnt 'charki'. The Quechua used meat from the alpaca and llamas with the fat and bone removed, the meat was then cut into strips and pounded thin and tumbled with salt. The meat was then sun dried or smoked over a fire. The Spanish Conquistadors developed the process and finally called it Charqui. After the Spanish captured the Northern part of America they noticed that the indigenous were drying meat from buffalo, elk and deer, within some short period the local people acquired the Spanish word, Charqui, only adding their tone and the name "jerky" was given birth. This technique of preserving meats assisted the populace to eat food rich in protein and energy and was easily available during the lean season. The dominant staple food that was consumed by ancient American pioneers and cowboys was jerky (Easy Recipe, 2014). With the advancement of time the Americans realised that it is possible to prepare more appetizing products by the incorporation of different seasonings, eating it out of pleasure relative to need. Jerky is the leading snack food in the world due to the different flavours, shapes and various types of meats that have been used in the production of the product (Easy Recipe, 2014).

2.2 Manufacturing Process

Processing of fresh meat into jerky as a way of prolonging shelf life of a meat product started before the origination of cold storage and preservatives. Normally, lean meats are used in manufacturing jerky and excess fat are trimmed off, as fat serves as a shield that prevent moisture loss, thus causing deterioration as the fat becomes rancid. The meats are sliced into very thin strips from 1/8" to 1/4" thick. Meat cut into thin strips to a large extent reduce drying time. It is relatively easier to cut frozen meat using an electric slicer or knife. Slicers produce consistent sizes of meat strips. Jerky that are easy to chew are produced from meats that are cut across the grain (Bell, 1996). Apart from sliced jerky strips, another common form of jerky is the jerky snack stick or snack strip. First, lean cuts meats are minced using a meat mincer, which is then followed by incorporating spices into the minced meat either by hand or with a meat mixer. The spiced minced meat is stuffed into jerky gun or cannon to produce snack stick or snack strip ("How to make jerky," 2017).

Contemporary manufactured jerky is usually marinated in seasonings or spice rub or solution. Historically, as a way of extending the shelf life and introducing taste to jerky products, dry cure rub or solution was used. In addition, the ingredient that is used also affects the final colour of the product as well as act as an antimicrobial agent, which prevents the growth of harmful bacteria (Bell, 1996). Sodium chloride is commonly used as the basic preservative for jerky, however, modern marinade solutions contains acids such as vinegar and citrus juice which can also destroy bacteria("How to make jerky," 2017). A common curing solution consists of water and salt plus sodium nitrite. The salt dehydrates the meat whereas the sodium nitrite inhibits the development of rancidity and stabilises the colour. Pink colour of meat

can be improved using sodium ascorbate (Bell, 1996). Fresh meat weight of about 453.6grams will reduce to 113.4g after it has been processed into jerky (Nummer *et al.*, 2004).

2.3 Marinade

A marinade is a sauce which is designed to flavour and tenderise meats. Marination is a procedure whereby meat is submerged in a marinade sauce which prolongs its storage life and improves flavour qualities (Lemos *et al.*, 1999). Acid marinades contain vinegar, lemon juice or wine. While enzymatic marinades are made with ingredients such as bromelain from pineapple or papain from papaya (Corriher, 2012). In addition alkaline marinade consists of salt and phosphate (Barbut *et al.*, 1989). The efficacy of most marinade sauces largely rely on their ingredients that is used (salt, phosphates, organic acids, tenderisers, sugar, seasonings and flavourings) (Xiong and Kupski, 1999; Smith and Acton, 2001). Soy sauce, worcestershire sauce, teriyaki sauce, lemon juice, pepper, monosodium glutamate (MSG) or garlic powder are the basic flavourings used in marinades. Sweetness that is added to marinade solutions includes sucrose, dextrose, brown sugar and dark corn syrup. Hickory and onion salt are also used to enhanced flavour (Bell, 1996). In order to enhance jerky tenderness, tenderising agents such as polyphosphates or papain enzyme can be added. The use of these tenderising agents is restricted, because it prolongs the time needed for drying (Bell, 1996). Meats are marinated in the refrigerator in order to avoid microbial contamination (“How to make jerky,” 2017).

2.3.1 Functionality of Marinades

Ke *et al.* (2009) reported that a food acidulant such as citric acid is used in marinade to enhance water-holding capacity and tenderness of muscle. It controls the activity of pro-oxidant metals by acting as a chelator. Vinegar is employed in the meat manufacturing sector as a decontaminant (Ricke, 2003). Manteuffel- Gross and Ternes (2009) stated that “common house-hold marinating ingredients are vinegar and fresh citric juices such as grapefruit, lemon, lime, and orange. Other marinades commonly used on game meats are teriyaki sauce, soy sauce, and red wines, alone or in combination”. With regard to alkaline marinade, “Phosphates used in meat and meat products have several functions, especially functions such as the adjustment of pH, buffer properties, sequestration of selected cations, changing the ionic charge distributions, changing the ionic strength of environment and/or bacteriostatic effects” (Nguyen *et al.*, 2011). In addition salt in alkaline marinade performs several functions such as preventing the growth of bacteria and enhancing meat flavour. Furthermore, salt has a great influence on meat ionic strength and can extract myosin from myofibrillar structures in meat. According to Knight and Parsons (1988) and Ranken (2000), salts could enhance swelling of protein structure but they (on their own) do not solubilise much protein”. Phosphate removes the link between actin and myosin however; it can barely activate proteins on its own (Feiner, 2006). Previous study by Froning and Sackett (1985) has shown the combined influence of salt and phosphate on meat to reduce weight loss during heating, improving texture and water holding capacity. In addition phosphate and salt combine synergistically inhibited *Escherichia coli* growth (Dickson *et al.*, 1994).

2.4 Acidic Marinades

Food additives used to acidified foods are normally studied and used in food production. Organic acids used in the preparation of acidic marinades include acetic acid, lactic acid, citric acid and wine or fruit juices (Stanton and Light, 1990; Lewis and Purslow, 1991; Burke and Monahan, 2003). Soy sauce, acetic, citric, ascorbic, and tartaric acids are examples of food additives that can be used to acidify meat proteins (Calhoun *et al.*, 1996). In addition they enhance meat flavour and colour.

2.4.1 Tenderisation Action of Acidic Marinades in Meat

The process through which acidic marinades tenderise meat include many factors such as swelling of the meat which result in weakening of structures, increased activity of cathepsins and increased gelatinisation in the presence of heat and low pH (Berge *et al.*, 2001; Offer and Knight, 1988). Water holding capacity exerts direct effect on meat tenderness. Whiles meat pH value is very vital because it has an impact on water holding capacity (Goli *et al.*, 2007), since water-holding capacity differ with muscle pH. Hamm and Deatherage (1960) reported that water holding capacity of fresh meat increases quickly as pH decreases below the electrically neutral state of muscle (5.1), which increases the relative number of positive charged protein groups. Furthermore, muscle pH value higher than 6.0 and lower than 4.0 will cause reactive groups that are available to greatly increase its water bind capacity (Gault, 1985). Additionally, Rao and Gault (1989) stated that stromal proteins swelled and retained moisture when meat was acidified below its isoelectric point, whiles myofibrillar proteins swelled and retained it moisture at a pH levels of 4.0 and below. Adding positive or negative charges result in repulsion of muscle fibres which creates space in which water can be held (Foster, 2004).

Berge *et al.* (2001) found that meat tenderness was enhanced when organic acids were injected pre-rigor and postmortem. The meat pH decreased rapidly to about 5.0 which were initiated by the addition of organic acid; however, swelling or moisture content increase was not achieved. It can be concluded that cathepsin activity was principally responsible for the tenderising effect of the meat. The explanation corresponds with the above observation. Similarly, Stanton and Light (1990) injected bovine muscle with lactic acid immediately after slaughter, the lactic acid caused rapid pH decline in prerigor meat and increased degradation of perimysial collagen. Injection of lactic acid marinade into muscle prerigor achieved both an earlier post-mortem activation of muscle cathepsins and accelerated more uniform distribution of acid throughout the meat. Also Ertbjerg *et al.* (1999) confirmed the above report, that lowering meat pH favoured increased release and activities of lysosomal cathepsin. Also lysosomal activity increased with increased in the concentration of the acid used. Lysosomal cathepsin (B and L) cleave both myofibrillar (Ouali *et al.* 1987; Mikami *et al.* 1987) and collagenous proteins (Etherington *et al.* 1974; Mason *et al.* 1984). Offer and Knight (1988) reported that collagen solubility was achieved when cross-links disintegrated. Again Offer and Knight (1988) suggest that “collagen may be soluble through the breakdown of cross-links. Some of these bonds are Schiff base aldimine bonds being ruptured easily by pH, heat changes, and denaturing agents”.

Wenham *et al.* (1976) and Berge *et al.* (2001) reported that meat treated with acid improved in tenderness within the first few days of marinating. In addition there is a slight increase in tenderness when the treated meat is marinated for a longer duration (over 21days); this suggest that meat marinated in an acid solution for extended period will not result in any distortion of sensory attributes. Ertbjerg *et al.* (1999)

suggested that cathepsin was responsible for improving tenderness of meat treated with acid and marinated for an extended period.

Hutton (1981) and Moeller (1977) revealed that lysosomal enzyme activity decreases when heated with either a microwave or conventional heat from 40 to 70°C, also cathepsin C activity is greater in the soluble and insoluble fraction at 2°C than 37°C". On the contrary, Lutalo-Bosa and Macrae (1969) observed a higher cathepsin enzymes activity at a temperature around 40°C and a lower activity as temperatures increased above 40°C. Temperature is apparently the major dominant factor affecting enzyme functionality. Some authors (Miles *et al.*, 1995; Berge *et al.*, 2001) have reported that acid marinating weakens connective tissue and cause a decreased in thermal stability by shifting the denaturation temperature downward by 5-10°C. Lewis and Purslow (1991) observed that the influence of acid marinating on connective tissue was minimal compared to myofibrillar proteins. Denaturing temperature is remarkably less if marinated in acid than in water or salt (Aktas and Kaya, 2001). Another study revealed that beef cores marinated in acetic acid at pH 2.5 for 72h significantly decreased collagen proteins compared with beef cores marinated in phosphoric acid at pH 1.5 for 72h (Oreskovich *et al.*, 1993). This indicates that the type of acid used as an effect on meat tenderness.

2.4.2 Antimicrobial Effect of Acidic Marinades

Organic acids have bacteriostatic and bactericidal properties, however, its ability to manifest these attributes depends on the physical state of the organism and the characteristics of the external environment (Davidson, 2001), the type of acid applied, amount used and method of application. Efficacy of organic acid could be influenced

by water activity, pH of the food, temperature, oxygen level, fat content and other antimicrobials (salt and nitrite). Potency of organic acids is enhanced at a low pH and when employed together with other hurdle technologies used to control microbial growth (Knipe, 2009; Samelis and Sofos, 2003). Organic acids exhibit their antimicrobial property by decreasing the pH in the water phase of foods. Weak lipophilic organic acids such as acetic, propionic, sorbic, benzoic exert their activity by permeating the cell membrane in the undissociated form to either retard microbial development or destroy the microbes by separating and lowering the pH of the cytoplasm of the organism (Samelis and Sofos, 2003). Microorganisms die because of their inability to maintain a near neutral pH cytoplasm to sustain useful macromolecules. The transport of these excess protons requires utilisation of energy stored in the cells and can lead to the exhaustion of energy stored in the cells.

The number of investigations carried out for nearly a decade now to ascertain the efficacy of organic acids or their salt on the growth of microorganisms in snack foods has increased. Derrickson-Tharrington (2001) reported that a significant inactivation of *E. coli* O157:H7 was achieved in beef jerky treated with ascorbic and citric acid marinades compared with the control treatment during drying. Similarly, Albright *et al.* (2002) observed a decrease of *E. coli* O157:H7 count in beef jerky processed using four multi-hurdles (immersing in boiling water then marinating, seasoning then immersing in hot pickling brine, immersing in vinegar then marinating, marinating then immersing in vinegar) and then inoculated with *E. coli* O157:H7. Also the bacteria were not observed in any of the treated samples after one month of storage. Naidoo and Lindsay (2010a) reported that conventional organic acids such as apple cider vinegar and brown spirit vinegar cannot control the growth of *S. aureus*. Naidoo

and Lindsay (2010b) again observed that a significant decrease of *L. monocytogenes* was achieved more rapidly in a conventional method (acetic acid dip then spiced) than the modern method (acetic acid and spice mixed), whereas the reverse was observed for *S. aureus*. From the above studies it can be deduced that acidic marinades could enhance microbial destruction during drying and in storage.

2.5 Enzymatic Marinades (Exogenous Proteolytic Enzymes)

Consumers of meat are pleased to spend more money on a soft textured meat product than tough one (Miller *et al.*, 2001). Therefore it is essential to develop a tenderisation technique that is hygienic, fast, uniform, affordable and efficient for the meat manufacturing sector. The application of enzymes in meat processing has been practiced for many decades to enhance meat products sensory characteristics so as to make it easier to masticate and swallow. Enzymes are protein molecules that speedup specific chemical reactions. According to Calkins and Sullivan (2007) majority of the enzymes do not act on the interior of the meat, making the procedure for applying the enzyme on meat to be very crucial. The meat manufacturing sector uses various techniques to incorporate tenderising enzymes into meat. The techniques used include the following: powder application to the meat surface, immersing the meat in enzyme solution or inclusion in marinade, injection brine and pre-mortem injections of the protease solutions into the animal prior to slaughter or via post- mortem (Gerelt *et al.*, 2000). The first two techniques are not good enough, since the enzymes cause excessive tenderisation of the meat exterior which leads to distortion of texture, while the interior is left unaltered (Lawrie and Ledward, 2006).

Temperature is apparently the major dominant factor affecting enzyme functionality. Majority of the commercial meat tenderisers' (enzymes) peak performance is noticed at temperature range of 50-70°C. Hence, the exogenous enzymes are more active during cooking and to a lesser extend during cool storage (Calkins and Sullivan, 2007). Hung *et al.*, (2013) examined the effect of *Aspergillus oryzae* proteases on the degradation of myofibrillar proteins in *Psoas major* from pork at 5°C. Samples were assessed for duration of one week. Hung *et al.*, (2013) found that *Aspergillus oryzae* extensively degraded titin, nebulin, desmin and α -actinin compared with control samples. The degree of titin and nebulin degradation was associated with improving meat tenderness (Huff-Lonergan *et al.*, 1995). Rapid denaturation of titin and nebulin could possibly breakdown the firm structure of muscle cells (Robson *et al.*, 1997) and reduce myofibrillar strength (Horowitz *et al.*, 1986). On the contrary, Pietrasik and Shand (2008) observed insignificant proteolytic activity of meat treated with *Aspergillus oryzae* and *Bacillus subtilis* stored at temperature of 4°C. The researchers concluded that meat treated with enzyme could therefore be stored without any negative enzymatic alterations in product attributes. It can also be deduced that *Bacillus subtilis* or *Aspergillus oryzae* proteinase are of higher quality compared with papain. Papain continues its activity at refrigeration temperature even after cooking hence increasing the risk of deteriorating sensory attributes of the meat. Similarly, Ashie *et al.* (2002) revealed that papain-treated meat showed slow decreased in toughness during refrigerated storage, while *Aspergillus oryzae* showed no change in tenderness. The researchers further observed that *Aspergillus oryzae* was active between 55°C to 75°C during cooking, while papain residual activity goes beyond 75°C. It can be concluded that tenderising effect of *Aspergillus oryzae* proteases arise chiefly during thermal process, it is possible to harness the features of *Aspergillus*

oryzae to treat, convey and distribute several packaged raw meat products. Regrettably, plant proteases are of higher quality compared with microbial extracted proteases basically due to hygienic health issues such as disease causing effect (Chen *et al.*, 2006). Similar to the above observation, Etherington (1984) also found some activity of papain treated meat at cold storage temperatures. A meat temperature of 80 °C was required for its inactivation. Therefore residual activity can often occur after thermal treatments of meat. Foegeding and Larick (1986) stated that papain has optimal activity at 60 - 70 °C; thus this enzyme is most active during thermal treatment of meat.

Substrate pH has a significant effect on enzymatic activity. Some enzymes express their optimum activity in a more acidic or alkaline medium for protein degradation, however, majority of the enzymes operate within the normal optimum pH range of meat (Calkins and Sullivan, 2007). Kim and Taub (1991) reported that optimum pH was 5.0 for bromelain while Ashie *et al.* (2002) found that *Aspergillus* had an optimum pH 7.0. Proteolytic enzymes such as papain, ficin, bromelain, *Aspergillus oryzae* and *Bacillus subtilis* protease have been classified as “Generally Recognized as Safe (GRAS)” to improve meat tenderness. Ashie *et al.* (2002); Gerelt *et al.* (2000); Kang and Rice (1970); Kim and Taub (1991); Takagi *et al.* (1992) have reported that “each of these enzymes have varying degrees of activity against myofibrillar and collagenous proteins”.

Table 1: Enzymes Classified as “Generally Recognised As Safe” (GRAS) for Meat Tenderisation

Enzyme	Type	Source	Protease class
Papain	Plant	Papaya	Cysteine
Bromelain	Plant	Pineapple	Cysteine
Ficin	Plant	Figs	Cysteine
<i>Bacillus</i> Protease	Bacterial	<i>Bacillus subtilis</i>	Serine
Aspartic Protease	Fungal	<i>Aspergillus oryzae</i>	Aspartic

USDA’s Food Safety Inspection Service (FSIS) (Payne, 2009).

2.6 Papain

Papain is recognised in the food manufacturing sector for its activity as a tenderiser for meat; weaken the structure rigidity of myofibrillar and connective tissue proteins (Aehle, 2007). Azarkan *et al.*, (2003) reported that commercial papain accessible in the shopping malls and stores is processed from the latex of the pawpaw plant. Papain, chymopapain A and B (EC 3.4.22.6), endopeptidase papain III, endopeptidase papain IV and endopeptidase papain omega are some of the proteases that can be found in the latex of unripe pawpaw fruit (*Carica papaya* L.). Papain consists of a single polypeptide chain with three disulfide bridges and sulfhydryl group necessary for activity of the enzyme. Additionally, papain molecular weight is about 23,406 Da while its maximum activity is achieved at optimum pH range of 6.0 to 7.0. The enzyme also displays wide specificity, splitting peptide bonds of basic amino acids, leucine or glycine. It also breaks down esters and amino acids (IUBMB Enzyme Nomenclature, 2009).

2.6.1 Myofibrillar and Connective Tissue Degradation by Papain

Geesink *et al.* (2011) suggested that addition of exogenous enzyme augment the activities of endogenous enzymes to enhance meat tenderness. Several studies have confirmed reports of non selective hydrolyse of meat proteins by papain (Foegeding and Larick 1986; Miller *et al.*, 1989; Takagi *et al.*, 1992). According to Ashie *et al.* (2002) “papain retained maximal activity even after cooking to 75°C thus increasing the risk of both texture and flavour defects”. Earlier report from Kang and Rice (1970) indicated that papain showed greater activity for myofibrillar fraction with stronger solubilising activity on connective tissue. In agreement Sullivan and Calkins (2010) also reported that papain displayed significant collagen solubility of meat muscle than bromelain, ficin, and *B. subtilis* proteases. Rawdkuen and Benjakul (2012) suggested that a higher solubility of meat collagen treated with enzyme is probably due to a rise in penetration of the connective tissue, which easily breaks into fragments. Furthermore, proteolytic enzyme may also assist in structural modifications through action on intermolecular cross-links. Meat tenderness is achieved when collagen is solubilised to gelatin. The function of collagen is of immense concern, as it is regarded as the main deciding element in the tenderness variations among several muscles. Contrary to earlier reports, Wada *et al.* (2002) indicated that papain degrademyosin and actin filaments. Pawar *et al.* (2003) also reported that papain hydrolyses fibrous protein and connective tissue and indicated that papain solubilised 15% connective tissue proteins and 60% salt soluble proteins. A detailed finding from Istrati (2008) indicated that papain breaks down less actomyosin than myosin. Muscle firmness is lost due to proteases degradation of meat proteins which result in increase solubilisation of free amino groups and hydroxyproline. In addition meat tenderness is enhanced (Fogle *et al.*, 1982).

Furthermore; Istrati (2008) found out that accumulation of free amino acids and non-protein nitrogen increased proportionally with increased in papain concentration and duration of ageing of meat. The formation of free amino acids and non protein nitrogen in meat is one way to measure the extent of protein degradation. Doneva *et al.* (2015) concluded that the rate of hydrolysis of meat proteins is contingent on the following factors – enzyme type, quantity of enzyme in a solution and treatment duration. Thus high dose of enzymes and longer duration of processing results in higher hydrolysis of collagen in meat. Higher hydrolysis of meat proteins leads to protein loss and deterioration of meat sensory attributes.

2.7 Marinating Techniques and Duration

A marinade can be in a form of paste, liquid or dry rub. Period for marinating widely differs based on the type, cut and size of the meat. Meats such as pork and steak can marinate for 24 h or beyond while chicken can marinate between 2 h and 24 h, meat cut into thin strips marinate more effectively and require shorter marinating time than larger strips (Christensen, 2009).

2.7.1 Marinating Methods

2.7.2 Immersion

According to Xargayó *et al.* (2001) “immersion is the oldest method, consists of submerging the meat in the marinade and allowing the ingredients to penetrate the meat through diffusion with the passage of time. This method is quite unreliable in the meat industry because it does not provide regularity in distribution of the ingredients and because it increases the risk of bacterial contamination”. Young and Yang (1975) reported of an improvement in meat tenderness when meat was immersed in papain

solution, however, meat tenderness improved with increased in papain concentration from 0.01% to 0.1% concentration. Ashie *et al.* (2002) confirmed that a higher dosage of the enzymes was required for marinating by immersion due to the inability of the enzyme to penetrate into the meat as compared to the injection method. On the other hand, Gerelt (2000) reported that dehydrated meat dipped for 3 h in a papain solution and kept at 4°C for 168 h, achieved 80% penetration rate. Both sensory and instrumental measurements recorded a decreased in tenderness of the treated samples than control samples. Papain fragmentations of myofibrils were observed at 24 h and beyond.

2.7.3 Multi-needle Injection Marinating

Xargayo *et al.* (2001) stated that “multi-needle injection marination is perhaps the most widely used method because it allows for dosing an exact quantity of brine, ensuring regularity in the products and without the time losses involved in immersion”. The procedure involves insertion of a needle or probe into a meat which the marinade is then released into the meat and the probe or needle withdrawn; the marinade is then uniformly distributed throughout the meat (Smith and Acton, 2001). Ertbjerg *et al.* (1999) reported that beef injected with lactic acid and marinated for 21 days resulted in an increased in the activity of cathepsin. Cathepsin activity increased with increased in lactic acid concentration and duration of ageing. Lactic acid significantly reduced shear force value. Wheeler *et al.* (1993) also reported of a decreased in tenderness of beef muscle (*Longissimus*, *Semimembranosus* and *Triceps brachii*) injected with Calcium chloride for 30 min and 24 h post-mortem. It was reported that Calcium chloride did not affect the meat colour at 24 h post-mortem;

however, a slightly colour change was observed after 30 min post-mortem. Indicating that duration of marinating has less effect on colour and tenderness of the meat.

2.7.4 Vacuum or Manual Tumbling

Meat tumbling is normally carried out using a vacuum tumbler, which assists marinade solution permeation and enhance colour consistency of meat. Massaging and tumbling produce protein exudates (which compose of actin and myosin); which support bonding during cooking process. Tumbling exist in two forms, which are continuous and intermittent. Intermittent tumbling is used to establish equilibrium between maximum tumbling time and marinade permeation time (Hayes *et al.*, 2007), while continuous tumbling eliminate the period of rest that occurs during the intermittent tumbling which results in elastic shrinkage of meat. Although several studies have been carried out to outline the benefits of using intermittent tumbling (Ockerman and Organisciak, 1978; Plimpton *et al.*, 1991) however, Gillett *et al.* (1982) still suggested that “continuous tumbling was more effective than intermittent tumbling”. Investigation by Gao *et al.* (2015) indicated that vacuum continuous tumbling marinating treatment improved functional properties and sensory qualities of meat compared to vacuum intermittent tumbling marinating treatment. Smith and Acton (2001) reported that tumbling enhance products juiciness and slicing characteristics, due to the extraction of salt proteins to the meat exterior; which promote protein coagulation during thermal treatment to enhance binding properties. Furthermore, the protein exudates act as a shield during cooking processes to prevent moisture loss in the meat.

2.8 Marinade Ingredient Functionality

There are many varieties of ingredients that are used in the production of different flavours of jerky. Commercial jerky available in the markets comes in many flavours with different food grade chemicals, additives and preservatives. Commercial jerky producers use different ingredients such as salt, sweeteners, monosodium glutamate (flavouring agent), garlic, black pepper, paprika, tomato powder, sodium nitrite, sodium erythorbate, worcestershire sauce, soy sauce or teriyaki sauce, wine, vinegar, citric acid, succinic acid, potassium sorbate (to prevent mould growth), apple juice and papaya juice (Ingham *et al.*, 2006).

2.8.1 Spices

Spices and herbs, added in marinades significantly enhance meat safety and controlled or minimised lipid oxidation (Gutierrez *et al.*, 2009). Several studies have been carried out for many years to explore the benefit of using herbs and spices to enhance sensory attributes and prolong shelf life of foods (Fernandez-Gines *et al.*, 2005). The chief purpose of using spices and herbs are the flavour they generate, however, some have demonstrated antimicrobial characteristics (Tiwari *et al.*, 2009; Tajkarimi, *et al.*, 2010). In addition, phenolic compounds which exhibit antioxidant activity have been found in many spices and herbs (Sasse *et al.*, 2009). The two main spices that are commonly used in cooking to improve the flavour of meat products are garlic and onion (Tang and Cronin, 2007). Garlic and onion contain phenolic and sulphur compounds and act as antioxidant and flavour enhancer respectively (Griffiths *et al.*, 2002). Hence, the use of these two spices will probably cover, influence or enhance odour/flavour of meat product sensory attributes.

Yang *et al.* (2011) observed that 0.5% onion included in irradiated raw minced meat exhibited antioxidant effect, but had no influence on colour of irradiated raw minced meat but generated a weak aroma. On the other hand, a combination of garlic and onion generated a greater quantity of sulphur compounds in non-irradiated ground beef, but quantity reduced and profiles altered after irradiation. Whiles 0.1% garlic inclusion generated very strong garlic aroma in irradiated raw ground beef. Similarly, Sallam *et al.* (2004) also found that incorporation of fresh garlic or garlic powder in sausage products generated no strong flavour and also exhibited antioxidant and antimicrobial activity which prolonged the shelf life of the sausage for up to 21 d. Deducing from the results of the above authors garlic and onion could be used to prolong the shelf life of meat products by acting as natural antimicrobials and antioxidants in meat products. However, their effectiveness depends on the quantity used.

2.8.2 Salt (sodium chloride)

Lazarides *et al.* (1995) stated that salt is the major essential ingredient used in the production of dried meat products. Historically, it has been used for years to preserve meat; salt has the potential to act as a desiccant but at lower level could elevate moisture content in a meat product. Salt contains chloride anion which extracts myofibrillar proteins during processing. Small amount of salt about 1.4% or 1.75% is needed for appreciable product bind and quality in normal and less fat meat products (Ruusunen and Puolanne, 2005). Salt is said to associate with taste buds in aqueous solutions including saliva to generate a taste response (Spielman, 1990). Research has revealed that inclusion of salt elevates the degree of salivation (Neyraud *et al.*, 2003) and could explain the decreased taste observed in products with low salt mixtures.

Moreover, salt improves meat product flavour and over palatability (Doyle and Glass, 2010). While too much salt generates harsh flavour; too little salt will cause rejection of a meat product (Martin, 2001). Salt act as a desiccant that enables it's to exhibit antimicrobial activity in processed meat products. The preservative effect of salt is achieved due to the presence of chloride which exerts this control (Taormina, 2010). Salt can effectively inhibit microbial growth in combination with other hurdle technologies such as ingredients used, pre - treatments and proper storage conditions (Doyle and Glass, 2010). Some bacteria can tolerate the presence of higher concentrations of salt; an example is *Staphylococcus aureus* that can survive in a meat product containing 20% salt or beyond (Doyle and Glass, 2010).

Beside the good attributes of salt, it can also act as a pro-oxidant in processed meat product by elevating the degree of metmyoglobin formation (Chem *et al.*, 1992) and increased lipid oxidation (Andersen and Skibsted, 1991). Other contaminants such as metal ions in processed meat products can expedite the rate of oxidation (Townsend and Olson, 1987). The use of sea salt could pose such a challenge; it is of necessity to use high quality salt in order to avert such problems.

2.8.3 Soy Sauce

Soy sauce is well known throughout the world, it has a low pH value due to formation of organic acids derived from the main ingredients (soybean or wheat) during microbial fermentation (Choi *et al.*, 2000). Soy sauce has an intense flavour that is used to mask objectionable flavours emanating from meat obtained from animals such as venison and wild boar. Additionally, it provides acidity, salt flavour and colour to the meat. Soy sauce contains a multitude of acids (lactic acid and pyroglutamic acid)

with lactic acid and pyroglutamic acid as the chief acids but lactic acid is the predominant acid found in soy sauce. Due to the multitude of acids it contains it will be difficult to determine the exact acid that cause improved tenderness in meat when it is used as the main acidulant in marinades. Other lesser organic acids found in soy sauce are in order of commonness, acetic, formic, citric and succinic acids. Additionally, it is also high in salt (18%) (Manteuffel-Gross and Ternes, 2009). Kim *et al.* (2014) observed significant enhancement in tenderness and colour of chicken breast treated with soy sauce. Lim *et al.* (2013) also reported that beef jerky treated with soy sauce had higher moisture content, lower salt concentration, enhanced colour, flavour and tenderness compared with control products. This shows that soy sauce has a positive effect on meat products sensory attributes.

2.8.4. Sweeteners

According to Martin (2001) different types of ingredients can be used as sweeteners to impact positive effect on meat flavour, colour quality and microbial development. White sugar, brown sugar, dextrose and corn syrup are mostly used in meat processing, additionally, honey, maple syrup, and molasses can as well be used to generate distinct flavour attributes (Pearson and Gillett, 1999). The basic role of sweeteners in processed meats is to reduce the harsh flavour of salt (Townsend and Olson, 1987). Additionally, flavour and colour are generated by Maillard browning reaction of sugars during heating processes (Pearson and Gillett, 1999). Maillard reaction is the voluntary interactions between reducing sugars and amino groups of proteins (Ajandouz *et al.*, 2008). The reaction is intensely dependent on pH, time and temperature (Quintas *et al.*, 2007; Ajandouz *et al.*, 2008). Kwak and Lim (2004) reported of the browning intensity of lysine which reacted with five reducing sugars,

the sugar reactivity was in the order of xylose higher than arabinose, glucose, maltose and fructose, respectively. Similarly, Wongwiwat and Wattanachant (2014) investigated browning intensity of four sugar types incorporated in dried chicken meat product. It was reported that product prepared with fructose caused darker brown colour compared to sucrose, lactose and sorbitol. Product prepared with sucrose had the highest sensory score in glossy attribute.

Also heat treatments could cause changes in functional characteristics of proteins. High temperatures can cause modifications in proteins which will affect the food texture by causing conformational changes or aggregation (Arakawa *et al.*, 2001). Sugar can act to stabilise proteins to heat denaturation (Rich and Foegeding, 2000). Allen *et al.* (2007) observed a correlation between water activity and moisture content and Han *et al.* (2007) also suggested that sugar can be added to meat product during processing to assist in decreasing water activity of the product. Both sugar and salt exhibit similar antibacterial activity in processed meat products by elevating ionic strength and reducing water activity (Jay, 2000). However, the percentage of sugar incorporated into processed meat products without additional hurdle is too small to inhibit microbial growth (Pearson and Gillett, 1999).

2.9 Preservation of Meat

Meat and food preservation was an important tool that assisted ancient farmers to increase their produce and prolong food supply by retarding spoilage. Also meat preservation became imperative for conveying meat over extended distances without deterioration of sensory attributes and nutritional properties after the establishment and fast expansion of grocery stores and shopping malls (Nychas *et al.*, 2008). The

objectives of meat preservation techniques are to reduced oxidation, prevent microbial and enzymatic deterioration. Historically, foods have been preserved by salting, drying and smoking, methods that have been enhanced by scientific, techniques. In addition, early hunters use to freeze foods. The methods used for the preservations of foods were based on the surrounding environment (Wentworth, 1956). Areas with low humidity depended on the sun for drying foods. Meat was later dried and smoked on fires. Freezing, as a method of preservation, was restricted to geographical areas with cool weather. Salting of meat was an efficient preservative method that was carried out in Arabian Peninsula and in coastal regions by early hunters (Wentworth, 1956; Binkerd and Kolari, 1975).

Currently the methods of meat preservation include controlling of temperatures, water activity, use of chemical or bio-preservatives and a mixture of the various methods (Bagamboula *et al.*, 2004; Zhou *et al.*, 2010). Although, there are several preservation techniques, drying of food is among the best ancient and effectual technique developed (Hotchkiss and Potter, 1995).With the development of scientific technique in meat preservation, some conventional meat products (fermented sausages, dry-cured hams, pastrami, jerky, Bresaola (Italy), Biltong (Southern Africa), Odka (Somalia), Kuivaliha (Finland), Qwanta (Ethiopia), Kilishi (Nigeria), etc.), in which drying is one of the chief processes, are still manufactured in great quantities due to their distinct and approved flavour (Rahman *et al.*, 2004). All over the world, techniques and recipes used for meat preservation varies among cultures. Meats that are salted, cured, dried or smoked can be preserved with or without the inclusion of spices or fruits. Dried meat from animals such as cattle, turkey, horse, camel, sheep,

pig, and ostriches are still consumed to this day. Odka, biltong, qwanta and Kilishi are some of the popular dried meat products that can be found in Africa (FAO, 1990).

2.9.1 Odka

Odka is a traditional dry meat product of the people of Somalia. Odka is made using lean beef which is cut into larger strips. The cut strips are rubbed with salt and then sun dried for four to six hrs. The dried product is then cut into small strips and cooked in oil. The cooked product is spiced, sauced and further dried in the sun. The product is then masked with oil and stored in an air tight closed container. The product can be kept for more than one year (FAO, 1990).

2.9.2 Qwanta

Qwanta is a meat product from Ethiopia, is made using lean beef. The meat is cut into strips of about 20 to 40cm long. The strips are then sauced using 50% pepper, 25% salt and 25% other spices. The meat is hung on wire and air dried for 24 to 36h in a room. It is further dried on fire and followed by frying using butter. Additional drying is carried out after the frying. The product is then stored in an air tight container (FAO, 1990).

2.9.3 Biltong

Biltong is a traditional salted meat product of the people from Southern Africa. The product is produced using meat made from cattle or antelope. The meat is cut into strips of about 1 to 2 cm long. It is then rubbed with salt and pepper which are the main ingredients, however, other additives and preservatives may also be used to enhance colour, flavour and taste as well as inhibit microbial growth. The meat strips

is then cured for some hrs but not more than 12 h. In order to add flavour to the product and also inhibit fungi growth, the meat strips are blanched in a mixture of warm water and vinegar (about 10:1). The meat strips are then sun dried for a day and then kept under a shade for the remaining drying period. The product is done when the interior is soft, moist and red in colour with a hard brown outer layer (FAO, 1990).

2.9.4 Kilishi

Kilishi is a dry meat product from Nigeria. Lean meat from sheep, goat or cattle can be used to manufacture kilishi. The meat is sliced into sheets of less than one metre for fast drying. The dried meat is then marinated in sauce consisting of peanuts, spices and salt. It is then further dry in the sun. After drying the meat is roasted in oil and then consumed or stored for several months (Igene *et al.*, 1990; Musonge and Njolai, 1994).

2.10 Drying of Meat

Keey (1975) defined drying as any process by which water is removed from a substance. It can also be said to be the removal of volatile substances by heat from a mixture that yields a solid product. The principal volatile substance is water, and water is the constituent whose removal is sought. Some of the factors that control drying of food products include air temperature, relative humidity and air velocity. Three distinct phases are involved in the drying of food products; first is the induction phase, the induction phase marks the beginning of the drying, with rapid elimination of water from the meat. The second is the constant rate phase, the constant rate phase correspond to the constant evaporation of water from the outer layer of the meat.

Lastly, the third phase is the falling rate phase, the falling rate phase relate to the most arduous elimination of water because of its slow diffusion to the outer surface of the meat (Hui *et al.*, 2012). Fat in meat acts as a shield which helps to retained moisture during cooking. The fat delays drying by preventing water transfer from the exterior to the surface of the meat. The drying rate decrease when fat content is high (Hui *et al.*, 2012). Meat moisture content is decreased when there is evaporation of water from the outermost layer to the surrounding air and continuous migration of water from the innermost layer to the outermost layer of the meat. Continuous decrease of moisture content cause a conformational change in the shape of the meat starting from small, thin and to some extends shrinkled or wrinkled meat product. The texture also alters from soft to slightly tender to tough (Arason, 2003). Furthermore, high quantity of fat in meat interacts with high temperatures during drying and in storage which influences oxidation and hence may affect the palatability of the product. Lean meat is recommended for the production of jerky in order to minimize undesirable changes due to fat oxidation (FAO, 1990).

2.10.1 Methods of Drying Meat

Jerky processing involves the use of different drying techniques. Some of these drying methods include natural drying, vacuum drying, freeze – drying, hot and cold air-drying (Edward and Pauline, 1965; Labelle and Moyer, 1966; Holdsworth, 1971; Karel *et al.*, 1978; Kim, 1990).The two basic types of meat drying methods include natural or traditional drying and artificial heat source drying.

2.10.2 Natural or Traditional Drying Method

The traditional drying of meat involves the use of natural conditions such as sunshine and air circulation. The two drying conditions clearly differ based on the degree of effect of the solar energy. These drying methods are the sun drying and solar drying and are delineated hereunder.

2.10.3 Sun Drying

Traditionally, the main drying method is called sun drying, distinguished by direct solar radiation and natural air circulation on the product. Meat pieces are cut into strips or flat leaf-shaped pieces. They are then hang on lines in the open air or spread on wire mesh or tray. Specifically, the meat is sometimes blanched in about 14% salt solution to prevent microbial and insect attack. For fast and simple preservation of excess meat that cannot be consumed instantly, the sun drying method can be performed at the farm level (FAO, 1990). However, due to contamination from the environment and lack of stable heat source FSIS (2011) do not recommend the use of natural drying for making jerky. Furthermore, sun drying is time consuming and difficult to control moisture contents (Lee and Park, 2004).

2.10.4 Solar Drying

In the rural settings commercial meat processors use advanced solar drying systems. Contrary to sun drying where there is direct contact of the sun on the meat, solar drying uses indirect solar radiation. The concept of the solar drying method is to gather solar energy by heating-up the air volume in solar collectors and conduct the hot air from the collector to an attached enclosure, the meat drying chamber. Here the products to be dried are laid out. In this closed system, consisting of a solar collector

and a meat drying chamber, with this system there is no direct contamination from the environment (FAO, 1990).

2.11 Artificial Heat Source

FSIS (2011) reported that hot air-drying is an example of an artificial heat source which is popularly used in the meat processing plants and is carried out by placing food in either a warm oven or a food dehydrator. Labelle and Moyer (1966) and Kim (1990) also reported that hot air drying method is effective in lowering moisture content which helps to prevent microbial growth and dries products uniformly. However, the authors again mentioned that besides the good attributes of the hot air drying system, the method deteriorate the sensory properties of meat products through case hardening and lipid oxidation. This change in sensory attributes occurs as a result of rise in drying time and temperature. Other drying methods involving the use of artificial heat sources include smoke house drying, oven drying, freeze drying, microwave drying and dehydrators.

2.11.1 Smoke House Drying

The use of smokehouse as a means of drying meat is probably as old as open air drying. The jerky strips are hanged on racks and smoke circulates around the meat surface (Bell, 1996). Smoke impart desirable distinct flavours to food. Additionally, smoke produces compounds that have a bactericidal effect on microbes (Poligne *et al.*, 2001; Arboix, 2004). Although not basically used to decrease the moisture content of the food, the heat affiliated with the production of smoke act as a desiccant (Cohen and Yang, 1995). This gradual cooking method keeps the final product soft.

2.11.2 Oven Drying

Gas, electric and convection ovens are the most commonly used devices for producing jerky. Ovens heat up the surrounding air, but unlike the convection ovens, they do not circulate it. As a result, jerky dried in an oven varies a great deal from one type of oven to another and exhibits more of a cooked flavour compared to the jerky dried in a dehydrator. Also, if the temperature of the oven is too high, jerky becomes tough, has a burnt flavour, a mealy texture and is more brittle than when dried in a dehydrator (Bell, 1996).

2.11.3 Freeze Drying

Sublimation and desorption is the procedure used to freeze dry meat products. Sublimation converts a product from ice directly into a gaseous state without changing into liquid. Sublimation happens when the vapour pressure and the temperature of the ice surface are below the triple point of water (4.58 mmHg, 0°C). Freeze drying was first introduced in the early 1900's as a way of preserving high quality biological materials such as human serum (Irzytic *et al.*, 1995). Freeze dried products have a distinct characteristics such as high structural firmness, high rehydration capacity, low density and good sensory properties (Hui and Yiu, 2004). Microwave and dehydrators are also used in drying jerky.

Literature abounds on the influence of the various drying methods on meat products quality. Lim *et al.* (2012) evaluated the influence of various drying methods (hot air, shade and sun drying) on the physicochemical quality and microbiological safety of beef jerky stored under room condition. It was reported that regardless of the cooking techniques used in drying the products, moisture content and water activity (aw)

reduced with increased storage time. Also shade-dried jerky showed higher water activity compared to the others. Additionally, hot air-dried jerky was tough compared with sun-dried or the shade-dried jerky. The total plate count (TPCs) was also high in naturally dried jerky than hot-air dried jerky after storage for 20d. With regard to sensory attributes, naturally dried jerky showed improvement in attributes than the hot air-dried jerky. In conclusion, although natural drying methods are more prone to microbial contamination than hot air-drying, however, desirable sensory attributes are produced. Recent report by Talib *et al.* (2014) also found a higher microbial count in meat dried using hot air oven compared with solar and sun drying method. In addition, solar drying method also recorded a lower microbial count compared with sun drying. Nayar *et al.* (2014) also observed significantly higher water activity, moisture content, fat content and pH in hot air oven drying products than microwave. Meat colour and microbial quality were also reported to be significantly higher in microwave products than in hot air oven. In addition all sensory attributes were higher in hot air oven samples than microwave with significant difference in flavour and overall acceptability. Microwave drying was found to cause an uncontrolled drying with development of burnt flavours which resulted in lower sensory scores and reduced acceptability than hot air oven. The low sensory attribute scores in some of the above drying methods especially hot air oven drying, was probably due to excessive drying and loss of moisture in meat caused by high temperature during drying. In meat drying processes, both shorter and longer duration could cause denaturation and coagulation of meat proteins that may influence meat texture yielding products that could be described as either too tender or too tough (Konieczny *et al.*, 2007). The natural drying method with high microbial count was due to low drying temperature (FSIS, 2011; Park and Park, 2007). Faith *et al.* (1998) observed

that combination of low temperature and longer drying time could efficiently reduced microbial count to at least 5 Log CFU/g.

2.12 Rehydration Rate

According to An *et al.* (2012) rehydration is a procedure which is aimed at reinstating the attributes of a raw material when the dehydrated material comes in contact with water. Rehydration is usually done by submerging dried material in water (Garcia – Pascual *et al.*, 2005). Rehydration may be regarded as a measure of the degree of damage a food substance sustains during drying and treatment before drying (McMinn and Magee, 1997). The magnitude of rehydration depends on the level of structural and cellular disruption (Krokida and Marinos – Kouris, 2003). Lewicki (1998) reported that rehydration properties of dried food materials are used as a quality index and show whether physicochemical alteration happened during the drying process due to process conditions, pretreatments and sample constituent. It has been observed that the quantity of water absorbed is equivalent to swelling of the biological materials. The ratio between the dry material weight and water volume differs from 1:5 to 1:50; temperature of rehydrating water is from ambient temperature to hot. Time of rehydration differs from 2min to 24 h (Lewicki, 1998).

2.13 Microbiology of Meat and Meat Products

Meat the muscle tissue of slaughter animals consist of water, proteins, lipids, minerals and a small amount of carbohydrates. Due to the rich nutritional composition of meat and meat products they are liable to quality declination (Jay, 2005). The quality declination is due to physicochemical and microbial changes. Deterioration starts soon after blood draining, resulting in microbial and physicochemical changes. The

animals hide/skin and gastrointestinal tract (gut) are the major contamination points. Fungi mould and bacteria are the three commonly found microorganisms in meat products. Bacteria thriving in meat could be aerobic, anaerobic or facultative. According to Romans *et al.* (1994) organisms of concern affiliated with the contamination of meat include *Salmonella*, *Escherichia coli*, *Campylobacter jejuni*, *Listeria monocytogenes* and *Staphylococcus aureus*. On the other hand, those associated with the contamination of jerky products include *Salmonella sp.*, *Staphylococcus aureus* and *Escherichia coli* O157:H7 (Calicioglu *et al.*, 2002, 2003; Ingham *et al.*, 2005).

2.14 Food Safety Concerns of Jerky

The method of jerky production either from whole muscle or restructured ground meat varies from the production of other snack meat products because thermal treatments is used to achieved the required product attributes and shelf safety. The dehydrating step may decrease the process lethality against disease causing organisms, however, outbreak of food borne diseases have been connected to the eaten of jerky (CDC, 1995; Keene *et al.*, 1997; Eidson *et al.*, 2000). Many outbreaks of microbial infections demanded an upgrade of food safety measures and processing techniques for jerky. USDA - FSIS (2004) recognized stages in commercial jerky processing where producers require improving current practices.

First, because jerky may not be sufficiently heat treated to achieve the lethality performance criteria, use of moist cooking was suggested as an option. A relative humidity beyond 90% should be sustained throughout the heating process by using an enclosed oven or steam injection. However, adding humidity to the processing of

jerky is uncommon for most jerky producers. Also, some jerky manufacturers may not be able to manage humidity well in the smoke house.

Secondly, USDA - FSIS (2004) suggested cooking of meat to 71.1°C before drying. Harrison and Harrison (1996) found a >5 log cfu/g decrease of *E.coli* O157 and *Salmonella* and >4 log cfu/g decrease of *L. monocytogenes* after thermal treatment at 71°C and no detection of these microbes after additional drying at 60°C, however, preheating meat and or drying jerky at high temperatures for prolonged duration may result in a product that varies from conventional jerky and decrease the level of acceptability (Calicioglu *et al.*, 2002).

Other authors have reported that using marinade in jerky processing may increased the log reductions of pathogens observed. Harrison *et al.* (1997) found that *Salmonella* and *Listeria* levels decreased to about 1.0 log cfu/g in marinated than non-marinated samples during the initial stages of drying. Borowski *et al.* (2009) also found that marinades seasonings can have an effect on the decrease in total population of disease causing microbes. Several studies have evaluated the efficacy of drying treatments and index (time, temperature), Holley (1985) reported of 15% decrease in *S. aureus* inoculated on a jerky after dehydrating for 8h at 68°C, additional 5% decrease was recorded after one week of storage. This however, contradicted the report by Keene *et al.* (1997), where viable *E. coli* O157:H7 were retrieved after drying whole venison strip jerky 10 hrs at 62.8°C.

Also, the use of chemical intervention approaches have been studied widely, Calicioglu *et al.* (2002, 2003), observed >4 log cfu/g decrease in *L. monocytogenes*

and no survival of *Salmonella* or *E.coli* O157 when beef strips were dipped in 1% Tween followed by 5% vinegar before marinating and drying at 60°C for 10h. Similarly, Yoon *et al.* (2006) also reported that 5% vinegar improved pathogen reductions. Additional variation that can be recommended in jerky manufacturing is the implementation of a post drying thermal treatment. Borowski *et al.* (2009) reported of 3 log cfu/g decreases in *Salmonella* and *E.coli* O157 when jerky was post dried at 135°C/10min. After an expansive analysis of the microbial control in ready to eat meat products, the United States Department of Agriculture (USDA) reconsidered the measures for these shelf staple food products, which is found in Food Standards and Labelling Policy Book (USDA - FSIS, 2004). The new standards recommend having at least moisture to protein ratio of $\leq 0.75:1$ and water activity of not beyond 0.85 to ensure the safety of jerky products. However, the USDA - FSIS (2004) recommended that critical water activity limit for jerky, which is in contact with air, be ≤ 0.70 , as mould growth is seized at this water activity level.

2.15 Principles of Preservation of Shelf-Stable Dried Meat Products

Basically, the word “shelf stable products” refers to products that can sustain their desirable sensory attributes without the need for refrigeration. Usually, such products are stored under ambient condition. This shelf-stability is usually based on the quality of the packaging material to control rancidity and potential fungi development. The shelf life for these products is often defined for satisfactory quality, not stability because the stability has been catered for in the manufacturing process. The shelf life of the product is described as the time the particular product can be stored under précised conditions that maintains desirable sensory attributes. Shelf-life is regulated

by two types of spoilage: microbiological (spoilage) and chemical (oxidation) (Wilson *et al.*, 1981).

2.16 Shelf-Stability and Hurdle Effect

Shelf-stability is due to a collection of factors, commonly referred to as the “hurdle effect”. The engagement of these factors affects particular microbes and chemical reactions. Managing the many factors and their associations increases the overall impact and attain shelf-stability. Scientific food preservation techniques are often categorized into three types: 1. prevention/elimination of contamination e.g., decontamination of raw materials (steam treatment and organic acid washes of carcasses, irradiation of spices), aseptic processing 2. Inactivation of microorganisms e.g. heat (pasteurisation and sterilisation), high pressure processing 3. Gradual or complete inhibition of microbial growth e.g., low temp, water activity, redox potential, pH or preservatives (Beauchat, 1981).

The most basic factors connecting with the safety or shelf-stability in dried meat products are water activity, pH, time/temperature/relative humidity, salt/brine strength and microflora types (Sumner and Jenson, 2011). Over the total range of products, water activity is the major essential factor causing shelf – stability in dried meat products; that is if diseased causing microbes are still alive and the product is debased (Beauchat, 1981). Protection of food from microbial contamination is directly affected by the water activity. Ghaly *et al.* (2010), defined water activity (a_w) as “water which is not bound to food molecules and can support the growth of microorganisms. It represents the ratio of the water vapour pressure of the food to the water vapour pressure of pure water under the same conditions”. The growth of microorganisms is

at its peak when water activity is at a range of 0.98-0.99 and growth arrested at water activity <0.90 . At a water activity 0.6 of yeasts and moulds can thrive (Ghaly *et al.*, 2010). Most bacterial pathogens cannot tolerate low water activity, *Staphylococcus aureus*, reportedly will not develop aerobically at water activity of 0.85 (Jay, 1992) or anaerobically at water activity of ≤ 0.88 (ICMSF, 1996). To attain shelf stability, United State Department of Agriculture (USDA - FSIS, 2005) standards request products labelled as jerky to have moisture to protein ratio (MPR) of 0.75:1 or lesser and a water activity of <0.70 for product in contact with air, which is low enough to arrest mould growth. It is possible mould will thrive at water activity level greater than 0.70. Hence, a combination of hurdles should be used in a product with water activity greater than 0.70 to arrest mould growth. Some recommendations are: vacuum package, modified atmosphere package (no oxygen in mixture), oxygen scavenger, potassium sorbate spray (3oz/gallon) applied post-drying. Ingham *et al.* (2006) suggested that jerky with a water activity greater than 0.85 should not be stored under ambient condition; whiles products to be stored in oxygen free packaging should not exceed a 0.88.

Beside water activity a product pH is the next most vital factor in shelf stability of dried meat product. Suppressing the growth of microorganisms by pH is based on many factors, including the type of acid and the temperature. Generally, the minimum pH for *E. coli* O157:H7 nearer to 4.4, but it will thrive well at lower pH values, especially if refrigerated (Adams and Moss, 1995). Microbiological minimum or maximum limits for growth are basically dependent on temperature, water activity, pH or the presence of preservatives (Adams and Moss, 1995). In ready to eat products especially dried meats, the environmental conditions are hardly favourable for

microbial growth, however, a combination of hurdles or preservatives present becomes an added advantage. The hurdle impact happens when the mixture of inhibitors is more restrictive than single inhibitor (synergistic effect). The most vital hurdles in food preservation are: high temperature, low temperature, reduced water activity, increased acidity, reduced redox potential, preservatives and competitive micro flora. Since shelf-stable dried meats products are not sterilised or pasteurised and as well stored under ambient condition, the last five hurdles mentioned above are of primary importance (Wilson *et al.*, 1981).

2.17 Packaging

The basic principle of packaging is to retain the acceptable qualities of a product and also assure the safety until it reach the consumer at the final point of consumption (Kropf, 2004). Although most dried meats are shelf-stable with respect to food safety (due to lower water activity and pH), a correct packaging system is essential for microbial (Jay, 2005) and chemical shelf-stability. Mostly, the products are packaged under vacuum or modified atmosphere where oxygen is removed. Ingham (2006) suggested the use of either vacuum-packaged or an oxygen-scavenger inserted in the package along with the jerky product and the bag then sealed under air. These scavengers are responsible for the elimination of remnant oxygen that may still be present after packaging. All jerky products should be inspected and seal secured when packaged under oxygen-free conditions. The technique used to reduce oxygen or altering food package or chamber atmosphere by flushing different gas mixtures of CO₂, N₂ or O₂ is known as modified atmosphere packaging (MAP) (Phillips 1996; Jay, 2005). Modified atmosphere packaging comprise of vacuum packaging, controlled atmosphere packaging (CAP) and modified atmosphere packaging systems

or dynamic modified atmosphere packaging (Kropf, 2004; Phillips, 1996). Phillips (1996) described some of the packaging materials used for modified atmosphere packaging, including polyvinylchloride (PVC), polyethylene terephthalate (PET), polyethylene (PE), and polypropylene (PP). The chief gases that are utilised in modified atmosphere packaging are O₂, N₂ and CO₂. These gases are utilised in various quantities and mixtures based on the nature of the commodity and the requirement of the manufacturers and consumers (Phillips, 1996). However, the final selection is based on the type of microflora ability to thrive on the product, the susceptibility of the product to O₂ and CO₂ and the need to stabilise product colour.

On the other hand, vacuum packaging is a type of packaging in which air is eliminated prior to sealing. It is a form of modified atmosphere packaging because the usual air composition has been changed. Vacuum packaging of meat products affords a lot of advantages such as prolonged shelf-life, decreased weight or moisture loss, assists in controlling rancidity, inhibits spoilage bacteria growth and stabilise food colour (Jay, 2005).

Many research works (Singh *et al.*, 2011 and Xiao *et al.*, 2011) have been carried out on the effect of the various method of packaging on processed meat stability. Ingham *et al.* (2005) reported of a reduction in *S. aureus* count from 1.0 – 2.6 log to 3.2 – 4.5 log CFU in one month, when a product containing a water activity of 0.68 – 0.82 was vacuum packaged. Also Choi *et al.* (2007) reported of higher total plate count in jerky product stored in plastic compared to samples in vacuum packs. Water activity was higher in samples in vacuum packs compared with that of plastic packs. Meshram *et al.* (2014), also observed that sensory attributes deteriorate with time in both aerobic packaging and modified atmosphere packaging (nitrogen), however, the sensory

attributes decline faster in aerobic than modified atmosphere packaging when stored for a extended period. Kim *et al.* (2014), also obtained a similar result, however, tenderness improved in vacuum pack samples than modified atmosphere packs. While water activity, pH and moisture content were significantly lower in modified atmosphere packs compared with that of vacuum packs. Sharma and Nanda (2002) reported of a decrease in flavour of chicken chips that were vacuum-packaged and stored at ambient temperature. Change in meat flavour during storage is due to lipid oxidation (Aguirrezábal *et al.*, 2000). From the above authors results it can be concluded that irrespective of the packaging methods sensory attributes of meat deteriorate with time.

2.18 Eating Qualities of Meat

Meat eating qualities including tenderness, juiciness and flavour are regarded the major essential meat palatability traits by consumers (Lawrie and Ledward, 2006; Smith *et al.*, 2008). Similarly, Albright *et al.* (2000) reported that the most essential sensory characteristics of jerky are texture, colour and flavour, which are determined by the raw ingredients and many technological factors.

Flavour is an essential eating attribute when meat products are served (Behrends *et al.*, 2005). Raw meat has little or no aroma and only has a blood – like taste, hence meat flavour is heat derived. Huang and Ho (2001), reported that meat flavour constituents are formed from the heat degradation of compounds mostly contain in meat such as fats, proteins and carbohydrates and thermal processes that essentially impact overall meat flavour. In meat, two reactions that occur in the cooking process are largely responsible for flavour development: Maillard reaction and oxidation of

meat. Maillard reaction and the oxidation of lipids during thermal treatment cause to the development of meat flavour. The Maillard reaction, which happens between amino compounds and reducing sugars, is one of the major vital channels for the production of flavour compounds in cooked meat. On the other hand, lipids can break down via oxidation of fatty acids to give volatile odour compounds that can be either desirable or undesirable (Mottram, 1998). During storage, autoxidation of lipids can happen to generate a “rancid odour” in raw meat or a “warmed-over” flavour in cooked meat (Farmer, 1994). A major quality spoiler of stored foods is attributed to off-odours and flavours of oxidative rancidity (chemical change in an unsaturated bond of a fat or oil). The fat component of meat is believed to contribute to the species specific flavours associated with beef, lamb and pork (Calkins and Hodgen, 2007). In addition, Melton (1990) determined that meat flavour is influenced by fatty acid composition. Smith *et al.* (1974) reported that chevon was not significantly different from beef or lamb in flavour desirability when oven-baked rib or loin samples were evaluated by untrained panelists. Factors such as age, diet, breed and sex may also influence the odour and flavour of mutton or chevon (Shahidi, 1994). The dissimilarities between different muscles of meat, preparation methods and cooking conditions may also influence the production of aroma compounds (Fu and Ho, 1997; Priolo *et al.*, 2001). These technologies as well as marinating can be combined and their use can add value to meat products.

The chief factor which contributes to the overall eating quality and consumer fulfillment of meat is the tenderness (Mori *et al.*, 2001). Tenderness is defined as the ease of chewing, which involves the initial ease of biting through, the ease with which the meat breaks into pieces and the quantity of remnant left after chewing

(Lawrie, 1998). Meat tenderness is influenced by pre slaughter factors (species, breed, age, sex, feeding, management, genetic and stress conditions) and post slaughter factors (postmortem glycolysis, postmortem shortening, conditioning, processing and cooking methods). Some of the above factors that affect meat tenderness are discussed below. There is a broad difference in tenderness which occurs between animals and muscles within the same animal. For example, the muscles from the round that are used in movement are higher in connective tissue content than muscles from the loin that are mainly used for structural support. The functions of the muscle within the animal are the primary reason for variation in tenderness of the muscles within the same animal. Smith *et al.* (1974) evaluated sensory attributes of chevon, pork, beef and lamb. It was reported that chevon had the same juiciness, but less tender and acceptable when compared to pork, beef and lamb at the same maturity and fatness. Wheeler *et al.* (2004) compared *Bos taurus* with *Bos indicus*. The latter species presents tougher meat, due to lower proteolysis of myofibrillar proteins, as a result of the greater activity of calcium-dependent protease inhibitor (Shackelford *et al.*, 1991). Variation of meat tenderness within and among breeds of animals was attributed to genetic effect (Shackelford *et al.*, 1994; Wheeler *et al.*, 1996).

As animal increased in chronological age, tenderness decreases (Purslow, 2005) and sensory panel scores for tenderness also decreases (Shackelford *et al.*, 1995). Kannan *et al.* (2003) found *longissimus* muscle from young dairy goat to be tenderer than those from older dairy goats. However, Madruga *et al.* (2000) found similarities in sensory properties of complete and wether goats slaughtered at different maturity stage. Harper (1999) mentioned that the chief cause of toughness in meat of older animals is due to alteration in collagen properties. Collagen content in meat does not

alter much, but its solubility reduces as animal matures which influences meat tenderness. Several studies have shown that tenderness, measured by shear force, increases when better marbling is attained. The connective tissue rigidity is weakened with increased marbling accumulation resulting in tender meat (Berry, 1993; Killinger *et al.*, 2004). A study carried out by Nishimura *et al.* (1999) seems to confirm this theory, since the development of intramuscular fat in the *Longissimus dorsi* muscle appears to disorganise the structure of connective tissue, leading to the tenderisation of highly marbled beef. In addition during cooking, distribution of fat throughout the muscle fibre forms a uniform shield that blocks some moisture loss, thus indirectly contributing to the juiciness (Cross, 1987; Bejerholm and Asalyng, 2004) and tenderness of meat. The effects of cooking on meat texture are quite complex and do not always result in tenderisation. Time, temperature and heating rate are the three variables which ultimately determine how cooking affects meat texture. Davey (1974) measured toughening of meat during isothermal heating. Compared to raw meat, isothermal heating at temperatures of 40 – 50°C produced a significant toughening of fibres which they attributed to myofibrillar protein denaturation. In the range of 50 – 65°C the fibres became tenderer during heating, but when heated at 65 – 75°C fibres were again observed to become tougher. The authors attributed the toughening at 65 – 75°C to collagen shrinkage. This indicates that myofibrillar proteins denatures at temperatures lower than that of collagen (Martens *et al.*, 1982). Christensen *et al.* (2011) reported no decrease of shear force with pork after heating 5hrs at 53°C isothermal. The shear force decreased only after cooking was extended for 17h and decreased even further when heating was at 58°C isothermal. This suggests that tenderisation is achieved at an extended cooking time. In addition, cooking method has an effect on meat tenderness. A muscle with high amounts of connective tissue

requires moist heat cooking method over a longer and slower cooking times to help break down connective tissue without losing moisture and make meat tender. For muscles with only few amounts of connective tissue, dry heat cooking method is recommended, this method transfer heat to meat without added moisture. In addition this method requires higher heat temperature and short cooking time (Bratzler, 1971).

Meat juiciness is an essential factor when it comes to meat quality. Juiciness is described as the quantity of moisture squeezed out of a piece of meat by few gentle mastication (Ritchey and Hostetler, 1964). Sensory juiciness can be broken down into two parts: initial wetness and sustained juiciness. Initial juiciness is the wetness during the first few mastication generated by a quick release of meat juices, and sustained juiciness is caused by fat in the sample that causes a slow release of saliva after continued mastication (Bratzler, 1971). Previous work has shown the factors that have the highest influence on meat juiciness include: ultimate pH, fat content, cooking procedures and scale of doneness (Montgomery and Leheska, 2008). Initial liquid release from meat is absolutely impacted by level of doneness and procedure of cooking, whereas sustained juiciness is linked to intramuscular fat content (Pearson, 1966). Procedures of cookery which result in the highest retention of meat liquid and lowest cooking losses are linked with improved juiciness of the final product (Smith, 1972). Honikel (1998) described cook loss as a way of determining the water holding capacity of meat. Water holding capacity of meat is also influenced by meat pH. A low pH is highly damaging to meat water-binding if storage temperature is above 20°C (Briskey and Kauffman, 1971). According to Aaslyng *et al.* (2003) cooking loss is based on raw meat quality, final temperature and cooking procedure. With higher degrees of doneness, there is more opportunity for cook loss and a reduction in

juiciness. During cooking denaturation of meat proteins causes structural changes to cell membranes of muscle fibres, along with shrinkage of muscle fibres and connective tissue (Honikel, 1998). During heating, water is lost as temperature increases. A rise in the scale of shrinkage during cooking is directly associated with loss of juiciness. Cooking losses due to rise in internal temperature are known to be inversely linked to juiciness (Ackerman *et al.*, 1981). Beef cooked "rare" is juicier compared with beef cooked "well-done"; and pork, lamb, and veal, which are ordinarily cooked "well-done," are less juicy than beef (Weir, 1960).

Marbling is a contributing factor to meat juiciness. When meat is heated, melted intramuscular fat becomes translocated along bands of perimysial connective tissues (Cross, 1987; Bejerholm and Asalyng, 2004). It has been discussed that, during cooking, distribution of fat throughout the muscle fibre forms a uniform shield that blocks some moisture loss, thus indirectly contributing to the juiciness of the meat (Cross, 1987; Bejerholm and Asalyng, 2004). Also Carpenter (1962) suggested that fats that surround muscle fibres helps to moisturize the fibres and so as to make it juicier. As marbling increases, palatability traits rated by consumers, such as flavour, juiciness and tenderness also increase (Smith *et al.*, 1984; Parrish *et al.*, 1991). Similarly, top loin steak with a moderate scale of marbling was juicier and more flavourful compared with modest, small and slight steak (Smith and Crouse, 1984; Lorenzen *et al.*, 2003). Despite all the above explanation on eating quality of meat, acceptability of a meat product is dependent on the degree of preference, acceptance or liking of one product over another.

CHAPTER THREE

3.0 Materials and Methods

3.1 Experimental Design

The experimental design used was a 3x3 factorial with three levels of the papain:(0, 0.004g and 0.04gw/v) and 3 levels of the vinegar (0, 2.5% and 5%v/v) as the final concentration of the solution. 200g meat cubes from hindquarter of goat were added. The experimental design composed of nine treatments with three replications. Microbial testing for shelf life studies was conducted at three storage periods (1d, 15d and 30d) while sensory testing was conducted at two storage periods (1d and 15d).

3.2 Sample Preparation

The chevon was purchased from the Livestock and Poultry Research Centre, University of Ghana Legon and taken to the Cameron Meat Laboratory, University of Ghana, Legon. In all seven goats (three males and four females) between the ages of 2 to 3years old and with average dressed weight of 6.5kg were used. The meat was processed and maintained at approximately 4°C. The hindquarter (approximately 1300g) was deboned and all subcutaneous and intermuscular fat and visible connective tissues were removed. Meat was cut into 1.5cm x 1.5cm cubes and randomly assigned to nine treatments of marinade solutions in a ratio 1:1 (200g meat and 200ml mix).

3.2.1 Treatments

Marinade treatments which consisted of 3 levels of papain and 3 levels of vinegar are shown in Table 2.

Table 2: Treatments of chevon jerky with papain and vinegar at various concentration levels

Treatments	Papain (g)	Vinegar (%)
1	0	0
2	0.004	0
3	0.04	0
4	0	2.5
5	0.004	2.5
6	0.04	2.5
7	0	5
8	0.004	5
9	0.04	5

3.2.2. Marination

Chevon cubes (1.5cm²) were marinated in a closed zip-lock plastic bag (18cm x17cm) for about 12h at 4°C in a refrigerator; deionised water was used as control. The samples were removed from the marinade solution blotted with tissue paper to remove excess fluid. A spice-mix of (7.79% black pepper powder, 16.23% garlic powder, 19.48% onion powder and 56.50% salt) was further sprinkled on the chevon at 1.54g per 200g meat and tumbled to ensure uniform spice distribution.

3.2.3 Drying

The oven (Elegance- Gaz, Tripoli – Lebanon) was preheated to approximately 65°C. Samples were arranged on wire mesh over laid with aluminium foil and dried at 65 °C for 10h. After drying, the chevon jerky samples were held in the oven for thirty minutes to cool. Samples were then placed in vacuum bags (18cm x 20cm), vacuum

packaged and stored at ambient temperature of between 29 to 30 °C. Samples were then randomly assigned to three storage time (1d, 15d and 30d) for shelf life studies. For the determination of drying rate (percent moisture content), the samples were weighed before drying. Samples were taken out from the oven and weighed every one hour during drying. The samples were dried for ten hrs. The loss in weight of the sample was calculated and hence its moisture content was obtained.

$$\text{Drying rate (DR)} = \frac{\text{Initial moisture content} - \text{final moisture content}}{\text{Final time} - \text{initial time}}$$

3.3 Measurement

3.3.1 pH Measurement

The pH of the marinade solutions were measured before marinating the meat samples, using a pH meter (SND04819, Symphony, Singapore). The pH meter was first calibrated with standard buffer solutions of pH 4.0 and 7.0 at 25°C. The pH was measured by immersing the electrode in the marinade solution and recording the pH. Deionised water was used to clean the electrode after each testing and then blotted with tissue paper.

3.3.2 Sensory Evaluation

Sensory evaluation was conducted using six trained panelists (two post graduate students, three service personnel and one staff of the University). Their ages were between twenty two to forty years. The six panelists comprise of three males and three females. Three training sessions were organized. Panelists were also trained with representative samples as anchors for respective sensory attributes and screened based on their response on the attributes of the actual cooked meat

samples for various treatments during previous training session. Sensory evaluation was conducted on samples stored for 1d and 15d. This was due to massive mould growth on some of the samples from treatments containing papain only, after the 15 d of storage during the preliminary work. On the days of evaluation chevon jerky samples were presented in plastic containers marked with 3-digit codes. Panelists cleansed their palates in between sample evaluation using water and apple juice. The tenderness (1 = extremely tough to 8 = extremely tender), juiciness (1= extremely dry to 8= extremely juicy), chewiness (1= extremely creamy to 8 = extremely rubbery), flavour (1 = extremely strong to 8 = extremely bland) and acceptability = (1 extremely dislike to 8 = extremely like) of the samples were evaluated using 8 – point hedonic scale. Independent evaluation of samples was carried out by each panelist.

3.3.3. Rehydration Ratio

Rehydration of chevon samples was done according to the method of Doymaz and Smail (2011), the rehydration rate was carried out on sample with distilled water at ratio of 1:40 for 300min rehydration period under ambient condition. The sample was withdrawn from the distilled water every 30min and excess water was carefully removed by blotting with a tissue paper, before weighing. Weights of dried and rehydrated samples were measured using an electronic digital balance (Model: AAA 250L, AE Adam, United Kingdom). The rehydration ratio (RR) was calculated by the following equation:

$$\text{Rehydration ratio} = \frac{\text{Weight of sample after rehydration}}{\text{Weight of sample before rehydration}}$$

3.3.4 Microbiological Analysis

Chevon jerky samples were aseptically removed from the vacuum packages after the respective days of storage (1d, 15d and 30d). Samples were weighed and further homogenised in sterilised phosphate buffer solution (ratio 1:2). An aliquot of samples extract (0.1ml) was pipetted into Eppendorf tube containing 0.9ml of phosphate buffer solution (first dilution 10_1). A 1:10 serial dilution was prepared from this stock (10^1 - 10^3).

3.3.4.1 Total Plate Count

Total aerobic count was carried out using plate count agar (Oxoid Ltd, England, Oxoid CMO 325). An aliquot (0.1ml) of each sample from previously prepared stock of 10^2 and 10^3 diluents were pipetted onto sterile petri dishes and 15ml of melted and cooled plate count agar was added. Plates were gently swirled to uniformly mix the sample and incubated at 37°C for 48h. Colonies were counted from the plates expressed as colony forming unit (cfu) per gram of sample.

3.3.4.2 Yeast and Mould

Yeast and mould count was determined on potato dextrose agar medium (Titan Biotech Ltd, India, Oxoid CMO 139). An aliquot (0.1ml) of each sample from previously prepared stock of 10^2 and 10^3 diluents were pipetted onto petri dishes and 15ml of melted and cooled potato dextrose agar medium were added. Plates were gently swirled to uniformly mix the sample and incubated for 72 h at 25°C . Colonies were counted from the plates expressed as colony forming unit (cfu) per gram of sample.

3.3.4.3 *E. coli*

E. coli count was carried out using eosin methylene blue agar (EMB) (Central Drug House (P) Ltd, India, DM 1317). An aliquot (0.1ml) of each sample from previously prepared stock of 10^2 and 10^3 diluents were pipetted onto petri dishes and 15ml of melted and cooled EMB agar were added. Plates were gently swirled to uniformly mix the sample and incubated for 48h at 44°C. Colonies were counted from the plates expressed as colony forming unit (cfu) per gram of sample.

3.3.4.4 *Staphylococcus aureus*

Staphylococcus aureus count was determined using mannitol salt agar (MSA) (Merck Baird Parker, Germany, 1.07236). An aliquot of (0.1ml) of each sample from the previously prepared stock of 10^2 and 10^3 diluents were pipetted onto petri dishes and 15ml of melted and cooled MSA were added. Plates were gently swirled to uniformly mix the sample and incubated for 24h at 35°C- 37°C. Colonies were counted from the plates expressed as colony forming unit (cfu) per gram of sample.

3.4 Statistical Analysis

Data for sensory evaluation were analysed using the frequency procedure of SAS 9.0. (Institute, Cary, NC). The chi-square test was used to test for significance of differences at $p < 0.05$. The microbiological data were log transformed and data analysed using mixed procedure of SAS 9.0 with marinade treatment and storage time as fixed effects. Means were separated using Proc mixed procedure. Comparisons of least square means were adjusted using the Bonferroni option. Means were considered significantly different at $p < 0.05$. Additionally, graph of drying and rehydration ratio data were drawn using Microsoft Excel.

CHAPTER FOUR

4.0. Results

4.1 Sensory Evaluation

A trained panel of six was used to evaluate the sensory attributes of the treated jerky using 8 – point hedonic scale. The sensory evaluation data of chevon jerky indicated that vinegar and papain had an effect on tenderness and overall acceptability ($p < 0.05$); however, it had no effect on juiciness, flavour and chewiness. Also there was no effect in all the sensory attributes among the treatments in terms of storage time on the chevon jerky except juiciness. The results of the attributes evaluated are shown in the tables below.

4.1.1 Effect of Treatments on Chevon Jerky Tenderness

The response of panelists to tenderness is as shown in Table 3. The distribution of tenderness scores was significantly different ($p < 0.05$) across treatments. Chevon jerky treated with papain 0.04g (T3) had the highest score of 50%, however, it was ranked similarly with vinegar 2.5% (T4) and papain 0.04g +vinegar 5% (T9) as “very tender to extremely tender”.

Table 3: Frequency (%) of panelist’s response on tenderness scale of chevon jerky

Treatment	Scale			
	Extremely tough to very tough	Moderately tough to slightly tough	Slightly tender to moderately tender	Very tender to extremely tender
T1	13.89	19.44	33.33	33.33
T2	30.56	25.00	30.56	13.89
T3	0.00	22.22	27.78	50.00
T4	27.77	19.44	25.00	27.78
T5	36.11	22.22	16.66	25.00
T6	8.34	19.45	38.89	33.33
T7	19.44	41.66	25.00	13.89
T8	47.22	11.11	27.70	13.89
T9	16.67	25.00	25.00	33.33

Chi-Square (χ^2)=81.55, df= 56

T1= Control, T2=Papain 0.004g, T3= Papain 0.04g, T4= Vinegar 2.5%, T5= Papain 0.004g +vinegar 2.5%,T6= Papain 0.04g +vinegar 2.5%, T7= Vinegar 5%, T8=Papain 0.004g +vinegar 5%, T9=Papain 0.04g +vinegar 5%.

Samples from control (T1) were ranked similarly as papain 0.04g (T3), vinegar 2.5% (T4),papain 0.04g +vinegar 5% (T9) however, it was ranked between “slightly tender to moderately tender” and “very tender to extremely tender”. Samples from papain 0.004g +vinegar 2.5% (T5) and papain 0.004g +vinegar 5% (T8) were the least ranked and were ranked similarly as “extremely tough to very tough”. Based on the observed chi square (χ^2) value of 81.55, the null hypothesis is rejected at $p > 0.05$ and it was concluded that different marinades had different effects on the tenderness of the chevon jerky.

4.1.1.2 Effect of Storage Period on Chevron Jerky Tenderness

The response of panelists to the effect of storage period on chevon jerky tenderness is presented in Table 4.

Table 4: Frequency (%) of panelist’s response on the effect of storage period on tenderness of chevon jerky

Storage Period (Day)	Scale			
	Extremely tough to very tough	Moderately tough to slightly tough	Slightly tender to moderately tender	Very tender to extremely tender
1	24.07	20.37	28.4	27.16
15	20.37	25.31	27.16	27.16

Chi square (χ^2)=3.02, df = 7

Tenderness scores for the various treatments were not significantly different ($p > 0.05$) by the duration of storage. Samples analysed at 1d was ranked as “slightly tender to moderately tender” whereas 15d was ranked between “slightly tender to moderately tender”.

4.1.2 Effect of Treatments on Chevron Jerky Chewiness

The response of panelists to chewiness is as shown in Table 5.

Table 5: Frequency (%) of panelist's response on chewiness scale of chevon jerky

Treatment	Scale			
	Extremely creamy to very creamy	Moderately creamy to slightly creamy	Slightly rubbery to moderately rubbery	Very rubbery to extremely rubbery
T1	11.11	27.77	44.45	16.67
T2	11.11	22.22	47.23	19.44
T3	11.11	30.55	41.67	16.67
T4	8.34	13.89	50.00	27.78
T5	19.44	27.78	30.56	22.23
T6	11.11	13.89	44.44	30.55
T7	5.56	22.22	50.00	22.22
T8	13.89	13.89	36.11	36.11
T9	8.33	25.00	50.00	16.67

Chi-Square (χ^2) =66.62, df= 56

T1= Control, T2=Papain 0.004g, T3= Papain 0.04g, T4= Vinegar 2.5%,
T5=Papain 0.004g +vinegar 2.5%, T6= Papain 0.04g +vinegar 2.5%,
T7=Vinegar 5%, T8=Papain 0.004g +vinegar 5%,
T9=Papain 0.04g +vinegar 5%.

In connection with chewiness, the scores were the same ($p > 0.05$) across treatments.

The control and the test treatments were all ranked by panelists as “slightly rubbery to moderately rubbery” with the exception of papain 0.004g +vinegar 2.5% (T5) which was ranked between “slightly rubbery to moderately rubbery” and “very rubbery to extremely rubbery”.

4.1.2.1 Effect of Storage Period on Chevon Jerky Chewiness

Table 6 shows no effect of storage period on chevon jerky chewiness.

Table 6: Frequency (%) of panelist’s response on the effect of storage period on chewiness of chevon jerky

Storage Period (Day)	Scale			
	Extremely creamy to very creamy	Moderately creamy to slightly creamy	Slightly rubbery to moderately rubbery	Very rubbery to extremely rubbery
1	11.11	20.99	38.27	29.63
15	11.11	22.84	49.38	16.67

Chi square (χ^2)=13.08, df= 7

The distribution of chewiness scores was the same across storage period. Samples evaluated at 1d and 15d were similarly ranked as “slightly rubbery to moderately rubbery”.

4.1.3 Effect of Treatments on Chevron Jerky Juiciness

The response of panelists to juiciness is as shown in Table 7. The distribution of juiciness scores was not significantly different ($p > 0.05$) across treatments.

Table 7: Frequency (%) of panelist’s response on juiciness scale of chevon jerky

Treatment	Scale			
	Extremely dry to very dry	Moderately dry to slightly dry	Slightly juicy to moderately juicy	Very juicy to extremely juicy
T1	25.00	8.34	44.44	22.22
T2	27.78	36.11	22.22	13.89
T3	13.89	27.78	44.44	13.89
T4	19.45	27.78	27.77	25.00
T5	19.45	16.67	36.11	27.78
T6	30.55	16.67	36.11	16.67
T7	25.00	19.44	27.77	27.78
T8	33.33	19.45	36.11	11.11
T9	22.23	19.45	36.11	22.22

Chi-Square (χ^2)=71.44, df = 56

T1= Control, T2=Papain 0.004g, T3= Papain 0.04g, T4= Vinegar 2.5%, T5= Papain 0.004g +vinegar 2.5%, T6= Papain 0.04g +vinegar 2.5%, T7=Vinegar 5%, T8=Papain 0.004g +vinegar 5%, T9=Papain 0.04g +vinegar 5%.

Samples from papain 0.04g (T3) and the control (T1) obtained the highest percent score and were similarly ranked as “slightly juicy to moderately juicy”. All the other treatments with the exception of papain 0.004g (T2), vinegar 5% (T7) and vinegar 2.5% (T4) were also similarly ranked as “slightly juicy to moderately juicy” as the

above however, they obtained a lower percentage. Samples from papain 0.004g (T2) and vinegar 2.5% (T4) were the least ranked as “moderately dry to slightly dry”.

4.1.3.1 Effect of Storage Period on Chevon Jerky Juiciness

The response of panalists to the effect of storage period on chevon jerky juiciness is presented in Table 8.

Table 8: Frequency (%) of panelist’s response on the effect of storage period on juiciness of chevon jerky

Storage Period (Day)	Scale			
	Extremely dry to very dry	Moderately dry to slightly dry	Slightly juicy to moderately juicy	Very juicy to extremely juicy
1	24.69	24.08	35.19	16.05
15	23.46	18.52	33.95	24.08

Chi square (χ^2) =15.44, df= 7

Juiciness scores for the various treatments were significantly different ($p < 0.05$) by the duration of storage. Samples evaluated at 1d were ranked as “extremely dry to very dry” (24.69%) but were ranked as “very juicy to extremely juicy” (24.08%) at 15d.

4.1.4 Effect of Treatments on Chevron Jerky Flavour

Table 9 shows the response of panalists to chevon jerky flavour.

Table 9: Frequency (%) of panelist’s response on flavour scale of chevon jerky

Treatment	Scale			
	Extremely bland to very bland	Moderately bland to slightly bland	Slightly strong to moderately strong	Very strong to extremely strong
T1	13.89	19.44	44.44	22.33
T2	5.56	22.22	63.89	8.34
T3	16.67	41.67	33.33	8.33
T4	2.78	13.89	55.56	27.78
T5	11.11	11.12	55.56	22.22
T6	8.33	22.22	44.45	25.00
T7	8.33	16.67	30.55	44.44
T8	11.11	30.55	38.89	19.45
T9	5.56	27.77	41.67	25.00

Chi-Square(χ^2) =60.54, df= 56

T1= Control, T2=Papain 0.004g, T3= Papain 0.04g, T4= Vinegar 2.5%, T5= Papain 0.004g +vinegar 2.5%, T6= Papain 0.04g +vinegar 2.5%, T7=Vinegar 5%, T8=Papain 0.004g +vinegar 5%, T9=Papain 0.04g +vinegar 5%.

The distribution of flavour scores was the same ($p > 0.05$) across treatments. The results for flavour analyses indicated that with the exception of papain 0.04g (T3) and vinegar 5% (T7), all the other treatments were similarly ranked by panelists as “slightly strong to moderately strong”. Papain 0.04g (T3) and vinegar 5% (T7) were ranked as “moderately bland to slightly bland” and “very strong to extremely strong” respectively.

4.1.4.1 Effect of Storage Period on Chevon Jerky Flavour

Table 10 shows the response of panelists to the effect of storage period on chevon jerky flavour.

Table 10: Frequency (%) of panelist’s response on the effect of storage period on flavour of chevon jerky

Storage Period (Day)	Scale			
	Extremely bland to very bland	Moderately bland to slightly bland	Slightly strong to moderately strong	Very strong to extremely strong
0	8.02	21.6	44.44	25.93
2	10.49	24.07	46.29	19.14

Chi square (χ^2) = 7.29, df= 7

The flavour scores for the various treatments were not significantly different ($p > 0.05$) by the duration of storage. Samples evaluated at 1d and 15d were similarly ranked as “slightly strong to moderately strong” (Table 10).

4.1.5 Effect of Treatment on Chevon Jerky Acceptability

The response of panelists to chevon jerky acceptability is as shown in Table 11.

Table 11: Frequency (%) of panelist’s response on acceptability scale of chevon jerky

Treatment	Scale			
	Extremely dislike to very dislike	Moderately dislike to slightly dislike	Slightly like to moderately like	Very like to extremely like
T1	5.56	19.45	22.22	52.78
T2	2.78	5.56	50.00	41.67
T3	13.89	13.89	52.78	19.45
T4	11.11	30.56	41.67	16.67
T5	8.34	19.44	38.88	33.33
T6	16.67	13.89	55.56	13.89
T7	11.11	33.33	47.22	8.33
T8	5.56	16.67	38.89	38.89
T9	16.67	8.34	58.33	16.67

Chi-Square (χ^2) =84.14, df= 56

T1= Control, T2=Papain 0.004g, T3= Papain 0.04g, T4= Vinegar 2.5%,
T5= Papain 0.004g +vinegar 2.5%,T6= Papain 0.04g +vinegar 2.5%,
T7=Vinegar 5%, T8=Papain 0.004g +vinegar 5%, T9=Papain 0.04g +vinegar 5%.

The distribution of acceptability scores was significantly different ($p < 0.05$) across treatments. Panelists scored all the treatments as “slightly like to moderately like” with the exception of papain 0.004g + vinegar 5% (T8),which was ranked between “slightly like to moderately like” and “very like to extremely like” as well as control (T1) which was also scored as “very like to extremely like”.

4.1.5.1 Effect of Storage Period on Chevron Jerky Acceptability

Table 12 shows the response of panelists to the effect of storage period on chevon jerky acceptability.

Table 12: Frequency (%) of panelist’s response on the effect of storage period on acceptability of chevon jerky

Storage Period (Day)	Scale			
	Extremely dislike to very dislike	Moderately dislike to slightly dislike	Slightly like to moderately like	Very like to extremely like
1	10.49	19.76	43.21	26.54
15	9.88	16.05	46.92	27.16

Chi-Square(χ^2) =5.49, df= 7

The distribution of acceptability scores was the same ($p > 0.05$) across storage period. Samples evaluated in 1d and 15d were similarly rated as “slightly like to moderately like”.

4.2 Microbiological Evaluation

Microbial flora analyses were carried out at 1d, 15d and 30d of storage, vacuum packaged chevon jerky samples from each treatment were aseptically removed and analysed. Total plate count, *Staphylococcus aureus*, *E. coli*, yeast and mould were evaluated. Results from the various microbiological analysis of the vacuum packaged chevon jerky stored within 30d period are presented in Table 13 and 14.

Table 13: Effect of treatments on microbial count (log CFU/g meat sample) of vacuum packaged chevon jerky stored for 30d

Treatment	TPC	SEM	<i>E.coli</i>	SEM	<i>S. aureus</i>	SEM	Yeast and mould	SEM
1	1.00	0.43	0.31	0.28	0.74	0.46	0.59	0.43
2	1.18	0.43	0.00	0.28	0.95	0.46	0.68	0.43
3	1.27	0.43	0.31	0.28	0.74	0.46	1.12	0.43
4	1.22	0.43	0.92	0.28	1.06	0.46	0.87	0.43
5	1.46	0.43	0.64	0.28	1.04	0.46	0.90	0.43
6	1.60	0.43	0.00	0.28	1.14	0.46	0.98	0.43
7	0.87	0.43	0.00	0.28	0.71	0.46	0.96	0.43
8	1.59	0.43	0.72	0.28	0.99	0.46	0.59	0.43
9	1.76	0.43	0.00	0.28	0.38	0.46	0.56	0.43

No significant difference was found among treatments ($p > 0.05$)

Treatments: T1= Control, T2=Papain 0.004g, T3= Papain 0.04g, T4= Vinegar 2.5%, T5=Papain 0.004g +vinegar 2.5% T6= Papain 0.04g +vinegar 2.5%, T7=Vinegar 5%, T8=Papain 0.004g +vinegar 5%, T9=Papain 0.04g +vinegar 5%., TPC= Total plate count, SEM= standard error mean

Table 14: Effect of storage time on microbial count (log CFU/g meat sample) of vacuum packaged chevon jerky stored for 30d

Storage Period (Day)	TPC	SEM	<i>E.coli</i>	SEM	<i>S. aureus</i>	SEM	Yeast and mould	SEM
1	0.46 ^a	0.25	0.68 ^a	0.16	1.96 ^a	0.26	0.95 ^a	0.25
15	1.59 ^b	0.25	0.19 ^c	0.16	0.62 ^b	0.26	1.17 ^a	0.25
30	1.93 ^c	0.25	0.09 ^b	0.16	0.00 ^c	0.26	0.30 ^a	0.25

Figures with different superscript in a column are significantly different $p < 0.05$

SEM= standard error mean, TPC= Total plate count

4.2.1 Effect of Treatment on Total Plate Count

The results for total plate counts for vacuum packaged chevon jerky stored for 30d are provided in Table 13 and 14. There was no significant difference ($p > 0.05$) in total plate count among treatments (table 13). Thus, treatments had no effect on total plate count. The highest total plate count was observed in samples from papain 0.004g +vinegar 5% (T8) whereas the lowest count was observed in vinegar 5% (T7). Samples from control (T1) recorded the second lowest in total plate count.

4.2.1.1 Effect of Storage Period on Total Plate Count

The result for the effect of storage period on total count is as shown in table 14. Significant differences ($p < 0.05$) in total plate count during storage were observed. As storage period increased from 15d to 30d total plate count increased from 1.59 to 1.93 log cfu/g.

4.2.2 Effect of Treatment on *E.coli*

The results for *E.coli* counts for vacuum packaged chevon jerky stored for 30d are shown in Table 13. There was no significant difference ($p > 0.05$) in *E.coli* count among treatments. Thus, treatments had no effect on *E.coli*. Samples from vinegar 2.5% (T4) recorded the highest *E.coli* counts whereas papain 0.04g (T3) recorded the same microbial count as that of the control (T1), however, samples from papain 0.004g (T2), papain 0.04g +vinegar 2.5% (T6), vinegar 5% (T7), and papain 0.04g +vinegar 5% (T9) all recorded 0.00log cfu/g in *E.coli*.

4.2.2.1 Effect of Storage Period on *E.coli*

The results indicated a significant difference in storage time ($p < 0.05$) as shown in table 14. As storage period progressed from 15d to 30d there was a declined in *E.coli* count from 0.19 to 0.09log cfu/g. However, no significant difference was observed at 15d and 30d.

4.2.3 Effect of Treatment on *Staphylococcus aureus*

S. aureus counts for vacuum packaged chevon jerky stored for 30d are presented in table 13. There was no significant difference in *S. aureus* counts among treatments ($p > 0.05$). The highest *S. aureus* count was observed in papain 0.04g +vinegar 2.5% (T6) whereas the lowest *S. aureus* count was recorded in samples from papain 0.04g +vinegar 5% (T9). Samples from control (T1) and papain 0.04g (T3) recorded similar *S. aureus* count.

4.2.3.1 Effect of Storage Period on *Staphylococcus aureus*

The results for *S. aureus* counts indicated a significant difference ($p < 0.05$) in storage period (table 14). As storage period increased from 1d to 30d, there was a decreased in *S. aureus* count, *S. aureus* count decreased from 1.96 to 0.00log cfu/g.

4.2.4 Effect of Treatment on Yeast and mould

Results for yeast and mould counts for vacuum packaged chevon jerky stored for 30days are presented in table 13. As presented in table 13 no significant difference ($p > 0.05$) was observed in yeast and mould counts among treatments. The highest yeast and mould count was recorded in papain 0.04g (T3) whereas the lowest was observed in papain 0.04g +vinegar 5% (T9). Control (T1) and papain 0.004g +vinegar 5% (T8) recorded a similar yeast and mould count.

4.2.4.1 Effect of Storage Period on Yeast and mould

There was a significant difference in storage time in yeast and mould counts ($p < 0.05$) as shown in table 14. As storage period progressed from 15d to 30d, there was a declined in yeast and mould count from 1.17 to 0.30log cfu/g.

4.3 Moisture content (%)

Figure 1 shows the effect of papain and vinegar on chevon jerky moisture content (%) during drying. The samples were dried at approximately 65°C for 10h.

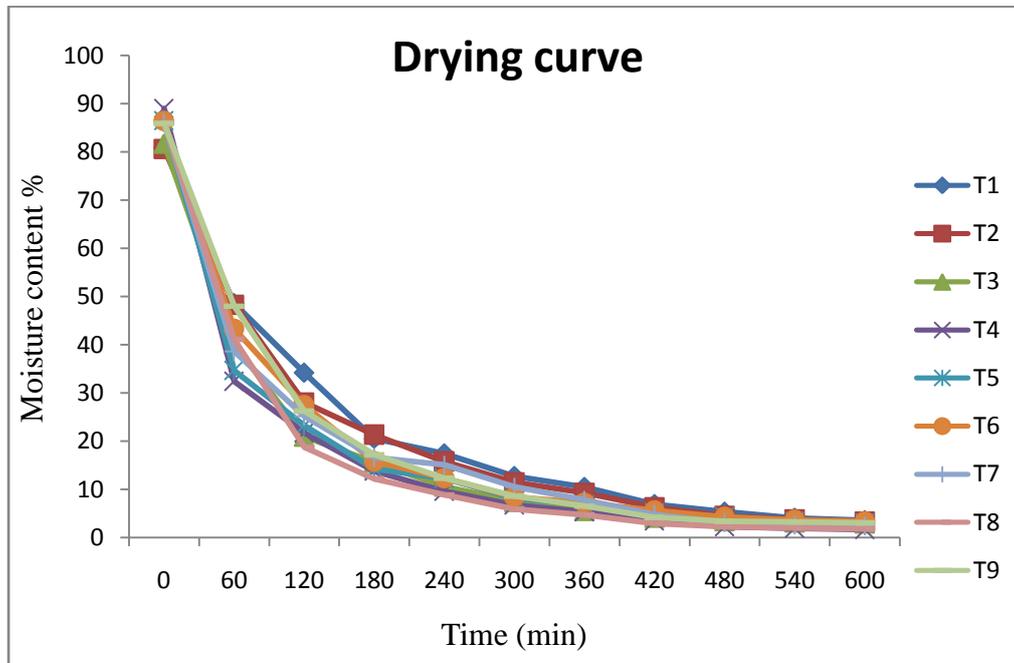


Figure 1: The effect of papain and vinegar on moisture content of chevon jerky during drying

Treatments: T1= Control, T2=Papain 0.002%, T3= Papain 0.04g, T4= Vinegar 2.5%, T5= Papain 0.004g +vinegar 2.5%, T6= Papain 0.04g +vinegar 2.5%, T7= Vinegar 5%, T8=Papain 0.004g +vinegar 5%, T9=Papain 0.04g +vinegar 5%.

As drying time progressed from time 0 to 60min there was rapid decreased in moisture content among all treatments. Moisture content decreased continuously at a decreasing rate with increased in drying time from 60min to 360min, however at 420min to 600min there was no difference in moisture content reduction among treatments. At the end of the drying period all the test samples recorded lower moisture content than that of the control (T1). Samples from vinegar 2.5% recorded

the least (1.71%) moisture content whereas the highest (3.61%) was observed in control (T1) samples.

4.4 Rehydration Characteristics

Sample from each treatment was soaked in water and their weights recorded after every 30min for 300min. Results of the effect of the respective treatments on rehydration rate of the chevon jerky are presented in Figure 2.

Figure 2 shows the rehydration curve of the various treatments. All the treatments increased in percent moisture content as rehydration time increased from 0 -300min.

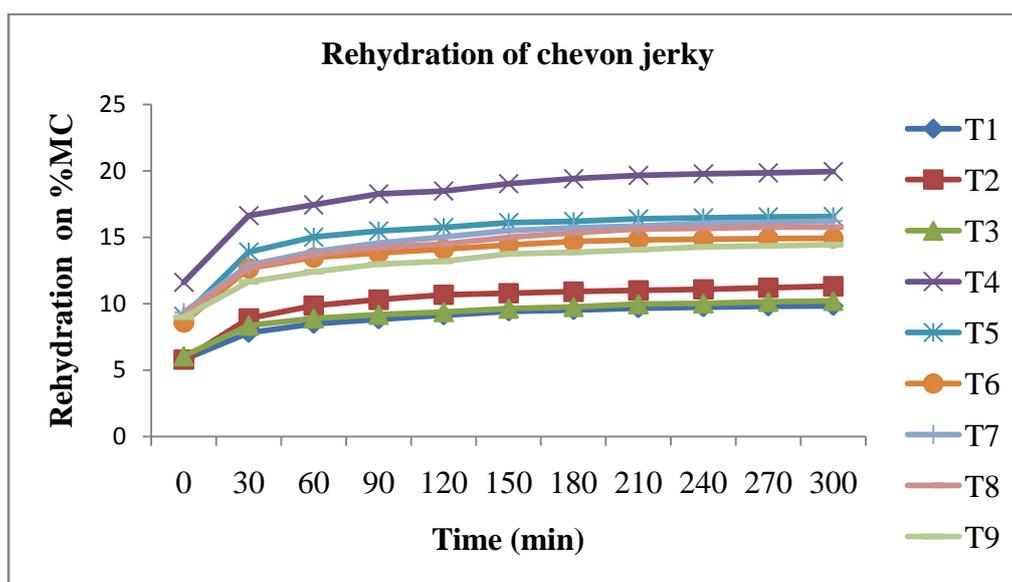


Figure 2: Effect of treatments on rehydration on percent moisture content (%MC) of chevon jerky

Treatments: T1= Control, T2=Papain 0.004g, T3= Papain 0.04g, T4= Vinegar 2.5%, T5= Papain 0.004g +vinegar 2.5%, T6= Papain 0.04g +vinegar 2.5%, T7= Vinegar 5%, T8=Papain 0.004g +vinegar 5%, T9=Papain 0.04g +vinegar 5%, % MC = Percent moisture content.

As rehydration time progressed from time 0 to 300min there was an increase in weight among all treatment samples. Samples from papain 0.004g (T2) and papain 0.04g (T3) were the same with samples from control (T1). Similarly, all treatment combination samples from papain 0.004g + vinegar 2.5% (T5), papain 0.04g +vinegar 2.5% (T6), papain 0.004g +vinegar 5% (T8) and papain 0.04g +vinegar 5% (T9) were the same from the beginning of rehydration to the end. Samples from control (T1)

recorded the least %MC of 9.83 whereas samples from vinegar 2.5% (T4) recorded the highest %MC (19.94) after rehydration.

CHAPTER FIVE

5.0 Discussion

5.1 Sensory Evaluations

Dried meat products, in general are associated with toughness due to the low moisture content. Marinades are sauces that are designed to flavour and tenderise meat and marination is commonly used to improve functional and sensory properties of meat (Latif, 2011). Results from table 3 shows that papain at higher concentration 0.04g (T3) made the meat more tender as compared to lower concentration 0.004g (T2). Several authors have reported of papain's ability to breakdown connective tissue and myofibrillar proteins and sometimes resulting in deterioration of sensory attributes of meat (Dransfield and Etherington, 1981; Miller *et al.*, 1989; Iizuka and Ashima, 1999). Doneva (2015) reported that higher concentration of papain resulted in a complete hydrolysis of meat proteins, deteriorating the appearance and taste of the meat. Also Ashie *et al.* (2002) found a decrease in toughness of beef briskets and top rounds injected with papain whereas an increased in the dosage resulted in deterioration of sensory qualities. However, in this study the concentration of papain used did not cause any deterioration of sensory characteristics. Lower concentration of vinegar 2.5% (T4) also had effect on meat tenderness and made the meat more tender compared to higher concentration of vinegar 5% (T7), according to Stanston and light (1989) and Berge *et al.* (2001) acidic treatment of meat speedup the activation of cathepsin and improved collagen breakdown to gelatin at low pH during thermal treatment, however, it could be that 5% vinegar (T5) extensively denatured proteins which diminished protein quality properties and reduced water holding capacity. Pearson and Young (1989) has stated that water lost due to unreparable loss of protein quality properties includes free, immobilised, and bound water, leading to

lost of tenderness. On the contrary, Wijayawardana *et al.* (2001) reported that an increase in marinating time decreased shear force value of meat treated with vinegar. However, the type of muscle (*Longissimum dorsi* muscle) used could have contributed to the reduction in shear force value. In contrast to this study Hinkle (2010) found no significant change ($p > 0.05$) in tenderness of beef bottom round treated with acetic acid, lactic acid and sodium citrate dehydrate at low concentration but significant difference was observed at high concentration. The result from this study was different because Hinkle (2010) injected the acids into the meat and cured the meat for 2 wk whereas in the case of this study the meat were immersed in the marinade and marinated for 12h.

With regard to chewiness, dried meat is associated with toughness and jerky is no exception due to its exceptional low moisture content to inhibit microbial growth. The lack of effect of treatments on chewiness of the chevon jerky could be due to loss of moisture during drying, in agreement with this study Pietrasik and Shand (2008) compared moist and dry cooking and found reduced shear force value in moist cooking than dry cooked method with *Aspergillus oryzae* injected roasts.

On the other hand, the lack of effect of treatments on juiciness of the chevon jerky was unexpected since significant difference were observed in the tenderness of the samples and juiciness is directly correlated to the tenderness of meat. The inability of the treatments to have effect on juiciness may be due to low water holding capacity and loss of moisture during drying. This result is in agreement with Gerelt *et al.* (2000) who observed lower values in juiciness of meat treated with papain for a longer duration of time. Ashie *et al.* (2002) also reported of papain activity during

refrigerator storage. Subsequent to the drying of the meat, papain treated samples were softer, slimy and slippery to touch compared to the other treatments, this indicates that papain caused excessive degradation of myofibrillar protein structure at the time of marinating as well as during cooking resulting in excessive loss of moisture. Also most of the marinades had lower pH values which can negatively affect the juiciness of the meat; Goli *et al.* (2007) reported that pH value of meat products is greatly essential because it has a major impact on water holding capacity (WHC), tenderness and juiciness. As the pH of meat diminishes nearer to the isoelectric point (pH 5.2), it follows with a reduction in the capacity of the microstructure to immobilise and bind moisture (Hamm, 1975). The low pH of the marinades probably caused excessive denaturing of the myofibrillar proteins and resulted in loss of meat juice before and during cooking.

The sensory results indicated that the treatments did not have any effect on chevon jerky flavour; this is probably due to the marinade concentration of the test treatments which were satisfactory. The result partly agrees with Djeri (2007) who found no significant differences ($P > 0.05$) in flavour of treated chevon ribs with apple cider vinegar at 1d; however as storage days progress there was a significant difference in flavour among treatments. This may suggest that the effects of treatments on chevon jerky flavour could have been more pronounced if the storage time increased beyond the 15d. The rating of samples from control (T1) as “slightly strong to moderately strong” with the other treatments containing vinegar may be due to a halo effect or a carryover effect from tasting the other treatments which contains vinegar.

According to Ashie *et al.* (2002) and Doneva *et al.* (2015) higher concentration of papain resulted in deterioration of organoleptic qualities of meat and produce undesirable flavours. Papain is also associated with a bitter or pungent odour, however, in this study it was rated as moderately bland to slightly bland which may be due to the fact that the papain did not cause excessive hydrolysis of the meat proteins to result in a mushy texture associated with those undesirable flavours at the concentration tested.

The treatments had an effect on overall acceptability of the chevon jerky and since the major essential sensory qualities of jerky are texture, colour and flavour, which are depended on the raw ingredients and several technological factors (Albright *et al.*, 2000), it can be suggested that tenderness contributed to the acceptability of the chevon jerky, since only papain 0.004g +vinegar 5% (T8) and papain 0.004g +vinegar 2.5% (T5) out of the nine treatments were scored as extremely tough to very tough. Lack of effect of treatments on flavour of the chevon jerky may have also accounted for the acceptability of the chevon jerky; however, Maughan *et al.*, (2012) has shown that sourness is negatively connected to liking. In this study the presence of the acidic taste associated with vinegar did not cause dislike to any of the treatments. Overall samples from control (T1) had the highest acceptability score and was ranked as “very like to extremely like” which may be due to its high rating in tenderness.

5.2 Microbiological Evaluation

The processing of jerky varies from the processing of other snack products because thermal treatment is used to achieve the desired sensory quality and stored safely at ambient temperature. Jerky is dried to a low water activity in order to prevent microbial development and prolong shelf life. However, outbreak of food borne diseases has been connected to the consumption of jerky (CDC, 1995; Eidson *et al.*, 2000). The degree and duration of the survival of pathogens on jerky during storage may differ based on the type of bacteria and the varied antimicrobial hurdles that is employed (Torres *et al.*, 1994; Quintion *et al.*, 1997; Shimokomaki *et al.*, 1998). To attain stability, jerky must have moisture protein ratio (MPR) 0.75:1.0 and water activity (a_w) <0.8 (USDA - FSIS, 2004). The water activity is defined as the free water accessible to microorganisms for their development. Hence, water activity is essentially for accessing the degree of microbial development in meat products and the effect on products characteristics during storage (Choi *et al.*, 2007). Microbial contamination of meat can be categorized as aerobic or anaerobic, based on the environments in which it thrives and the type of microbes involved. The quantity of microorganisms contained in a product will dictate the rate of product quality spoilage or effect of disease cause to humans (Fleet, 1999).

In this study the treatment did not have effect on any of the targeted microbes. However, extending storage period led to a reduction in the total number of microbes present at the end of the shelf life studies. This may be ascribed to the inhibition of aerobic microbial development by the vacuum packaged material, since vacuum packaging objective is to protect meat products from contact with oxygen from the air which aids the growth of aerobic microorganisms (Jeremiah, 2001). Microorganisms

such as *Staphylococcus aureus* (Surimi and Surimi, 2013), *E.coli* (Singleton, 1999) and yeast (Carlile *et al.*, 2001) are facultative anaerobes. Drying is known to decrease the water content of meat product which most importantly lowers the water activity to a degree where microorganism are no longer able to obtain adequate amount of water for their growth (Santchurn *et al.*, 2012).

The microbial count recorded for the entire microbiological analysis (total plate count, *E. coli*, *S. aureus*, yeast and mould) at the various sampling time 1d, 15d and after the 30d of the shelf life studies was in a range of 0.00-1.96log cfu/g. The low microbial levels seem to be due to the fact that microbial growth was inhibited at low water activity. Faith *et al.* (1998) reported that viability of bacteria in jerky was decreased as the drying temperature and time were extended. Also, Jung *et al.* (1994) observed moisture content and water activity of jerky decreased during storage. Moisture content and water activity are closely related (Leistner, 1987). Choi *et al.* (2008) also observed a reduction in water activity of hot air-drying jerky in plastic pack as the storage period prolonged. In this study the length of drying time which was 10h, may have contributed to the reduction in microbial numbers in all the treatments through reduction of moisture content in meat. In the case of total plate count there was an increase with increased storage period, however, the total plate count remained well below the spoilage limit of 7.0log cfu/g (Egan *et al.*, 1980). *S. aureus* and *E. coli*, counts were high at the initial sampling 1d, however they were reduced at 15d and 30d as storage period progressed which may be due to unfavourable hurdles conditions such as low moisture and water activity. The prevention of *S. aureus* grow that water activity of 0.91 in anaerobic conditions has already been reported by Leistner *et al.* (1981). This indicates the synergistic effect of low water activity and

vacuum packaging on the development of *S. aureus* in this study. *S. aureus* counts required to produce detrimental effects has been reported to be $7 \log_{10} \text{cfu/g}$ (Troller, 1976). However, *S. aureus* in this experiment was zero at the end of the shelf life of studies 30d. Yeast and mould count was low at the initial sampling 1day; however, it increased in count at 15d. Yeast and mould have the capacity to thrive in acidic medium and at low water activity (Corry, 1978; Jay, 1987); this might have allowed them to grow to some degree at 15d however, unfavourable hurdles conditions may have led to a reduction in yeast and mould count at 30d. Ingham *et al.* (2006) reported that although toxin-producing moulds can develop on some intermediate meat products, however, commercial jerky producers use vacuum bags to arrest their development. Moulds are aerobic microorganisms that require oxygen for their growth, whereas in vacuum packaged bacteria that can thrive and cause deterioration to product quality are facultative anaerobic and anaerobic (Ray and Bhunia, 2013). Also Leistner (1987) reported that deterioration of several ready to eat meat products by mould could be prevented when the product pH is decreased, however, in this study vinegar which was part of the treatments with a low pH of approximately 3, did not have effect on yeast and mould count of the chevon jerky. Gourama and Bullerman (1995) has also reported that lactic acid and acetic acid with pH 3.35 and 3.81 respectively, displayed little efficacy in controlling fungi growth.

5.3 Moisture Content (%) (Drying curve)

A major property that defines the good characteristics of meat is its capacity to maintain water found in the meat and water included. Moisture in meat is essential for palatability but is also a medium for microbial growth. Drying meats into jerky will typically eliminate any concerns with moisture. One of the major essential characteristic of dry meat products is moisture content (Yang *et al.*, 2009). Whole muscle jerky is said to be either too dehydrated or tough (Miller *et al.*, 1996) and some minced or restructured jerky products are tender, however, they contain great amount of fat as well as water activity, leading to the promotion of rancidity and microorganism growth (Quinton *et al.*, 1997). USDA - FSIS (2004) suggest that jerky must have a moisture-to-protein ratio of less than or equal to 0.75:1 and a water activity (aw) less or equal to 0.85. Lowering water activity by decreasing moisture content will generate tougher meat products, but the inclusion of papain and vinegar will help in controlling the water activity as well as texture.

Figure 1 shows the influence of papain and vinegar on the moisture content of chevon jerky during drying. The figure shows that there is a correlation between moisture content and drying time. Moisture content decreases continuously with increase in drying time for all treatments. The rate of moisture content reduction was rapid from time 0 to 60min among all treatments probably due to evaporation of surface water. As drying time progressed from 60min to 360min the rate of moisture content decreased was low. As drying time progressed from 0 to 600min, samples from higher concentration of papain 0.04g (T3) recorded a higher decreased in moisture content from 81.72 to 2.93% compared to lower concentration of papain 0.004g (T2) (80.64 to 3.33%). Rawdkuen *et al.* (2011) found that higher dosage of enzyme caused a

reduction in meat moisture content. Similarly, Ionescu *et al.* (2008) reported that higher concentration of papain resulted in higher cooking loss during thermal treatment. Istrati (2008) also found that higher break down of myofibrillar proteins by papain caused a decrease in the capacity of the meat to hold water. In this study the proteolytic enzymes probably may have caused the low moisture content recorded in high concentration of papain 0.04g (T3) possibly due to the degradation of the myofibrillar and collagen protein which created more avenues for moisture to escape during the drying process. Samples from lower concentration of vinegar 2.5% (T4) recorded a higher initial moisture content of 89.02% compared with that of higher concentration of vinegar 5% (T7) 86.06%. Moisture content decreased continuously between the above treatments with increased in drying period from 0 to 600min. However, moisture content reduction was high in samples from vinegar 2.5% (T4) compared to vinegar 5% (T7). At the end of the drying period samples from lower concentration of vinegar 2.5% (T4) recorded a lower moisture content of 1.71% compared with higher concentration of vinegar 5% (T7) (2.45%). Meat pH value is very essential because it has influence on water holding capacity (Goli *et al.*, 2007). Also Hammand Deatherage (1960) reported that raw meat water-holding capacity rises quickly as pH reduces below muscle electrically neutral point of 5.1, which increases correlatively to the number of positive charged protein groups. In addition, at a higher pH value of 6.0 or less than 4 the quantity of these reactive groups accessible to bind water is greatly increased (Gault, 1985). Additionally, Rao and Gault (1989) stated that lowering the pH of meat below its electrically neutral point favoured the expansion and moisture absorption by stromal proteins; collagen, elastin and reticulin whereas lowering the meat pH further to pH 4.0 and below, will result in the expansion and absorption of added water by the myofibrillar proteins. This

probably contributed to the high moisture content observed in vinegar 5% (T7), since it was able to retained more moisture during cooking compared with vinegar 2.5% (T4). Samples from treatment combination papain 0.004g+ vinegar 5% (T8) also recorded higher initial moisture content of 86.10%. There was a rapid decreased in moisture content from 0 to 60min. There was continuous decreased in moisture content as drying time progressed from 420 to 600min. At the end of the drying period the above sample recorded the second lowest moisture content of 1.83%. This shows the synergistic effect between lower concentration of papain 0.004g and higher concentration of vinegar 5% in moisture content reduction.

5.4 Rehydration Rate

According to An *et al.* (2012) the purpose of rehydration processes is to reinstate the standard properties of a fresh material when the dehydrated material is submerged in an aqueous solution. Lewicki (1998) reported that rehydration properties of dehydrated food substance are employed as a standard to check whether physicochemical alterations happened during the dehydrated process due to processing methods, pre- treatments and product constituents.

Figure 2 shows the effect of treatments on percent moisture content rehydration of chevon jerky. As rehydration time increased from 0 to 300min there was an increased in percent moisture content among all the treatments, however, percent moisture content increased at a gradual pace as rehydration time progressed. Rate of rehydration was high at the early stage (from 0 to 30min), among all the treatments, probably due to surface and capillary suction. Deng *et al.* (2014) also obtained the same result as above. Jayaraman *et al.* (1990) observed unreparable biological cell fracture and separation, which resulted in reduction in firmness and subsequently, a heavy frame break down, massive shrunk capillaries with low affinity for water, as seen by the incapability for sufficient amount of water to permeate and completely rehydrate. In this study, the low % MC rehydration and the similarity between samples from papain 0.004g (T2), papain 0.04g (T3) and control (T1) was probably due to excessively shrunken cellular structure due to loss of moisture during drying which led to low rate of rehydration. Samples from lower concentration of vinegar 2.5% (T4) recorded higher %MC rehydration probably due to less degradation of muscle protein and little or no shrunken cellular structure during drying which led to higher water uptake during rehydration. Shiby *et al.* (2015) observed an increased in

rehydration ratio in freeze dry product than both hot air dry and solar dry products. However, in this study all the test treatments received the same drying method. The high %MC and the similarity between samples from papain 0.004g + vinegar 2.5% (T5), papain 0.04g +vinegar 5% (T9), papain 0.04g +vinegar 2.5% (T6), vinegar 5% (T7) and papain 0.004g+vinegar 5% (T8) may be due to the presence of vinegar. Since all treatments containing vinegar only recorded a higher %MC rehydration than that of control samples and papain only treatments. The above treatments probably had little or no shrinkage and a higher porous structure leading to a higher rehydration of samples. On the other hand, samples from papain 0.004g + vinegar 2.5% (T5) recorded a higher %MC compared with papain 0.04g +vinegar 5% (T9) and both treatments differed in %MC rehydration.

Rehydration was halted at 300min due to loss of meat firmness, as some parts of the meat samples started to wear off (leached) during rehydration, especially samples from papain 0.004g (T2) and papain 0.04g (T3). All the treatments were not able to fully rehydrate to the moisture content of the fresh weight. Okos *et al.* (2007) reported that it is not possible to completely rehydrate a dried material to its fresh weight.

CHAPTER SIX

6.0 Summary, Conclusions and Recommendations

6.1 Summary

Majority of animals slaughtered in Ghana for meat consumption are over aged and meats from such animals are tough and difficult to chew when cooked. The toughness of the meat is due to increased collagen cross-linking which increases with age. Since jerky is dried to a low water activity in order to inhibit microbial growth, it is expected that using whole muscle from over aged animals would result in very tough and coarse textured jerky. Additionally, despite the low water activity there have been several reports of the outbreak of food borne diseases associated with the consumption of jerky. Marinades are known to enhance eating quality and extend shelf life of processed meat products. This study investigates the potential of using marinades to produce jerky products that are microbiologically safe with desired sensory quality. The objectives of this study were to:

- a. Evaluate the effect of vinegar and papain marinades on sensory characteristics of the chevon jerky,
- b. Compare the effect of the treatments on microbial characteristics and shelf life of chevon jerky during storage.

A 3x3 factorial design with three papain levels: (0, 0.004g and 0.04g (w/v)) and three vinegar levels (0, 2.5% and 5% (v/v)) were used to test the combinatorial concentration effect on quality characteristics of the chevon jerky. The experiment composed of nine treatments with three replications. Samples were marinated for 12h and dried in an oven for 10h at temperature of 65°C. The parameters measured included sensory and microbial quality characteristics as well as drying and

rehydration ratio. The samples for sensory and microbial test were vacuum packaged and stored at room temperature.

Sensory evaluation was conducted on samples stored for 1d and 15d. Meat samples were presented to trained panelists in plastic containers marked with 3-digit codes. Tenderness, chewiness, juiciness, flavour and overall liking of the samples were evaluated using 8 point hedonic scale. Microbial quality analysis was conducted at 1d, 15d and 30d of storage. Effects of the nine treatments on the growth of four different microbes (total plate count, *Staphylococcus aureus*, *E.coli*, yeast and mould) during storage were investigated. Drying rate (% moisture content) was determined by weighing samples before drying and every 1h during drying. The samples were dried for 10h. The loss in weight of the sample was calculated and hence its moisture content was obtained. Moisture content (%) during rehydration was carried out on sample to distilled water ratio of 1:40 for 300min under ambient condition. The sample was withdrawn from the distilled water every 30min and excess water was carefully removed by blotting with a tissue paper, before weighing. The result of sensory properties showed that out of the nine treatments tested, papain (0.04g) was effective in tenderising the chevon jerky compared with all the other treatments. Samples were ranked as very tender to extremely tender while samples treated with vinegar (5%) was ranked as moderately tough to slightly tough. With regard to acceptability, samples from control obtained the highest acceptability score. Panelists ranked the control treatments between “very like to extremely like” No significant ($p < 0.05$) difference were observed among treatments for chewiness, juiciness and flavour. However, juiciness improved as storage time progressed from 1d to 15d.

With microbial tests, no significant ($p > 0.05$) difference were observed among marinade treatments for all the four target organisms (total plate count, *Staphylococcus aureus*, *E.coli*, yeast and mould) tested. However, there was a reduction in microbial counts among all the test treatments as storage period progressed from 1d to 30d which was due to the low moisture content in the chevon jerky products and the anaerobic conditions (vacuum packaging) which inhibited microbial growth.

Samples from lower concentration of vinegar (2.5%) recorded the least percent moisture content of 1.71% after drying, whereas the highest (3.61%) was observed in control samples. The low moisture content attests to the lack of effect of the treatments on chewiness and also low microbial counts that was recorded in all the test samples.

Finally, all the treatments were not able to fully rehydrate to the moisture content of the fresh weight which may suggest a significant structural disruption of myofibrillar proteins due to the duration of drying. However, samples from control recorded the least percent moisture uptake (%MC) of 9.83 whereas samples from lower concentration of vinegar 2.5% recorded the highest %MC (19.94) after rehydration.

6.2 Conclusions

Conclusions drawn from the results:

- a. Papain at higher concentration (0.04g) resulted in a tenderer chevon jerky compared with all the other treatments and was ranked by panelists as “very tender to extremely tender”.
- b. Vinegar had no effect on tenderness at the concentrations tested.
- c. Marinade treatments tested, diminished the overall likeness of chevon jerky since samples from control were ranked by panelists as “very like” to “extremely like” while the rest of the treatments were ranked as “slightly like” to “moderately like”, the marinades did not have effect on any of the microbial counts (total plate count, *Staphylococcus aureus*, *E. coli* and yeast and mould) that were tested,
- d. Microbial count (*Staphylococcus aureus*, *E. coli* and yeast and mould) decreased with increasing storage time up to 30d.

6.3 Recommendations

Control samples were more preferred compared with marinade treated jerky; however, it is possible to improve meat toughness using papain to produce meat with acceptable sensory attributes than vinegar.

Marinade treatments were not able to inhibit microbial growth, however vinegar can be added to introduce variety and enhance jerky flavour.

Further research should be carried out in beef, since cattle are slaughtered at a much older age than goats. Also further research should be carried out on the shelf life studies with a much extended storage time.

REFERENCES

- Aaslyng, M. D., Bejerholm, C., Ertbjerg, P., Bertram, H. C. and Andersen, H. J. (2003). Cooking loss and juiciness of pork in relation to raw meat quality and cooking procedure. *Food Quality and Preference*. 14: 277–288.
- Ablordeppey, S. D., and Osabutey, F. (2015, November 14). Samuel Doe Ablordeppey. Retrieved November 14, 2015, from <http://www.graphic.com.gh/news/general-news/4-ministries-allocated-gh-2-59-billion-in-2016.html>.
- Ackerman, S. A., C. E. Cohen, C. Swift, and R. Benedict. (1981). Evaluation of the press method for “frankfurter” juiciness estimation. *Fleischwirtsch* 61: 1169-1170.
- Adams, M. R. and Moss, M. O. (1995). *Food Microbiology*. Royal Society of Chemistry, UK. pp 18-45.
- Aehle, W. (2007). *Enzymes in industry, production and applications*. Weinheim: Wiley-VCH Verlag GmbH and Co.pp517.
- Aguirrezábal, M. M., Mateo, J., Domínguez, M. C and Zumalacárregui, J. M. (2000). The effect of paprika, garlic and salt on rancidity in dry sausages. *Meat Science*. 54: 77–81.
- Ajandouz, E. H., Desseaux, V., Tazi, S. and Puigserver, A. (2008). Effects of temperature and pH on the kinetics of caramelisation, protein cross-linking and maillard reactions in aqueous model systems. *FoodChemistry*.107 (3): 1244-1252.
- Aktaş, N. and Kaya, M. (2001). Influence of weak organic acids and salts on the denaturation characteristics of intramuscular connective tissue. A differential scanning calorimetry study. *Meat Science*. 58: 413–419.
- Albright, S. N., Kendall, P. A., Avens, J. S. and Sofos, J. N. (2000). Sensory properties of beef jerky processed under various conditions. In Proceedings of IFT annual meeting, June 10-14, Dallas, TX, USA, Session 11.
- Allen, K., Cornforth, D., Whittier, D., Vasavada, M. and Nummer, B. (2007). Evaluation of high humidity and wet marinade methods for pasteurisation of jerky. *Journal of Food Science*. 72(7): 351–355.
- Alvarado, C. and McKee, S. (2007). Marination to improve functional properties and safety of poultry meat. *The Journal of Applied Poultry Research* 16:113–120.
- Andersen, H. J. and Skibsted, L. H. (1991). Oxidative stability of frozen pork patties. Effect of light and added salt. *Journal of Food Science*.56: 1182–1184.

- An, K., Ding, S., Hongyan Tao, Zhao, D., Wang, X., Wang, Z. and Hu, X. (2012). Response surface optimisation of osmotic dehydration of Chinese ginger (*Zingiber officinale* Roscoe) slices. *International Journal of Food Science and Technology*. 48: 28–34.
- Arakawa, T., Prestrelski, S. J., Kenney, W. C. and Carpenter, J. F. (2001). Factors affecting short-term and long-term stabilities of proteins. *Advanced Drug Delivery Reviews*. 46 (1-3): 307–326.
- Arason, S. (2003). The drying of fish and utilisation of geothermal energy; the Icelandic experience. *International Geothermal Conference, Reykjavik*. Paper 076.
- Arboix, A. A. (2004). Ham production: cooked ham. In: *Encyclopedia of Meat Sciences*. (Editors. W. Jensen, C. Devine, M. Dikeman), 1st edition. Elsevier, Oxford, pp 557–567.
- Ashie, I. N. A., Sorensen, T.L. and Nielsen, P.M. (2002). Effects of Papain and a microbial enzyme on meat proteins and beef tenderness. *Journal of Food Science*. 67: 2138–2142.
- Azarkan, M., El Moussaoui, A., van Wuytswinkel, D., Dehon, G. and Looze, Y. (2003). Fractionation and purification of the enzymes stored in the latex of *Carica papaya*. *Journal of Chromatography B*. 790: 229–238.
- Bagamboula, C. F., Uyttendaele, M. and Debevere, J. (2004). Inhibitory effect of thyme and basil essential oils, carvacrol, thymol, estragol, linalool and p-cymene towards *Shigella sonnei* and *S. flexneri*. *Food Microbiology*. 21: 33–42.
- Barbut, S. H., Draper, H. and Hadley, M. (1989). Lipid oxidation in chicken nuggets by meat type, phosphate, and packaging. *Journal of Food Protection*. 52(1):55–58.
- Beauchat, L. R. (1981). Microbial stability as affected by water activity. *Cereal Foods World*. 26(7):345–349.
- Behrends, J. M., Goodson, K. J., Koohmaraie, M., Shackelford, S. D., Wheeler, T. L., Morgan, W.W., Reagan, J. O., Gwartney, B. L., Wise, J. W. and Savell, J.W. (2005). Beef customer satisfaction: Factors affecting consumer evaluation of calcium chloride-injected top sirloin steaks when given instructions for preparation. *Journal of Animal Science*. 83: 2869.
- Bejerholm, C. And Asalyng, M. D. (2004). Cooking of Meat. In: Werner Klinth, J. (Editor). *Encyclopedia of Meat Science*. Oxford: Elsevier. pp342 – 349.
- Bell, M. (1996). Just jerky. The complete guide to making it. Madison, W. I: The Dry Store Publishing Company. pp 39.

- Berge, P., Ertbjerg, P., Larsen, L. M., Astruc, T., Vignon, X. and Moller, A. J. (2001). Tenderisation of beef by lactic acid injected at different times post mortem. *Meat Science*. 57: 347–357.
- Berry, B. W. (1993). Tenderness of beef loin steaks as influenced by marbling level removal of subcutaneous fat and cooking method. *Journal of Animal Science*. 71:2412-2419.
- Bhaisare, D.B., Thyagarajan D., Churchi, R.R., Punniamurthy, N.(2014). Bacterial Pathogens in Chicken Meat: Review. *International Journal of Life Sciences Research*, 2, (3), 1-7.
- Binker, E. F. and Kolari, O. E. (1975). The history and use of nitrate and nitrite in curing of meat. *Food and Cosmetics Toxicology*. 13:655–661.
- Borowski, A. G., Ingham, S. C. and Ingham, B. H. (2009). Validation of ground and formed beef jerky processes using commercial Lactic acid bacteria starter cultures as pathogen surrogates. *Journal of Food Protection*. 72(6):1234–1247.
- Bratzler, L. J. (1971). Palatability factors and evaluation. In: *The Science of Meat and Meat Products*, 2nd edition. (Editors. J. F. Price and B. S. Schweigert). Freeman. W. H. San Francisco, Calif. pp. 328-348
- Briskey, E. J., and Kauffman, R. G. (1971). Quality characteristics of muscle as food. In: *The Science of Meat and Meat Products*. (Editors. J. Price and B. S. Schweigert). W. H. San Francisco, Calif. pp. 367.
- Burke, R.M. and Monahan, F.J. (2003). The tenderisation of shin beef using a citrus juice marinade. *Meat Science*. 63(2): 161–168.
- Calhoun, C. M., Eilert, S. J. and Mandigo, R. W. (1996). Connective tissue/Acidic phosphate pre- blend effects on reduced fat “frankfurters”. *Journal of Food Science*. 61: 459–464.
- Calicioglu, M., Kaspar, C.W., Buege, D. R. and Luchansky, J. B. (2002). Effectiveness of spraying with Tween 20 and Lactic acid to decontaminate inoculated *E. coli* O157 and indigenous *E. coli* biotype I on beef. *Journal of Food Protection*. 65: 26–32.
- Calicioglu, M., Sofos, J. N. and Kendall, P. A. (2003). Fate of acid-adapted and non-adapted *Escherichia coli* O157: H7 inoculated post-drying on beef jerky treated with marinades before drying. *Food Microbiology*. 20: 169–177.
- Calkins, C. R. and Hodgen, J. M. (2007). A fresh look at meat flavour. *Meat Science*. 77:63-80.
- Calkins, C. R. and Sullivan, G. (2007). Ranking of beef muscles for tenderness. Beef facts. Product enhancement. National Cattlemen’s beef Association.

Available: <http://beefcentral.com/u/lib/cms/ranking-of-beef-muscles-for-tenderness.pdf> (2012 May 20).

- Carlile, M. J., Watkinson, S. C. and Gooday, G.W. (2001). "The Fungi" 2nd edition. Academic Press: London, UK. pp 588.
- Carpenter, Z. L. (1962). The histological and physical characteristics of pork muscle and their relationship to quality. Ph.D.University of Wisconsin, Madison.
- CDC, (1995). Centres for Disease Control and Prevention. Outbreak of Salmonellosis associated with beef jerky – New Mexico. *Morbidity and Mortality Weekly Report*. 44:785-788.
- Chen, Q. H., He, G. Q., Jiao, Y. C and Ni, H. (2006). Effect of elastase from a *Bacillus* strain on the tenderization of beef. *Food Chemistry*. 98: 624 – 629.
- Chem, C. M., Huffman, D. L., Egbert, W. R. and Smith, R. C. (1992). Oxidation of purified bovine myoglobin – effects of Ph, sodium – chloride, sodium tripolyphosphate, and binders. *Journal of Agricultural and Food Chemistry*.40: 1767 – 1771.
- Choi, K. S., Choi, J. D., Chung, H. C., Kwon, K. I., Im, M. H., Kim, Y. H. and Kim W. S. (2000).Effects of mashing proportion of soybean to salt brine on Kanjang(soy sauce) quality. *Journal of Food Science and Technology*. 32:174-180.
- Choi, J. H., Jeong, J. Y., Han, D. J., Choi, Y. S., Kim, H. Y., Lee, M. A., Lee, E. S., Paik, H. D., and Kim, C. J. (2008). Effects of pork/beef levels and various casings on quality properties of semi-dried jerky. *Meat Science*. 71: 278-286.
- Choi, Y. S., Jeong, J. Y. and Lee, M. A. (2007). Effect of packaging methods on the quality of Korea Style, beef and pork jerky during storage. *Korean Journal of Food Science of Animal Resource*.27 (3): 290 – 298.
- Christensen, M. (2009). Injection of marinade with actinidin increases tenderness of porcine *M. biceps femoris* and affects myofibrils and connective tissue. *Journal of Science of Food Agriculture*.89(9): 1607-1614.
- Christensen, L., Ertbjerg, P., Aaslyng, M. D. and Christensen, M. (2011). Effect of prolonged heat treatment from 48°C to 63°C on toughness cooking loss and colour of pork. *Meat science*. 88(2): 280-285.
- Cohen, J.S. and Yang, T.C.S. (1995). Progress in food dehydration. *Trend in Food Science and Technology*.(6):20 -25.
- Corriher, S. (2012). Marinades add flavour but don't always tenderise – fine cooking recipes, techniques and tips. The Taunton Press. [http://www.finecooking.com/articles/marinades – flavour – tenderise. Asp.](http://www.finecooking.com/articles/marinades-flavour-tenderise.aspx) Retrieved 28 November.

- Corry, J. E. L. (1978). Relationships of water activity to fungal growth. In: Food and Beverage Mycology. (Editor. L. R. Beuchet). AVI Publish Company, USA. pp45-82.
- Cross, H. R. (1987). Sensory Characteristics of Meat. Part 1, Sensory Factors and Evaluation. In: The Science of Meat and Meat Product 3rd edition. (Editors. J. F. Price and B. S. Schwergert). Westport, CT: Food and Nutrition Press, Inc. pp. 307 –330.
- Davey, C. L. (1974). Temperature-dependent cooking toughness in beef. *Journal of Science of Food and Agriculture*. 25(8): 931-938.
- Davidson, P.M. (2001). Chemical preservatives and natural antimicrobial compounds. In: Food Microbiology: Fundamentals and Frontiers. 2nd edition. (Editors. M. P. Doyle, L. R. Beuchat and T. J. Montville). ASM Press, Washington, DC. pp 539 – 627.
- Deng, Y., Luo, Y., Wang, Y., Yue, J., Liu, Z., Zhong, Y., Zhao, Y. and Yang, H. (2014). Drying-induced protein and microstructure damages of squid fillets affected moisture distribution and rehydration ability during rehydration. *Journal of Food Engineering*. 123: 23–31.
- Derrickson-Tharrington, E. L. (2001). Evaluation of common acidulants for enhancement of destruction of *Escherichia coli* O157:H7 during drying of Gala apple slices and whole muscle beef jerky. M.S. thesis. Colorado State University, Fort Collins.
- Dickson, J. S., Cutter, C. G. N and Siragusa, G. R. (1994). Antimicrobial effects of trisodium phosphate against bacteria attached to beef tissue. *Journal of Food Protection*. 57: 952–955.
- Djeri, N. (2007). Development and evaluation of raw and pre-cooked vacuum packaged goat meat product. M.S. thesis. University of Florida.
- Doneva, M., Miteva, D., Dyankova, S., Nacheva, I., Metodieva, P. and Dimov, K. (2015). Efficiency of plant proteases bromelain and papain on turkey meat tenderness. *Biotechnology in Animal Husbandry*. 31(3):407–413.
- Doyle, M.E. and Glass, K.A. (2010). Sodium reduction and its effect on food safety, food quality, and human health. *Comprehensive Reviews in Food Science and Food Safety*. 9: 44–56.
- Doymaz, I and Smail, O. (2011). Drying characteristics of sweet cherry,” *Food and Bioproducts Processing*, vol. 89, no. 1, pp. 31–38.
- Dransfield, E. and Etherington, D. (1981). Enzymes in the tenderisation of meat. In: *Enzymes and Food Processing*. (Editors. G.G. Birch, N. Blakebrough and K. J. Parker). Applied Science Publishers, London. pp 177-194.

- Easy Recipe. (2014). Is it necessary to add water when making jerky? Retrieved February 9, 2017, from <http://www.hicountry.com/?s=jerky>.
- Edward, S. D. and Pauline, E. M. (1965). Comparison of beta-carotene content of dried carrots prepared by three dehydration process. *Food Technology* (19): 1597-1603.
- Egan, A. F., Ford, A. L., Shay, B. J. (1980). A comparison of micro-bacterium thermo-spectrum and *Lactobacilli* as spoilage organisms of vacuum - packaged sliced luncheon meat. *Journal of Food Science*. 45:1745–1748.
- Eidson, M., Sewell C. M, Graves G. and Olson R. (2000). Beef jerky gastroenteritis outbreaks. *Journal of Environmental Health* 62: 9 - 13.
- Ellis, D. I. and Goodacre, R.(2001). Rapid and quantitative detection of the microbial spoilage of muscle foods: Current status and future trends. *Trends Food Science. Technology*.12:414-424.
- Ertbjerg, P., Mielche, M. M., Larsen, L. M and Moller, A. J. (1999). Relationship between proteolytic changes and tenderness in prerigor lactic acid marinated beef. *Journal of Science Food Agriculture*. 79: 970–978.
- Etherington, D.J. (1974).The purification of bovine cathepsin B1 and its mode of action on bovine collagens. *Biochemistry Journal*. 137: 547–557
- Etherington, D.J. (1984).The contribution of proteolytic enzymes to postmortem changes in muscle. *Journal of Animal Science*. 59: 1644 – 1650.
- Faith, N. G., Le Coutour, N. S., Alvarenga, M. B., Calicioglu, M., Buegeb, D. R. and Luchansky, J. B. (1998). Viability of *Escherichia coli* O157:H7 in ground and formed beef jerky prepared at levels of 5 and 20% fat and dried at 52, 57, 63, or 68°C in a home-style dehydrator. *International Journal of Food Microbiology*.41: 213-221.
- FAO, (1990). Food Agriculture Organisations of the United Nations. Manual on simple methods of food preservation. FAO Animal Production and Health, Rome.Paper no 79.
- Farmer, L. J. (1994). The role of nutrients in meat flavour formation. *Proceedings of the Nutrition Society*. 53(02): 327–333.
- Feiner, G. (2006). Meat products handbook: Practical Science and Technology. Woodhead Publishing Limited Cambridge, England. pp 142 – 157.
- Fernández-Ginés, J. M., Fernández-López, J., Sayas-Barberá, E. and Pérez-Alvarez, J. A. (2005). Meat products as functional foods: A review. *Journal of Food Science*. 70(2):37–43.
- Fleet, G. (1999). Microorganisms in food ecosystems. *International Journal of Food Microbiology*. 50: 101–117.

- Fogle, D. R., Plimptong, R. F., Ockerman, H. W., Jarenback, L., Persson, T. (1982). Tenderisation of beef: Effect of enzyme, enzyme level and cooking method. *Journal of Food Science*. 47:1113–1118.
- Foegeding, E. A. and D. K. Larick. (1986). Tenderisation of beef with bacterial collagenase. *Meat Science*. 18:201-214.
- Foster, R. J. (2004). Meeting consumer expectations. Food Product Design. Available at: <http://www.foodproductdesign.com/articles/1204CS.html> .Virgo Publishing, Phoenix, AZ.
- FSIS, (2011). Food Safety and Inspection Service. Jerky and Food safety. Food Safety and Inspection Service, United States Department of Agriculture, Washington, DC, USA. Available from: http://www.fsis.usda.gov/Fact_Sheets/Jerky_and_Food_Safety/index.asp#1. Modified Nov. 15, 2011.
- Froning, G. W. and Sackett, B. (1985).Effect of salt and phosphates during tumbling of turkey breast muscle on meat characteristics.*Poultry Science*. 64: 1328–1333.
- Fu, H.-Y. and Ho, C.-T. (1997). Mechanistic studies of 2-(1-Hydroxyethyl)-2, 4,5-trimethyl-3- oxazoline formation under low temperature in 3-Hydroxy-2-butanone/ammonium acetate model systems. *Journal of Agricultural and Food Chemistry*. 45(5): 1878–1882.
- Gao, T., Li, J., Zhang, L., Jiang, Y., Song, L., Ma, R., Gao, F. and Zhou, G. (2015).Effect of different tumbling marinade treatments on the water status and protein properties of prepared pork chops. *Journal of the Science of Food and Agriculture*. 95(12): 2494–2500.
- García-Pascual, P., Sanjuán, N., Bon, J., Carreres, J.E. and Mulet, A. (2005). Rehydration process of *Boletus edulis* mushroom: Characteristics and modelling. *Journal of the Science of Food and Agriculture*. 85(8): 1397–1404.
- Gault, N.F.S. (1985).The relationship between water-holding capacity and cooked meat tenderness in some beef muscles as influenced by acidic conditions below the ultimate pH. *Meat Science*. 15: 15–30.
- Geesink, G., Sujang, S. and Koochmaraie, M. (2011).Tenderness of pre and post rigor lamb *Longissimus* muscle. *Meat Science*. 88(4):723–726
- Gerelt, B., Ikeuchi, Y. and Suzuki, A. (2000). Meat tenderisation by proteolytic enzymes after osmotic dehydration.*Meat Science*. 56(3):311–318.
- Ghaly, A. E., Dave, D. Budge, S. and Brooks, M.S. (2010). A review: Fish spoilage mechanisms and preservation techniques. *American Journal of Applied Sciences*. 7:846–864.

- Gillett, T., Cassidy, R. and Simon, S. (1982). Ham massaging: effect of massaging cycle, environmental temperature and pump level on yield, bind and colour of intermittently massaged hams. *Journal of Food Science*. 47(4):1083–1088.
- Goli, T., Abi Nakhoul, P., Zakhia-Rozis, N., Trystram, G. and Bohuon, P. (2007). Chemical equilibrium of minced turkey meat in organic acid solutions. *Meat Science*. 75(2):308–314.
- Gourama, H. and Bullerman, L. B. (1995). Relationship between aflatoxin production and mould growth as measured by ergosterol and plate count. *LWT - Food Science and Technology*. 28,(2), pp. 185 –189
- Griffiths, G., Trueman, L., Crowther, T., Thomas, B. and Smith, B. (2002). Onions? A global benefit to health. *Phytotherapy Research*. 16(7):603–615
- Gutierrez, J., Barry-Ryan, C. and Bourke, P. (2009). Antimicrobial activity of plant essential oils using food model media: Efficacy, synergistic potential and interactions with food components. *Food Microbiology*. 26: 142–150.
- Hamm, R. (1975). Water-holding capacity of meat. In: Meat.(Editors. D. J. A. Cole and R. A. Lawrie). Butterworths: London, UK. pp 321-337.
- Hamm, R. and Deatherage, F. E.(1960). Changes in hydration, solubility and charges of muscle proteins during heating of meat. *Journal of Food Science*. 25(5):587–610.
- Han, D.-J., Jeong, J.-Y., Choi, J.-H., Choi, Y.-S., Kim, H.-Y., and Lee, M.-A. (2007). Effects of drying conditions on quality properties of pork jerky. *Korean Journal of Food Science of Animal Research*. 27:29–34.
- Harper, G.S. (1999). Trends in skeletal muscle biology and the understanding of toughness in beef. *Australian Journal of Agricultural Research*. 50(7): 1105 - 1129.
- Harrison, J.A, Harrison, M. A. and Rose, R. A.(1997). Fate of *Listeria monocytogenes* and *Salmonella* species in ground beef jerky. *Journal of Food Protection*. 60:1139–1141.
- Harrison, J.A. and Harrison, M.A. (1996). Fate of *Escherichia coli* O157: H7, *Listeria monocytogenes*, and *Salmonella typhimurium* during preparation and storage of beef jerky. *Journal of Food Protection*. 59:1336–1338.
- Hayes, J.E., Kenny, T.A., Ward, P. and Kerry, J.P. (2007). Development of a modified dry curing process for beef. *Meat Science*. 77:314–323.
- Hinkle, J. B. (2010). Acid marination for tenderness enhancement of beef bottom round. M.S. Thesis. University of Nebraska - Lincoln.
- Holdsworth, S. D. (1971). Dehydration of food products. A review *International Journal of Food Science and Technology*. 6:331–370.

- Holley, R. A. (1985). Beef jerky: Fate of *Staphylococcus aureus* in marinated and corned beef during jerky manufacture and 2.5°C storage. *Journal of Food Protection*. 48: 107–111.
- Honikel, K. O. (1998). Reference methods for the assessment of physical characteristics of meat. *Meat Science*. 49(4):447–457.
- Horowitz, R., Kempner, E. S., Bisher, M. E. and Podolsky, R. J. (1986). A physiological role for titin and nebulin in skeletal muscle. *Nature*. 323(6084): 160–164.
- Hotchkiss, H. J. and Potter, N. J. (1995). Meat preservation and processing. Food Science 5th Edition New York. pp:261 – 265.
- How to make jerky (2017). Retrieved February 9, 2017, from <http://www.meatprocessingproducts.com/how-to-make-jerky.html>.
- Huang, T. C. and Ho, C. T. (2001). Flavours of meat products. In: Meat Science and Applications. (Editors. O. A. Young, R. W. Rogers, Y. H. Hui, and W.-K. Nip). CRC Press. Retrieved from <http://dx.doi.org/10.1201/9780203908082.ch4>. Retrieved 2011/08/27.
- Huff-Lonergan, E., Parrish, F. C. and Robson, R. M. (1995). Effects of postmortem aging time, animal age and sex on degradation of titin and nebulin in bovine *Longissimus* muscle. *Journal of Animal Science*. 73: 1064 - 1073.
- Huffman, K. L., Miller, M. F., Hoover, L.C., Wu, C. K., Brittin, H. C. and Ramsey, C.B. (1996). Effect of beef tenderness on consumer satisfaction with steaks consumed in the home and restaurant. *Journal of Animal Science*. 74: 91- 97.
- Hui, Y.H., Aalhus, J. J., Cocolin, L., Guerrero – Legarreta, I., Nollet, L.M., Purchas, R.W., Schilling, M.W., Stanfield, P. and Xiong, Y. L (2012). Hand book of Meat and Meat Processing. 2nd edition, pp 508.
- Hui, Y. H. and Yiu. (2004). Handbook of Frozen Foods. New York, NY: Marcel Dekker Inc. pp17-23.
- Hung, Y., Liu, J. H. and Chou, R – G. R. (2013). Effects of *Aspergillus oryzae* proteases on postmortem degradation of Taiwan black pig myofibrillar proteins. *Journal of Chinese Society of Animal Science*. 42 (1): 15 – 25.
- Hutton, C.W., Neggers, Y. H. and Love, T.O. (1981). Scanning electron microscopy, proteolytic enzyme activity and acceptability of beef *Semitenidinosus* cooked by microwaves and conventional heat. *Journal of Food Science*. 46: 1309–1314.
- Hwang, I. H., Lin, C.W. and Chou, R.G.R. (2000). Effect of lactic or acetic acid on degradation of myofibrillar proteins in post-mortem goose (*Anser anser*) breast muscle. *Journal of Science Food and Agriculture*. 80: 231–236.

- Igene, J. O., Farouk, M. M. and Akanbi, C. T. (1990). Preliminary studies on the traditional processing of Kilishi. *Journal of Science Food and Agriculture*. 50:89–98.
- Iizuka, K. and Aishima, T. (1999). Tenderisation of beef with pineapple juice monitored by Fourier transform infrared spectroscopy and chemometric analysis. *Journal of Food Science*. 64: 973–977.
- Ingham, S. C., Engel, R. A., Fanslau, M. A., Schoeller, E. L., Searls, G. A., Buege, D. R. and Zhu, J. (2005). Fate of *Staphylococcus aureus* on vacuum-packaged ready-to-eat meat products stored at 21°C. *Journal of Food Protection*. 68:1911–1915.
- Ingham, S. C., Searls, G., Mohanan, S. and Buege, D. R. (2006). Survival of *Staphylococcus aureus* and *Listeria monocytogenes* on vacuum-packaged beef jerky and related products stored at 21°C. *Journal of Food Protection*. 69(9): 2263–2267.
- ICMSF, (1996). International Commission on Microbiological Specifications for Foods, International Union of Biological Societies. Microorganisms in foods. 5. Characteristics of microbial pathogens. Blackie Academic and Professional, London.
- IUBMB, (2009). International Union of Biochemistry and molecular biology on the nomenclature and classification of enzymes by the reactions they catalyse.
- Ionescu, A., Aprodu, I and Pascaru, G. (2008). Effect of papain and bromelin on muscle and collagen proteins in beef meat. *Food Technology*. 31:9-16.
- Irzyntic, Z., Klimczak, K. and Michalowski, S. (1995). Freeze-drying of the black currant juice. *Drying Technology*. 13: 417–424.
- Istrati, D. (2008). The influence of enzymatic tenderisation with papain on functional properties of adult beef. *Journal of Agroalimentary Processes and Technologies*. 14 (1):140-146.
- Jay, J.M. (1987). Meats, poultry, and seafoods. In “Food and Beverage Mycology,” 2nd Edition. (Editor. L.R. Beuchat) Van Nostrand Reinhold, New York. pp. 155.
- Jay, J.M. (1992). Staphylococcal gastroenteritis. In: Modern food microbiology. 4th Edition. Van Nostrand Reinhold: New York, US. pp 455-478.
- Jay, J. M. (2000). Modern Food Microbiology. Aspen, Gaithersburg, Maryland, pp. 63.
- Jay, J. M. (2005). Modern Food Microbiology. In: Jay J. M., Loessner, M. J., Golden, D. A, (editors). NY: Springer Science + Business Media, Inc. pp 67.

- Jay, J. M., Loessner, M. J., Golden, D. A.(2008). *Modern Food Microbiology*. 7th edition. Springer Science + Business Media, Inc. New York.pp 51.
- Jayaraman, K. S., Gupta, D. K. D. and Rao, N. B. (1990).Effect of pre - treatment with salt and sucrose on the quality and stability of dehydrated cauliflower. *International Journal of Food Science and Technology*. 25(1): 47–60.
- Jeremiah, L .E. (2001).Packaging alternatives to deliver fresh meats using short- or long-term distribution. *Food Research International*. 34: 749–772.
- Jung, S. W., Baek, Y. S., Kim, Y. S. and Kim, Y. H. (1994). Quality changes of beef jerky during storage. *Korean Journal of Animal Science* 36:683-697.
- Kang, C. K. and Rice, E. E. (1970). Degradation of various meat fractions by tenderising enzymes. *Journal of Food Science*. 35(5):563-565.
- Kannan, G., Kouakou, B., Terrill, T. H. and Gelaye, S. (2003).Endocrine, blood metabolite and meat quality changes in goats as influenced by short-term, preslaughter stress. *Journal of Animal Science*. 81: 1499 - 1507.
- Karel, M., Fennerma, O. R., and Lund, D. B. (1978). *Physical Principles of Food Preservation*, Marcel Dekker, Boston.pp255-328.
- Ke, S., Huang, Y., Decker, E. A. and Hultin, H. O. (2009). Impact of citric acid on the tenderness, microstructure and oxidative stability of beef muscle. *Meat Science*.82(1): 113–118.
- Keene, W. E.,Sazie, E., Kok, J., Rice, D. H., Hancock, D.D., Balan, V. K., Zhao,T. and Doyle, M. P.(1997).An outbreak of *Escherichia coli* O157: H7 infections traced to jerky made from deer meat. *Journal of American Medical Association*. 277: 1229–1231.
- Keey, R. B. (1975). *Drying: Principles and Practice*. Pergamon Press, Oxford, pp. 1-4.
- Killinger, K. M., Calkins, C. R., Umberger, W. J., Feuz, D. M. and Eskridge, K. M. (2004).Consumer sensory acceptance and value for beef steaks of similar tenderness, but differing in marbling level. *Journal of Animal Science*. 82(11):3294.
- Kim, H.-J. and Taub, I.A. (1991).Specific degradation of myosin in meat by bromelain. *Food Chemistry*. 40: 337–343.
- Kim, M. H. (1990).Effects of pretreatments prior to conventional dehydration on dried product quality. *Journal of Biochemistry Engineering*. 4: 30-38.
- Kim, H. W., Hwang, K. E., Song, D. H., Kim, Y. J., Lim, Y. B., Choi, J. H., Choi, Y. S. and Kim, C. J. (2014). Effects of soy sauce on physicochemical and textural properties of tumbled chicken breast. *Poultry Science*. 93(3): 680–686.

- Knight, P. and Parsons, N. (1988). Action of NaCl and polyphosphates in meat processing: Responses of myofibrils to concentrated salt solutions. *Meat Science*. 24(4): 275–300.
- Knipe, C. L. (2009). Processing interventions to inhibit *Listeria monocytogenes* growth in ready-to-eat meat products. In: Thermal processing of ready-to-eat meat products. 1st edition. (Editors C. L. Knipe and R. E. Rust). Blackwell Publishing: Columbus, OH, USA. pp87-126.
- Konieczny, P., Stangierski, J. and Kijowski, J. (2007). Physical and chemical characteristics and acceptability of home style beef jerky. *Meat Science*. 76: 253–257.
- Koohmaraie, M., Babiker, A. S., Schroeder, A. L., Merkel, R. A. and Dutson, T. R. (1988). Acceleration of postmortem tenderisation in ovine carcasses through activation of Ca²⁺ dependent proteases. *Journal of Food Science*. 53:1638–1641.
- Koohmaraie, M. (1992). The role of Ca²⁺ dependent proteases (calpains) in post mortem proteolysis and meat tenderness. *Biochemistry*. 74: 239–245.
- Krokida, M.K. and Marinos-Kouris, D. (2003). Rehydration kinetics of dehydrated products. *Journal of Food Engineering*. 57(1): 1–7.
- Kropf, D. H. (2004) Packaging. In: Encyclopedia of Meat Sciences. (Editors. W. K. Jensen, C. Devine, M. Dikeman). 3rd edition. Elsevier Ltd: Oxford, UK. pp. 943-976.
- Kwak, E. and Lim, S. (2004). The effect of sugar, amino acid, metal ion, and NaCl on model Maillard reaction under pH control. *Amino Acids*. 27(1):85 – 90.
- Labadie, J. (1999). Consequences of packaging on bacterial growth. Meat is an ecological niche. *Meat Sci*. 52:299-305.
- Labelle, R. L. and Moyer, J. C. (1966). Dehydro - freezing red tart cherries. *Food Technology*. 20:1345-1352.
- Latif, S. (2011). Effect of marination on the quality characteristics and microstructure of chicken breast meat cooked by different methods. *Seria zootehnie lucrative* 54: 314-324.
- Lawrie, R. A. (1998). Meat science. In: The eating quality of meat. 6th edition. Woodhead Publishing Limited, Cambridge. Chap10, pp 229.
- Lawrie, R. A. and Ledward, D. A. (2006). *Lawrie's Meat Science*. 7th Edition. Woodhead Publishing Ltd, Cambridge: England and CRC Press Boca Raton, New York, Washington DC. pp 75 – 155.

- Lazarides, H.N., Katsanidis, E. and Nickolaidis, A. (1995). Mass transfer kinetics during osmotic preconcentration aiming at minimal solid uptake. *Journal of Food Science*. 25: 151–166.
- Lee, S. J. and Park, G. S. (2004). The quality characteristics of beef jerky prepared with various spices. *Journal of Food Cookery Science*.20:489-497.
- Leistner, L. (1987). Shelf stable product and intermediate moisture foods based on meat. In: Water activity theory and application to food. (Editors. L. Rockland and L. B. Beuchat) Marcel Dekker Inc., New York, pp. 295-328.
- Leistner, L., Rodel, W. and Krispien, K. (1981). Microbiology of meat and meat products in high and intermediate moisture ranges. In: Water Activity: Influences on Food Quality. (Editors. L.B. Rockland and G. F. Stewart). Academic Press, New York. pp 855.
- Lemos, A. L. S. C., Nunes, D. R. M. and Viana, A. G. (1999). Optimisation of the still-marinating process of chicken parts. *Meat Science*. 52(2): 227–234.
- Lewicki, P. P. (1998). Some remarks on rehydration of dried food. *Journal of Food Engineering*. 36:81 – 87.
- Lewis, G. J. and Purslow, P. P. (1991). The effect of marination and cooking on the mechanical properties of intramuscular connective tissue. *Journal of Muscle Foods*. 2:177–195.
- Lim, D.-G., Lee, S.-S., Seo, K.-S. and Nam, K.-C. (2012). Effects of different drying methods on quality traits of Hanwoo beef jerky from low-valued cuts during storage. *Korean Journal of Food Science of Animal Resources*, 32(5):531–539.
- Lim, H. J., Jung, E.Y., Kim, G .D., Joo, S.T., Yang, H. S. (2013). Quality properties of beef jerky replaced salt with soy sauce, red pepper paste and soybean paste during storage. *Korean Journal for Food Science and Animal Resources*. 33:181 – 188.
- Lorenzen, C. L., Miller, R. K., Taylor, J. F., Neely, T. R., Tatum, J. D., Wise, J. W., Buyck, M.J., Reagan, J.O. and Savell, J.W. (2003). Beef customer satisfaction: Trained sensory panel ratings and Warner-Bratzler shear force values. *Journal of Animal Science*. 81: 143 - 149.
- Lutalo- Bosa, A. J. And Macrae, H. F. (1969). Hydrolytic enzymes in bovine skeletal muscle, 3 activity of some catheptic enzymes. *Journal of Food Science*. 34(5):401 – 404.
- Madrugá, M. S., Arruda, S. G. B., Narain, N. and Souza, J. G. (2000). Castration and slaughter age effects on panel assessment and aroma compounds of the “mestiço” goat meat. *Meat Science*. 56(2):117–125.

- Manteuffel-Gross, R. and Ternes, W. (2009). Effects of marination on the aroma of pan-fried wild boar meat – Part 1: Red wine Marinade. 24:55-59.
- Marsh, B. B. and Leet, N. G. (1966). Studies in meat tenderness. III. The effects of cold shortening on tenderness. *Journal of Food Science*. 31: 450.
- Martens, H., Stabursvik, E. and Martens, M. (1982). Texture and colour changes in meat during cooking related to thermal denaturation of muscle proteins. *Journal of Texture Studies*. 13(3): 291–309.
- Martin, M. (2001) Meat curing technology. In: Meat Science and Applications. Hui, Y.H., Nip, W.-K., Rogers, R.W. and Young, O.A. Editors. Marcel Dekker, New York. pp. 491-508.
- Mason, R. W., Taylor, M. A. J. and Etherington, D. J. (1984). The purification and properties of cathepsin L from rabbit liver. *Biochemical Journal*. 217: 209–217.
- Maughan, C., Tansawat, R., Cornforth, D., Ward, R. and Martini, S. (2012). Development of a beef flavour lexicon and its application to compare the flavour profile and consumer acceptance of rib steaks from grass- or grain-fed cattle. *Meat Science*. 90(1):116–121.
- McMinn, W. A. M. and Magee, T. R. A. (1997). Quality and physical structure of dehydrated starch based system. *Drying Technology*. 15(6-8):1961 -1971.
- Melton, S.L. (1990). Effects of feeds on flavour of red meat: A review. *Journal of Animal Science*. 68: 4421 – 4435.
- Meshram, S. K., Mendiratta S. K., Mishra, B. P., Sharma, B. D., Chand, S. and Prabhakaran, P. P. (2014). Effect of packaging on sensory quality of micro-waved ready-to-eat mutton based snacks during storage. *International Journal of Advancements in Research and Technology*. 3: 2278-7763.
- Mikami, M., Whiting, A. H., Taylor, M. A. J., Maciewicz, R. A. and Etherington, D.J. (1987). Degradation of myofibrils from rabbit, chicken and beef by cathepsin I and lysosomal lysates. *Meat Science*. 21: 81–97.
- Miles, C.A., Burjanadze, T.V. and Bailey, A.J. (1995). The Kinetics of the thermal denaturation of collagen in unrestrained rat tail tendon determined by differential scanning calorimeter. *Journal of Molecular Biology*. 245: 437–446.
- Miller, A. J., Strange, E. D. and Whiting, R. C. (1989). Improved tenderness of restructured beef steaks by a microbial collagenase derived from *Vibrio* B-30. *Journal of Food Science*. 54(4):855–857.
- Miller, M. F., Carr, M. A., Ramsey, C. B., Crockett, K. L. and Hoover, L. C. (2001) Consumer thresholds for establishing the value of beef tenderness. *Journal of Animal Science*. 79(12): 3062 – 3068.

- Miller, M. F., Davis, G. W., Ramsey, C. B. and Irizarry, H. (1996). Water activity theory and application to food. (Editors. L. B. Rockland and L. R. Beuchat). Marcel Dekker: New York, USA. pp. 295-328.
- Moeller, P. W., Fields, P. A., Dutson, T. R., Landmann, W. A. and Carpenter, Z. L. (1976). Effect of high temperature conditioning on subcellular distribution and levels of lysosomal enzymes. A research note. *Journal of Food Science*. 41:216.
- Moeller, P. W., Fields, P. A., Dutson, T. R., Landmann, W. A. and Carpernter, Z. L. (1977). High temperature effects on lysosomal enzyme distribution and fragmentation of bovine muscle. *Journal of Food Science*. 42: 510–512.
- Montgomery, T. H. and Leheska, J. M. (2008). Effect of various management practices on beef-eating quality.
- Mori, K., Nishimura, T., Yasukawa, T. and Takahashi, K. (2001). Tenderisation of heated sliced beef by succinylated glycerol monostearate, a novel meat Tenderiser. *Journal of Food Science*. 66:524–529.
- Mottram, D.S. (1998). Flavour formation in meat and meat products: A review. *Food Chemistry*. 62: 415–424.
- Musonge, P. and Njolai, E.N. (1994). Drying and infusion during the traditional processing of kilishi. *Journal of Food Engineering*. 23:159–168.
- Naidoo, K. and Lindsay, D. (2010a). Pathogens associated with biltong product and their invitro survival of hurdles used during production. *Food Protection Trends*. 30: 532-538.
- Naidoo, K. and Lindsay, D. (2010b). Survival of *Listeria monocytogenes* and enterotoxin-producing *Staphylococcus aureus* and *staphylococcus pasteurii* during two types of biltong-manufacturing processes. *Food Control*. 21(7): 1042–1050.
- Nayar, R., Mendiratta, S. K., Prabhakaran, P., Chand, S. and Beura, C. K. (2014). Comparison of hot air oven dried and microwave dried extended and dehydrated goat meat cubes. Research. Opinion. *In Animal Veterinary Sciences*, 4(6):336-342.
- Neyraud, E., Prinz, J. and Dransfield, E. (2003). NaCl and sugar release, salivation and taste during mastication of salted chewing gum. *Physiology and Behaviour*. 79: 731–737.
- Nguyen, L., Gal, R. and Bunka, F. (2011). Use of phosphates in meat products. *African Journal of Biotechnology*. 10(8):9874-9882.
- Nishimura, T., Hattori, A. and Takahashi, K. (1995). Structural weakening of intramuscular connective tissue during conditioning of beef. *Meat Science*. 39:127–133.

- Nishimura, T., Hattori, A. and Takahashi, K. (1999). Structural changes in intramuscular connective tissue during the fattening of Japanese black cattle: Effect of marbling on beef tenderisation. *Journal of Animal Science*. 77:93 – 104.
- Nummer, B. A., Harrison, J. A., Harrison, M. A., Kendall, P., Sofos, J. N. and Andress, E.L.(2004). Effects of preparation methods on the microbiological safety of home-dried meat jerky. *Journal of Food Protection*. 67(10): 2337–2341.
- Nychas, G. J. E., Skandamis, P. N., Tassou, C. C. and Koutsoumanis, K.P. (2008). Meat spoilage during distribution. *Meat Science*. 78: 77–89.
- Offer, G. and Knight, P. (1988). The structural basis of water-holding in meat. Part 1: General principles and water uptake in meat processing. In: *Developments in Meat Science*. (Editor. R. A Lawie). London: Elsevier Applied Science. pp 63–171.
- Okos, M. R., Campanella, O., Narsimhan, G., Singh, R. K. and Weitnauer, A. C.(2007). Food dehydration. In: *Handbook of Food Engineering*. 2nd edition. (Editors. D. R. Heldman and D. B. Lund). Taylor and Francis Group, Boca Raton, Fla: USA. pp601- 743.
- Omojasola, P. F., Jilani, O. P. and Ibiyemi, S. A. (2008). Cellulase production by some fungi cultured on pineapple waste. *Nature and Science* 6(2): 64-79.
- Oreskovich, D. C., Bechtel, P. J., Mc Keith, F. K., Novakofski, J. and Basgall, E. J. (1993). Marinade pH affects textural properties of beef. *Journal of Food Science*. 57: 305–311.
- Ockerman, H. W. and Organisciak, C. S. (1978). Diffusion of curing brine in tumbled and non-tumbled porcine tissue. *Journal of Food Protection*. 41:178–181.
- Ouali, A., Garrel, N., Obled, A., Deval, C., Valin, C. and Penny, I.F. (1987). Comparative action of cathepsins D, B, H, L and of a new lysosomal cysteine proteinase on rabbit myofibrils. *Meat Science*. 19:83–100.
- Park, C. J. and Park, C. S. (2007). The effects of drying method and spice extracts added to beef jerky on the quality characteristics of beef jerky. *Korean Journal of Food Cookery Science*. 23(4):800- 809.
- Parrish, F. C., Boles, J. A., Rust, R. E. and Olson, D. G. (1991). Dry and wet aging effects on palatability attributes of beef loin and rib steaks from three quality grades. *Journal of Food Science*. 56: 601–603.
- Pawar, V. D., Surve, V. D. and Machewad, G. M. (2003). Tenderisation of chevon by papain and trypsin treatments. *Journal of Food Science Technology*. 40:296-298.

- Payne, C. T. (2009). Enzymes. In: *Ingredients in Meat Products*. Springer Nature, pp. 173–198. Retrieved from <http://dx.doi.org/10.1007/978-0-387-71327-48>.
- Pearson, A. M. (1966). Desirability of beef its characteristics and their measurement. *Journal of Animal Science*. 25: 843.
- Pearson, A. M. and Gillett, T. A. (1999). Curing In: *Processed meats*. (Editors. A.M. Pearson and T.A. Gillett). Aspen Publication Inc: Gaithersburg, Maryland. pp 448.
- Pearson, A. M. and Young, R. B. (1989). Composition and structure. In: *Muscle and Meat Biochemistry* (Editor. A. M. Pearson) pp 1-33. Academic Press: San Diego.
- Pegg, R. B., Amarowicz, R. and Code, W. E. (2006). Nutritional characteristics of emu meat and its value added products. *Food Chemistry*. 97: 193 - 202.
- Phillips, C. A. (1996). Review: Modified atmosphere packaging and its effects on the microbiological quality and safety of produce. *Journal of Food Science and Technology*. 31:463-479.
- Pietrasik, Z. and Shand, P. J. (2008). Effect of proteases from *Bacillus subtilis* and *Aspergillus oryzae* on the tenderness of beef. *CMSA News* March 2008.
- Pin, C. G., Fernando, G- De. and J. A. Ordonez, J. A. (2002). Effect of modified atmosphere composition on the metabolism of glucose by *Brochothrix thermosphacta*. *Applied Environmental Microbiology*. 68:4441-4447
- Plimpton, R. F., Perkins, C. J., Sefton, T. L., Cahil, V. R. and Ockerman, H. W. (1991). Rigor condition, tumbling and salt level influence on physical, chemical and quality characteristics of cured, boneless hams. *Journal of Food Science*. 56:1514 - 1518.
- Poligne, I., Collignan, A. and Trystram, G. (2001). Characterisation of traditional processing of pork meat into Boucane. *Meat Science*. 59(4): 377–389.
- Priolo, A., Micol, D. and Agabriel, J. (2001). A review: Effect of grass feeding systems on ruminant meat colour and flavour. *Animal Research* 50(3): 185-200.
- Purslow, P. P. (2005). Intramuscular connective tissue and its role in meat quality. *Meat Science*. 70: 435-447.
- Quintas, M., Guimarães, C., Baylina, J., Brandão, T. R. S. and Silva, C. L. M. (2007). Multiresponse modelling of the caramelisation reaction. *Innovative Food Science and Emerging Technologies* 8 (2): 306–315.
- Quinton, R. D., Cornforth, D. P., Hendricks, D. G., Brennan, C. P. and Su, Y. K. (1997). Acceptability and composition of some acidified meat and vegetable stick products. *Journal Food Science*. 62:1250-1254.

- Rahman, M. S., Guizani, N., Al-Ruzeiki, M. H. (2004). D and Z-values of microflora in tuna mince during moist- and dry-heating. *Lebensm.-Wiss. U.-Technol. Food Science and Technology*. 37: 93-98.
- Ranken, M. D. (2000). Handbook of Meat Product Technology. Blackwell Science Ltd., Oxford.pp29.
- Rao, M. V., Gault, N. F. S. and Kennedy, S. (1989). Variations in water holding capacity due to changes in the fibre diameter, sarcomere length and connective tissue morphology of some beef muscles under acidic conditions below the ultimate pH. *Meat Science*. 26: 19-37.
- Rawdkuen, S. and Benjakul, S. (2012). Biochemical and microstructural characteristics of meat samples treated with different plant proteases. *African Journal of Biotechnology*. 11(76): 14088-14095.
- Rawdkuen, S., Pintathong, P., Chaiwut, P. and Benjakul, S. (2011). The partitioning of protease from *Calotropis procera* latex by aqueous two-phase systems and its hydrolytic pattern on muscle proteins. *Food Bioproducts Processing*. 89:73-80.
- Ray, B. and Bhunia, A. (2013). Technology and Engineering. In: Fundamental Food Microbiology, 5th Edition. CRC Press. Boca Raton. London New York. pp256.
- Rich, L. M. and Foegeding, E. A. (2000). Effects of sugars on whey protein isolate gelation. *Journal of Agricultural and Food Chemistry* 48 (10): 5046-5052.
- Ricke, S. C. (2003). Perspectives on the use of organic acids and short chain fatty acids as antimicrobials. *Poultry Science*. 82:632-639.
- Ritchey, S. J., and Hostetler, R. L. (1964). Relationships of free and bound water to subjective scores for juiciness and softness and to changes in weight and dimensions of steaks from two beef muscles during cooking. *Journal of Food Science*. 29: 413-419.
- Robson, R. M., Huff-Lonergan, E., Parrish, Jr. F. C., Ho, C.Y., Stromer, M. H., Huiatt, T. W., Bellin, R. M. and Sernett, S. W. (1997). Postmortem changes in the myofibrillar and other cytoskeletal proteins in muscle. 50th Annual Reciprocal Meat Conference, Ames, Iowa, USA. American Meat Science Association. 50:43-52.
- Romans, J. R., Costello, W. J., Carlson, C. W., Greaser, M. L. and Jones, K. W. (1994). The Meat We Eat. Danville, I: Interstate, Inc. pp1193.
- Ruusunen, M. and Puolanne, E. (2005). Reducing sodium intake from meat products. *Meat Science*. 70(3): 531-541.
- Sallam, Kh. I., Ishioroshi, M. and Samejima, K. (2004). Antioxidant and antimicrobial effects of garlic in chicken sausage. *Lebensm.-Wiss. u.-Technology*. 37:849-855.

- Samelis, J. and Sofos, J. (2003). Organic acids. In: Natural Antimicrobials for the Minimal Processing of Foods. (Editor. S. Roller), CRC Press, Florida. pp98–132.
- Santchurn, S. J., Arnaud, E., Zakhia- Rozis, N. and Collignan, A. (2012). Handbook of Meat and Meat Processing. Drying: Principles and Applications. 2nd edition. pp 505.
- Sasse, A., Colindres, P. and Brewer, M. S. (2009). Effect of natural and synthetic antioxidants on oxidative stability of cooked, frozen pork patties. *Journal of Food Science*. 74: 30-35.
- Savell, J. W., McKeith, F. K. and Smith, G. C. (1981). Reducing postmortem aging time of beef with electrical stimulation. *Journal of Food Science*,46:1777-1781.
- Shackelford, S. D., Koohmaraie, M. and Wheeler, T. L. (1995). Effects of slaughter age on meat tenderness and USDA carcass maturity scores of beef. *Journal of Animal Science*.73: 3304-3309.
- Shackelford, S. D., Koohmaraie, M., Miller, M. F., Crouse, J. D. and Reagan, J. O. (1991). An evaluation of tenderness of the *Longissimus* muscle of angus by Hereford versus Brahman crossbred heifers. *Journal of Animal Science*. 69: 171 – 177.
- Shackelford, S. D., Koohmaraie, M., Cundiff, L. V., Gregory, K. E., Rohrer, G. A. and Savell, J. W. (1994). Heritability and phenotypic and genetic correlations for bovine postrigor calpastatin activity, intramuscular fat content, Warner-Bratzler shear force, retailproduct yield, and growth rate. *Journal of Animal Science*.72: 857-863.
- Shahidi, F. (1994). Assessment of lipid oxidation and off-flavor development in meat and meat products. In:Flavour of Meat and Meat Products. 1st edition.Chapman and Hall: London, U.K.pp 247 – 266.
- Sharma, B. D and Nanda, P. K. (2002). Studies on the development and storage stability of chicken chips. *Indian Journal of Poultry Science*.37: 155-158.
- Shiby, V .K., Tabassum, A., George, J., Pandey, M. C and Radhakrishna. K. (2015). Effect of drying methods on moisture sorption, microstructure and other quality characteristics of chicken cubes. *International Journal of Advanced Research*. 3(12):1200 – 1213.
- Shimokomaki, M., Franco, B. D. G. M., Biscontini, T. M., Pinto, M. F., Terra, N. N. and Zorn, T. M.T. (1998). Charqui meats are hurdle technology meat products. *Food Review International*. 14:339-349.
- Singh, V., Sanyal, M., Dubey, P. and Mendiratta, S. (2011). Quality assessment of vacuum packaged chicken snacks stored at room temperature. *Journal of Stored Products and Postharvest Research*. 2(6): 120-126.

- Singleton, P. (1999). *Bacteria in Biology, Biotechnology and Medicine*. 5th edition. Wiley. Hoboken. pp. 444 – 454. ISBN 0 – 471 – 98880 – 4.
- Smith, D. P., and Acton. J. C. (2001). Marination, cooking and curing of poultry products. In: *Poultry meat science*. (Editor. A. R. Sams) CRC Press, Boca Raton, FL pp 57 – 280.
- Smith, G. C. (1972). Relationship of the cow-calf producer to the consumer. In: *Commercial beef cattle production*. Lea and Febiger, Philadelphia, Pa.
- Smith, G. C., Carpenter, Z. L. Cross, H. R., Murphey, C. E., Abraham, H. C. Savell, J. W., Davis, G. W., Berry, B. W. and Parrish Jr, F. C. (1984). Relationship of USDA marbling groups to palatability of cooked beef. *Journal Food Quality*. 7: 289-308.
- Smith, S. B. and Crouse, J. D. (1984). Relative contributions of acetate, lactate and glucose to lipogenesis in bovine intramuscular and subcutaneous adipose tissue. *Journal of Nutrition* 114: 792-800.
- Smith, G. C., Pike, M. I. and Carpenter, Z. L. (1974). Comparison of the palatability of goat meat and meat from other animal species. *Journal of Food Science*. 39:1145 – 1146.
- Smith, G. C., Tatum, J. D. and Belk, K. E. (2008). International perspective: characterisation of United States Department of Agriculture and Meat Standards Australia systems for assessing beef quality. *Australian Journal of Experimental Agriculture*, 48: 1465-1480.
- Sofos, J. N., Beuchat, L. R., Davidson, P. M. and Johnson, E. A. (1998). *Naturally Occurring Antimicrobials in Food*, Task force report No.132. Council for agricultural Science and Technology, Ames, IE pp103.
- Spielman, A. I. (1990). Interaction of saliva and taste. *Journal of Dental Research*. 69: 838-843.
- Stanton, C. and Light, L. (1989). The use of pre-rigor lactic acid injection to accelerate conditioning in bovine meat. *Meat Science* 27: 141 – 159.
- Stanton, C. and Light, N. (1990). The effects of conditioning on meat collagen: Part 4—the use of pre-rigor lactic acid injection to accelerate conditioning in bovine meat. *Meat Science*. 27: 141–159.
- Sullivan, G. A. and Calkins, C. R. (2010). Application of exogenous enzymes to beef muscle of high and low-connective tissue. *Meat Science*. 85:730-734.
- Surimi and Surimi Seafood, (2013). 3rd Edition. (Editor. J. W. Park). *Technology and Engineering* CRC Press, Taylor and Francis Group. Boca Raton. London New York. pp376.

- Sumner, J. and Jenson, I. (2011). The effect of storage temperature on shelf life of vacuum-packed lamb shoulders. *Food Australia*, 63:249–251.
- Tajkarimi, M. M., Ibrahim, S. A. and Cliver, D. O. (2010). Antimicrobial herb and spice compounds in food. *Food Control*. 21(9): 1199-1218.
- Takagi, H., Kondou, M., Hisatsuka, T., Nakamori, S., Tsai, Y. C. and Yamasaki, M. (1992). Effects of an alkaline elastase from an alkalophilic *Bacillus* strain on the tenderisation of beef meat. *Journal of Agric Food Chemistry*. 40:2364-2368.
- Talib, M. A., Hassan, M. A., Bouba, A. I., Ngargueudedjim, K. (2014). Microbiological properties of cows meat dehydrated using solar drying, sun drying and oven drying. *Journal of Medical and Biological Sciences*. 3(3):1-4
- Tang, X. and Cronin, D. A. (2007). The effects of brined onion extracts on lipid oxidation and sensory quality in refrigerated cooked turkey breast rolls during storage. *Food Chemistry*. 100: 712–718.
- Taormina, P. J. (2010). Implications of salt and sodium reduction on microbial food safety. *Critical Reviews in Food Science and Nutrition*. 50 (3): 209-227.
- Tiwari, B. K., Valdramidis, V. P., O'Donnell, C. P., Muthukumarappan, K., Bourke, P. and Cullen, P. J. (2009). Application of natural antimicrobials for food preservation. *Journal of Agricultural and Food Chemistry*, 57: 5987-6000.
- Torres, E. A. F. S., Shimokomaki, M., Franco, B. D. G. M., Landgraf, M., Carbalho, B. C., and Santos, J. C. (1994). Parameters determining the quality of charqui, an intermediate moisture meat product. *Meat Science*. 38: 229-234.
- Townsend, W. E. and Olson, D. G. (1987). Cured and cured meat products processing. In: *The Science of Meat and Meat Products*, (Editors. J. F. Price. and B. S Schweigert). Food and Nutrition Press: Westport, Connecticut. pp 431 – 456.
- Troller, J. A. (1976). *Staphylococcal* growth and enterotoxin production factors for control. *Journal of Milk Food Technology*. 39: 499-503.
- USDA – FSIS, (2004). U.S. Department of Agriculture–Food Safety and Inspection Service (USDA-FSIS). Compliance guideline for meat and poultry jerky. USDA-FSIS, Washington, D.C. Available at: <http://www.fsis.usda.gov/OPPDE/nis/outreach/models/Jerkyguidelines.htm>.
- USDA – FSIS, (2005). U.S. Department of Agriculture, Food Safety and Inspection Service. 2005. Food standards and labeling policy book. Available at: http://www.fsis.usda.gov/OPPDE/larc/Policies/Labeling_Policy_Book_082005.pdf.

- Wada, M., Suzuki, T., Yaguti, Y. and Hasegawa, T. (2002). The effect of pressure treatments with kiwi fruit protease on adult cattle *Semitendinosus* muscle. *Food Chemistry*. 78:167-171.
- Weir, C. E. (1960). Palatability characteristics of meat. In: *The Science of Meat and Meat Products*. W. H. Freeman and Company, San Francisco, Calif. pp 156.
- Wenham, L. M. and Locker, R. H. (1976). The effect of marinade on beef. *Journal of Science of Food and Agriculture*. 27:1079-1084.
- Wentworth, E. N. (1956). Dried meat: Early man's travel ration. *Agricultural History*. 30: 2- 10
- Wheeler, T. L., Cundiff, L. V., Shackelford, S. D. and Koohmaraie, M. (2004). Characterisation of biological types of cattle (Cycle VI): Carcass, yield and *longissimus* palatability traits. *Journal of Animal Science*. 82(4):1177-1189.
- Wheeler, T. L., Koohmaraie, M., Lansdell, J. L., Siragusa, G. R., and Miller, M. F. (1993). Effects of postmortem injection time, injection level, and concentration of calcium chloride on beef quality traits. *Journal of Animal Science*. 71: 2965-2974.
- Wheeler, T. L., Shackelford S. D., Koohmaraie, M. (1996). Sampling, cooking, and coring effects on Warner-Bratzlershear force values in beef. *Journal of Animal Science*. 74:1553–1562.
- Wijayawardana, K. H. R., Cyril, H. W. and Fonseka, T. S. G. (2001). Effect of different marinades on the tenderness of beef. *Tropical Agricultural Research*. 13:61-68.
- Wilson, N. R. P. Dyerdt, E. J., Hughes, B. R., Jones, C. R. V. (1981). Meat and meat products. In: *Factors affecting quality control*. 5th edition, pp 81 – 108. (Applied Science: London).
- Wongwiwat, P. and Wattanachant, S. (2014). Effect of sugar types on physical attributes and crystalline structure of sweet dried chicken meat products. *International Journal of food research*. 12 (6):2285 – 2291.
- Xargayo, M., Lagares, J., Fernández, E., Ruiz, D., Borrell, D. (2001). Marination of fresh meat by means of spray effect: Influence of spray injection on the quality of marinated products. *Fleischwirtschaft*. 70-74
- Xiao, S., Zhang, W., Lee, E., Ma, C. and Ahn, D. (2011). Lipid and protein oxidation of chicken breast rolls as affected by dietary oxidation levels and packaging. *Journal of Food Science*. 76(4) C612-C617.
- Xiong, Y. L. and Kupski, D. R. (1999). Time-dependent marinade absorption and retention, cooking yield and palatability of chicken fillets marinated with various phosphate solutions. *Poultry Science* 78:1053-1059.

- Yang, H. S., Hwang, Y. H., Joo, S. T. and Park, G. B. (2009). The physicochemical and microbiological characteristics of pork jerky in comparison to beef jerky. *Meat Science*. 82:289-294.
- Yang, S. H., Lee, E. J., Moon, S. H., Paik, H. D., Nam, K. and Ahn, D. U. (2011). Effect of garlic, onion, and their combination on the quality and sensory characteristics of irradiated raw ground beef. *Meat Science*. 89(2):202 – 208.
- Yoon, Y., Skandamis, P. N. and Kendall, P. A. (2006). A predictive model for the effect of temperature and predrying treatments in reducing *Listeria monocytogenes* populations during drying of beef jerky. *Journal of Food Protection*. 69(1): 62-70.
- Young, J. E. and Yang, R. (1975). Studies on the ageing of bovine muscle on adding proteolytic enzyme. V. studies on the tenderness evaluation of bovine muscle treated with papain by using penetration value. *Korea Journal of Food Science and Technol.* 7:208.
- Zhou, G.H., Xu, X. L. and Liu, Y. (2010). A review: Preservation technologies for fresh meat. *Meat Science* 86(210)119-128.

