EFFECTS OF INCLUSION OF GUAVA FRUIT PROCESSING BY-PRODUCT IN BROILER CHICKEN DIETS ON PERFORMANCE

EDITH BOSIBORI OGEGA, BVM (UON)

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR MASTERS OF SCIENCE DEGREE IN ANIMAL NUTRITION AND FEED SCIENCE OF THE UNIVERSITY OF NAIROBI

DEPARTMENT OF ANIMAL PRODUCTION

2022

DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

Signed Date…12th July 2022

EDITH BOSIBORI OGEGA

J57/13187/2018

This thesis has been submitted for examination with our approval as University Supervisors.

Signed……… …… Date……12th July 2022

Prof. Charles K. Gachuiri, PhD

Department of Animal Production

The University of Nairobi.

Signed: Date: 12th July 2022

Dr. George O. Abong, PhD

Department of Food Science, Nutrition and Technology

University of Nairobi

Signed Date: 12th July 2022

Prof. Joyce G. Maina

Department of Animal Production

University of Nairobi

ACKNOWLEDGMENT

I wish to thank God for giving me good health and strength, which enabled me to finish my studies. Thanks to the Fruits and Vegetables for all Seasons (FruVaSe) project for the funding to carry out this study.

I wish to express my appreciation and gratitude to my supervisors Profs. Charles Gachuiri, Joyce Maina and Dr. George Abong for their encouragement, guidance, and tireless assistance in reading, correcting and discussing this thesis.

I want to acknowledge Dr. Felix Kibegwa for the constant advice, motivation, and assistance he gave me during data cleaning and analysis. I am grateful to Mr. Benjamin Kyalo for his assistance during the entire research project, data collection, and laboratory work. I appreciate the assistance of Mr. Samwel Karanja in taking care of the experimental birds, helping in data collection, and the humane slaughter of the birds at the end of the experimental period. My thanks also go to Sam Githua, Mercy Wairimu, Purity Gaki, Michael Waweru and John Kanyi for their help during the research period. The assistance provided by my friends Lilian Musembei and Faduma Abdullahi is greatly appreciated.

Lastly, I would like to warmly appreciate my family. My parents David and Gladys Ogega, for the love, constant encouragement, and financial support. I thank my siblings for their tireless support.

DEDICATION

To my parents and siblings.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AODF - antioxidant dietary fiber

FAO – Food and agriculture organization

GDP – Gross domestic product

HCD – Horticultural crops directorate

HCDA – Horticultural crops development authority

HPAI –Highly pathogenic avian influenza

KALRO – Kenya agricultural and livestock research organization

MoLD – Ministry of livestock development

ABSTRACT

The utilization of fruit wastes as animal feed can contribute to alleviating feed shortages in most third-world countries and simultaneously help mitigate challenges in the environment that are caused by the disintegration of the wastes. A study was done to determine the effects of the inclusion of guava fruit processing by-product in broiler chicken diets on performance. Ripe guava fruits were crushed and sieved to separate the pulp from the peels, seeds, and other fibrous content. The separated peels, seeds, and other fibrous content (referred to as the guava fruit processing by-product) was sun-dried and stored. The guava fruit processing by-product was incorporated in broiler chicken feeds at different levels 0% (GB0), 2.5% (GB2.5), 5% (GB5) and 7.5% (GB7.5). Formulated diets were iso-nitrogenous and iso-caloric in mash form for the starter and finisher phases. One hundred and sixty (160) day-old cobb-500 broiler chicks bought from a reputable commercial hatchery (kenchic Ltd) were allocated randomly to the four diets and replicated four times with ten birds in each replicate. The feed intake, weight gained and feed conversion ratio were assessed. A digestibility trial of the finisher diet was carried out at the end of the feeding period. After the end of the feeding trial, some of the birds for each treatment were slaughtered and carcass characteristics evaluated.

The average daily weight gain was not affected ($p>0.05$) between GBO (56.53g), GB2.5 (54.88g), and GB5 (61.02g) but reduced ($P<0.05$) (45.68g) at higher (GB7.5) inclusion level. The average daily feed intake was similar for GB0 (59.03g) and GB2.5 (59.21g) ($p>0.05$) but increased at GB5 (62.47). The mean daily feed intake and weight gain at (GB7.5) were significantly lower ($p<0.05$) compared to ther other 3. Feed conversion ratio (FCR) was ($p>0.05$) 1.58, 1.66, 1.64 and 1.72 for the diets (GB0), (GB2.5), (GB5) and (GB7.5) reaspectively. The digestibility of the different nutrients was not significantly affected by diet. The absolute weights of the eviscerated carcass, the abdominal fat, drumstick, thigh, breast, heart, liver, spleen, gizzard, and the intestines were not affected by diet. Inclusion level did not affect the meat pH, color, crude protein, and ether extract content of the chicken breasts and thighs. The different diets did not affect the sensory attributes: after taste, fibrousness, hardness, juiciness, and oiliness. Overall acceptability was significantly affected by inclusion levels, GBO scored highest (5.4) and was different from GB2.5 (4.9), GB5 (4.91), and GB7.5 (4.58) ($p>0.05$).

According to the findings, the guava fruit processing by-product could be included up to 5% in broiler rations with no negative consequences on the growth performance and carcass characteristic.

Key words: broilers, digestibility, performance, guava by-product, meat quality

CHAPTER ONE:

INTRODUCTION

Background Information

Poultry plays a vital role in the livelihoods of people, making a significant contribution to domestic food security world wide. Poultry aids in the diversification of earnings and employment, renewable asset, and contributes to livelihood and social security (Riise *et al.,* 2005; Sonaiya, 2015). Poultry is not only a source of food but also a source of fertilizer from poultry manure, tourism, culture, and sports (Omiti & Okuthe, 2008).

Feed comprises up to 60-70% of the production cost in commercial poultry systems (Lukuyu *et al.*, 2011), with about 95% of the total feed cost being attributed to energy and protein sources (Abdollahi *et al.*, 2013). Poultry feed to satisfy their energy requirement and as such, energy source ingredients comprise the largest proportion of poultry diets, followed by protein sources (FAO, 2013).

In the developed world, there has been rerouting of maize grains from animal feeds to ethanol production leading to serious grain supply problems and a dramatic increase in prices in the world market (FAO, 2013). In Kenya, where maize is the staple food, it may not be available for animal feed and, if available, at a very high price (Jacob *et al.*, 1996). The increased cost of production leads to higher prices of poultry products. To increase margins for the farmer, different cheaper feed ingredients are to be sought (FAO, 2013).

The use of ingredients from the food processing industry, mainly from cereals, is common in Kenya (Hasan *et al*., 2007). However, there has been a minimal attempt to use by-products from the fruit processing industries. This has been attributed to the fact that most of the agro-industrial processing is based on cereals, as in many other developing countries, where the population consumes diets with carbohydrate-rich cereals and less high-value meat, fruits, and vegetables (Industries & Development, 2009). Consumers in developing countries are now shifting their demand towards foods that reflect increased nutrient value and also value-added products (Gehlhar & Regmi, 2014).

Due to increased awareness of health benefits of fruit consumption, the processing industry is expanding (Ayala *et al*., 2011). Wastes from the processing of fruits pose a problem of environmental pollution which is of great concern. The process of disposing of the wastes by utilizing them as animal feeds and fertilizers could be a good option (Jorge, 2005).

The guava fruit is referred to as a 'tropical apple' or a 'fruit of the poor' and is common under the subtropical and tropical climate (Singh, 2007). Due to its many nutrients, it is known as a super fruit (Verma *et al.*, 2013). It contains high levels of natural vitamin C compared to oranges and tomatoes (Singh, 2007). The by-products from guava fruit processing include seeds, peels, and fibrous tissue from the skin that are a result of pulping (Omayio *et al*., 2019; Kowalska *et al.*, 2017). By-products from fruit processing have high amounts of bioactive substances plus dietary fibers (O'Shea *et al*., 2015). The utilization of guava processing by-products as animal feed has recently been ranked highly by FAO (Bakshi *et al.*, 2016). In Kenya, there has been a recorded increase in guava fruit production and the area under guava production with a lot of unexploited potential (HCD, 2014; HCD, 2016; HCD, 2017).

Guava wastes have been used as animal feed ingredients, including in rations of layers, broilers, pigs, lambs, and rabbits. The adoption of guava by-products in poultry feed has been documented (El-Deek *et al*., 2009; El-Deek *et al*. 2009b: Oliveira *et al.*, 2018). However, there is no documentation of the use of different guava by-products as animal feed in Kenya. Little is also known about their nutritional composition (of the by-products), and thus there is a need for documentation of the same. The need for this information is due to the increased guava growing in Kenya, which will lead to increased processing, thus more by-products.

This study assessed the outcomes of the inclusion of guava fruit processing by-product in the feeds of broiler chicken on the amount of feed consumed and weight gained, digestibility, carcass yield, and carcass traits.

Problem statement

The world population is rising, with much of the increase (3.5-fold) happening in Africa (Gerland *et al*., 2014; Onsongo et al., 2018). By 2050, 60–70% more animal protein will be demanded in the world (Bakshi *et al*., 2016). Increased output of poultry meat is unavoidable, and it is likely to exacerbate the problem of expensive regular feeding (Onsongo *et al*., 2018). As livestock is one of the fast-growing subsectors of agriculture in emerging countries, this has resulted in increased demand for animal feeds. Lack of high-quality feeds and food insecurity are the major problems in the developing world, leading to food-feed competition (Bakshi *et al*., 2016).

Since feed represents 60-70% of the cost of poultry farming, alternate feed ingredients need to be frequently evaluated (Leeson, S., 2005). There is a need to enlarge the feed resource base and ensure there is an efficient use of available ones to meet the demand for animal feed. Novel feed sources, especially those that are not competing with human food, are key in the development of the livestock sector.

In the fruit processing industry, waste disposal has become an environmental problem (Fontanari et al., 2008). Environmentalists are disturbed by the pollution generated by the wastes disposed of from the agro-industries reinforcing the requirement for waste management (Jorge, 2005; Hussain *et al*., 2019). Agro-industrial processing generates millions of tons of by-product around the world. Of the total byproducts produced, some amounts are used in fields as manure, some incorporated in animal feeds, and most are disposed to the environment without treatment leading to pollution *(*Sadh *et al*., 2018). The fate of the wastes as handled leads to economic losses in the supply chain as a good amount is enriched with bioactive compounds, and some are in a position of preventing oxidative damage (Melo *et al*., 2011; Maria *et al*., 2012). It may also lead to increased greenhouse gases emanation from the dumpsites and overall environmental pollution (Zhang *et al*., 2019).

Justification

Several developing countries are shifting their cropping patterns away from grains and towards more profitable vegetable and fruit crops (Wadhwa & Bakshi, 2013). As a result, massive amounts of fruit and vegetable waste will be produced in the future. By converting them to animal feed, these might potentially be recycled and returned to the food chain (Bakshi *et al*., 2016). The guava tree produces many fruits annually with minimal input, resulting in many farmers taking up commercial cultivation of the guavas due to the profit margins (Singh, 2007; Kadam *et al*., 2012; Omayio *et al*., 2020).

Animal feed made from fruits and vegetable waste can help to alleviate feed inadequacy in most underdeveloped nations (Wadhwa *et al*., 2015). Simultaneously, it will aid in the mitigation of environmental issues caused by the degradation of such wastes. To fully utilize the animal husbandry potential of such wastes and by-products, concerted research and commercial initiatives are required. The use of these wastes is also anticipated to lower feeding costs, resulting in increased profits for animal keepers (Bakshi *et al*., 2016).

The study will provide an alternative feed source that will not compete with human beings, which is relatively cheaper and a solution to environmental degradation.

Study Objectives

General objective

Effort to mitigate against cost of broiler production by using guava fruit processing by-product in broiler chicken feed as an alternative feed source.

Specific objectives

1. To determine the proximate composition of the guava by-product.
2. To determine the effects of inclusion of different levels of guava fruit processing by-product in broiler diets on the feed intake, live weight gain, feed conversion ratio and carcass quality.
3. To determine the digestibility of the formulated finisher diets.

Hypothesis

1. The inclusion of different levels of guava fruit processing by-product in the broiler feeds does not significantly influence feed intake, live weight gain, feed efficiency, and carcass quality.
2. The inclusion of different levels of guava fruit processing by-product in the broiler finisher feeds does not affect the digestibility of the diets.

CHAPTER TWO

LITERATURE REVIEW

The poultry industry in Kenya

The poultry sector contributes approximately 30% to agriculture's Gross Domestic Product (GDP) and about 7.8 percent of the total Kenya GDP, with the agriculture sector contributing 25% of the GDP (FAO, 2008; Omiti & Okuthe, 2008; Zootecnica international, 2016). Kenya has a population of approximately 44.6 million poultry, making it the most important enterprise for both food and nutrition security for poor rural households (Pius *et al*., 2021; MoLD, 2019). About 98% of the poultry is chicken, and 70% of the chicken is free-range chicken (MoLD, 2019). These birds are farmed in three common production systems, namely backyard, smallholder intensive, and industrialized (FAO, 2013).

The feed costs constitute the largest proportion of poultry production costs (Wainaina *et al*., 2012). Depending on the intensification, feeds account for 60-80% of the cost of production (MoLD, 2008). The major constraint affecting the development of poultry farming is the high cost of commercial feeds due to the rise in the price of typical feed constituents such as soybean meal, maize, meat meal, and fishmeal (Ravinadan, 2009; EL-Manylawi, 2011).

Constraints to poultry production

The constraints to commercial poultry production in Kenya can be grouped into those that are related to production, consist of thievery, illnesses, animals of prey, bad environment, inadequate production skills, bad nutrition, marketing, flock sizes, and high feed costs (Ondwasy *et al*., 2006; Cheptarus, 2010; Justus *et al.*, 2013). Various management treatments including feed augmentation, vaccination, brooding, housing, and labor are not being implemented (Justus *et al*., 2013; Murangiri *et al*., 2016). Farmers have poor accesability of institutional support (Justus *et al*., 2013). Chicken producers have a low degree of awareness about common poultry diseases, particularly possible zoonotic diseases (Murangiri *et al*., 2016).

There is underperformance in the poultry production industry due to unstructured marketing systems, importation of raw eggs, and underdeveloped markets that negatively affect the industry (MoLD, 2019). The occasional deluge of low-quality and cheap imported products in the market outcompetes the local products (MoLD, 2019). These imported products are cheap because of the low production cost in the neighboring countries (Mutua *et al*., 2019).

Because feed makes up 60-80% of the total production cost (MoLD, 2008; Fiaboe & Nakimbugwe, 2017), it has become a significant constraint to poultry production. The supply of quality feed is a factor of the quality of raw materials, price of the materials, processing method, and the handling and storage (MoLD, 2008). In a bid to lower the cost of production, alternative, cheaper feed sources are sought (Leeson, S., 2005).

In Kenya, the use of ingredients from the food processing industry, mostly from cereals, is common (MoLD, 2019). This is because much of the agro-industrial processing is based on cereals, as in many other developing countries where the population consumes diets with carbohydrate-rich cereals and less high-value meat, fruits, and vegetables (Industries & Development, 2009). Consumers in developing countries are now shifting their demand towards fruit and vegetable crops and their value-added products (Wadhwa & Bakshi, 2013; Gehlhar & Regmi, 2014). The increase in demand for value-added products from fruits and vegetables will result in more by-products and thus need to incorporate in poultry feeds (Wadhwa *et al*., 2015).

In sub-Saharan Africa, and Kenya included, poultry feed ingredients consist of fish meal, bone and meat meal as animal protein ingredient, sunflower seed cake, soybean meal, and cotton seed cake as plant-based protein sources (Ochieng et al., 2021). Maize serves as the primary energy source (Ochieng *et al*., 2021). The traditional protein sources in poultry feed are fish meal and soybean meal, and over time they are becoming expensive and scarce, thus increasing the cost of poultry feed (Van Huis, 2013; FAO, 2013; Ochieng *et al*., 2021). The soybeans produced in the country can only meet less than 35% of the county's demand. At the same time, fish demand is also high as it cannot sustain both the animal and human needs, thus leading to increased importation from other countries (Onsongo *et al*., 2018).

In the developed world, there has been rerouting of maize grains from animal feed to ethanol production leading to serious grain supply problems and a dramatic increase in prices in the world market (FAO, 2013). In Kenya, maize is a dietary staple and a major food crop; therefore, its increased use in animal feed has increased production costs. (de Groote *et al.*, 2010).

Guava production in Kenya

Guava production in Kenya is practiced by farmers with limited resources (Kochhar, 2018), mostly in the rural areas of Meru, Mandera, Kisii, and Migori (HCD, 2014). Kitui and Taita Taveta counties have recorded a high capacity of guava fruit production (Omayio et al., 2020). Limited knowledge and ignorance of the guava potential both economically and nutritionally are some of the factors that hinder the processing of guava fruits (Chiveu *et al.*, 2016). At the same time, little is known about the available intra-specific guava germplasm in Kenya (Chiveu *et al*., 2016). Guava fruit is considered by local communities to be a fruit for the birds to feed on or to be eaten by herders as they tend to animals with little knowledge on value-addition for earning income (http://farmbizafrica.com, 2018).

Kenya has very diverse ecological zones allowing for the growth of different varieties of white-fleshed, strawberry, and pink-fleshed guava (Mahmoud *et al.*, 2013). The fruit may be eaten raw or processed, and it has a large market potential because it can grow in a variety of environments, including wastelands and soils with high pH levels, which explains its wide spread (Gautam *et al.*, 2010). The therapeutic benefits of the leaves, fruits, flowers, bark, roots, and stems have been used for centuries (Rosa *et al.*, 2008). Over the years, the guavas have been farmed and dispersed by humans and other animals, making their source unclear, with their worldwide production increasing through the years (Pommer *et al.*, 2009).

In Kenya, guava fruits are mainly grown for the fresh market, with an increase in production recorded in the year 2014 compared to the year 2013 (HCD, 2014). There exists an unexploited potential of most fruits in Kenya, guava being one of them (HCD, 2016). However, the area under guava production has also increased (HCD, 2017). The information on guava production, utilization, consumption, the area under production, and commercialisation is minimal (HCD, 2014; Omayio *et al.*, 2019; Omayio *et al.*, 2020).

There is a need for the development of structure and policy with the aim of maximizing the use of the guava fruits and reducing losses during post-harvest (Omayio et al., 2019). The Kenya Agricultural & Livestock Research Organization (KALRO) is on record as being on the frontline to promote guava production by providing seedlings to farmers (http://farmbizafrica.com, 2018).

Guava processing

In as much as the guava fruits are consumed while fresh, processing to other products can be done thus improving the fruits' market potential (McMullin et al., 2016; Chiveu, 2018). Guava being a climacteric fruit its rate of perishability is high, and it is highly susceptible to mechanical and chilling injuries resulting in qualitative losses and reduction of its market value (Rana et al., 2015;

Phani et al., 2016). There is a need to process the fruits to prevent/reduce the post-harvest losses (Bhuvaneswari & Tiwari, 2007) and to develop affordable guava processing technologies which can be adopted (Nikhanj *et al*., 2017).

The wastes from guava processing that contain peels, seeds, and leftovers from pulping make 30% of the guava (Oliveira *et al.*, 2020). Residue from guava fruit pulp processing is mainly composed of seeds and other fibrous tissues and it accounts for 4% to 12% of the pulp (Uchôa-thomaz *et al.*, 2014). The guava by-product made up of seeds, peelings, and pulp from industries that are most times discarded into the environment without treatment lead to environmental pollution (Chang *et al*., 2014). Kamel *et al*. (2016) documented that the guava agro-industrial wastes discarded in the environment become regarded as an environmental issue due to buildup in large and valueless amounts.

In Kenya, guava processing is relatively low as compared to other countries where the fruit has been processed to increase its shelf life and through value addition products (Kwambai & Wambani, 2000; Daily, 2012; Kumari *et al.*, 2017). The low level of processing of guava fruits in Kenya may be attributed to; processing and preservation procedures not being used to their full potential, minimal research as well as low knowledge on the economic potential of the fruit, and consequently, there are no well-organized marketing, distribution, and handling structures for the guava value chain (Wasilwa *et al*., 2018; Chiveu, 2018; Omayio *et al*., 2019). The small amount of information on guava processing and its constraints have made it hard to establish a sustainable value chain (Omayio *et al*., 2019).

Guava processing by-products

Different guava processing techniques result in various by-products. Different studies have described guava by-products differently. 'Decanter' refers to a guava by-product that is collected after decantation where the juice is separated from the pulp. The decanter is made up of a solid residue that is 10% of the processed guava pulp (Oliveira *et al*., 2018).

Guava by-products have also been referred to as ’guava waste,’ which contains inedible fruits, pulp, and peels obtained from the canning industry in Egypt (El-Deek et al., 2009a). Guava by-products (inedible fruits, pulp, and peel) are generated in large quantities from the industries (El-Deek *et al*., 2009; El-Deek *et al*., 2009b). Farid & Kamel (2016) reported guava waste to contain pulp, peels, and seeds. Lira et al., (2009), referred to the guava by-product as waste that mainly consists of seeds and makes 4% to 30% of the fruit.

The term ‘residue’ has also been used to refer to guava by-products, and it is mainly composed of seed and pulp, and it accounts for around 4% to 12% of the entire guava fruit and is collected after processing of pulp from guava fruits (Uchôa-thomaz *et al*., 2014). ‘Pomace’ refers to the by-product obtained after extracting pulp and accounts for 30-35% of the fruit and contains guava seeds and a guava rid (Rao *et al*., 2004; Bakshi *et al*., 2016).

Chemical composition of Guava processing by-products

By-products from guava fruit processing have been reported to have different chemical composition; this can be attributed to the different processing techniques. The crude protein (CP) content of the by-products has been reported to range from 9.08 to 10.09% (da Silva *et al*., 2009; El-Deek *et al*., 2009; Lira *et al*., 2009; El-Deek *et al*., 2009b). Ether extracts (EE) content from different studies ranged from 4.52 to 12%, the wide range was due to the different treatments the guava by-product was put through (da Silva *et al*., 2009, Lira *et al*., 2009, El-Deek *et al.*, 2009a, El-Deek *et al.*, 2009b). The crude fiber (CF) content of the guava by-product is generally high with a reported range of 39.5% to 56.01% (Marquina *et al*., 2008; Silva *et al*., 2009; Lira *et al*., 2009; El-Deek *et al*., 2009; El-Deek *et al*., 2009b). The gross energy (GE) content ranged between 3636 kcal/kg and 4,724 kcal/kg (El-Deek *et al*., 2009; Silva *et al*., 2009). The reported crude ash amount was between 1.25% and 5.62% (El-Deek *et al*., 2009b; Silva et al., 2009).

Inclusion of guava processing by-products in livestock rations

Guava processing by-products have been included in rations for poultry (layers and broilers), rabbits, lambs, and pigs. In an experiment by Rao *et al*. (2004) to determine the consequences of the addition of Guava pomace in swine feeds, crossed boars were fed on diets containing sun-dried the guava pomace at 0%, 10%, 20%, and 30% levels at the grower and finisher level. The study concluded that the addition of guava pomace did notsignificantly influence the growth performance and the traits of the carcass.

El-Deek *et al*. (2009) fed finishing broilers with treated (autoclaved, alkaline, and acid) and raw guava by-products at the inclusion levels of 2%, 4%, 6%, and 8%, to determine whether the guava by-product could be used in broiler feed. The study concluded that guava by-products that had been dried in the sun at a 4% inclusion level could be used efficiently with no negative effects on performance measures.

El-Deek *et al*. (2009b) fed laying hens on processed and unprocessed guava by-products at different inclusions (5, 10, and 15%). They concluded that the inclusion of up to 15% sundried guava by-products was acceptable and had no adverse effects on egg quality and productive performance, and thus could be used as a feed ingredient source. There was no need to process the sundried guava by-product (El-Deek *et al*., 2009b). The processing and treatment (boiling in water, acid and alkaline solutions) were done to better the low nutritive value of the guava by-product that contained inedible fruits, seeds, peels, the pulp (González *et al*., 2007; García *et al.*, 2008; El-Deek *et al.*, 2009).

Lira *et al*. (2009) fed broiler chicken diets with different guava waste inclusion at 3%, 6%, 9%, and 12% to evaluate the effects on carcass yield and performance of the broiler birds. The study reported that the inclusion of up to 12% was recommended as it's performance was higher than that of the control..

Mosaad & Hassan (2016) reported no significant difference in growth performance, digestibility of nutrients, carcass characteristics, and quality of meat of Ossimi lambs fed on diets containing 0%, 10%, and 20% guava. The guava waste inclusion had a significant economic effect as the diets with diet with 10% inclusion reduced cost by 51 Egyptian Pounds/ton and the diet with 20% 127.13 Egyptian Pounds/ ton.

Digestibility of guava based diets

Digestibility of a ration is dependent on the age, species, and strain of an animal, the ingredient composition, and the processing (Longo *et al*., 2005; Zarei *et al*., 2014; Oliveira *et al*., 2018; Atchade *et al*., 2019). The fraction of feed ingested that is not found in the fecal material is said to be digestible. Digestibility accounts for the loss of feed along the intestinal duct, but not on how it can be efficiently used in the metabolism of the animal (Atchade *et al*., 2019). A portion of feed can be highly digestible without supplying enough nutrients to meet the animal's nutritional requirement. (Atchade *et al*., 2019).

To determine the digestibility of feed, (Litz *et al*., 2017) used the formula;

Digestibility = ((ingested nutrient quantity - Excreted) / ingested nutrient Quantity) * 100

Guava by-products have a high fiber content that mainly constitutes pectin and lignin and thus has a limited digestion capacity (El-Deek *et al*., 2009b). The pectin constituent of the fiber content forms a viscous gel matrix (Mudgil, 2017). The viscous gel matrix has the ability to prevent products of digestion from accessing the absorptive sites and to hold on to protein molecules reducing the accessibility of digestive enzymes (Arnal-Peyrot & Adrian, 1974; Forman & Schneeman, 1980; El-Deek *et al*., 2009b). The viscous gel matrix has also been reported to inhibit the activity of the enzymes (Arnal and Adria, 1974). In a study by El-Deek *et al*., (2009b), the different treatments done to the guava by-product significantly reduced the crude fiber content with the intent of increasing the digestibility of the fibrous contents of guava by-product and increasing the carbohydrate availability. Guava by-products have a high fibrous content, such that there is minimal digestion in the small intestines and providing content in the colon for microbial fermentation (Budino *et al*., 2015; Jarrett & Ashworth, 2018; Martins *et al*., 2021).

Some research has been done to assess the digestibility of diets with guava by-product inclusion. According to Mosaad & Hassan (2016), the digestibility of guava waste was influenced by a number of factors that included processing methods, the plant variety, and the composition of the guava waste. Kamel *et al*.(2016) fed rabbits with diets with different guava waste inclusion of up to 20%. The diets with guava waste inclusion recorded an improved digestibility coefficient compared to the control.

According to a study by Martins *et al*., (2021), piglets were fed on guava seed meal at different inclusions (0%, 5%, 10%, 15%) as an alternative for dietary fiber. The nutrient digestibility was significantly reduced with increased inclusion, and the study attributed it to the high cellulose and lignin content. Macagnan *et al*., (2015) recorded that the high fiber amounts result in low viscosity and significant water retention, which rises the motility of the intestines, reduces transit time and escalates evacuation regularity.

CHAPTER THREE

MATERIALS AND METHODS

Study area

The study was carried out at the poultry unit in the Department of Animal Production, Faculty of Veterinary Medicine at the University of Nairobi (Latitude:-1.25287867437 Longitude: 36.7298431783). Red guava fruits were sourced from Kitui and Taita Taveta counties and processed at the pilot plant located in the Department of Food Science, Nutrition and Technology, Faculty of Agriculture, University of Nairobi.

Preparation of guava by-product

Whole pink fresh guava fruits were harvested in Kitui and Taita Taveta placed in gunny bags and transported to the pilot plant. On arrival, they were washed using tap water to get rid of any dust/soil and debris of leaves then sorted depending on ripeness. The ripe guavas were crushed using a commercial crusher and sieved using a 0.5 mm stainless steel screen to separate the pulp and the by-product that mainly consisted of the fruit peels and seeds. The by-product was then transferred to the poultry unit in the Department of Animal Production, where it was sun-dried (Figure 1), ground using a hammer mill (3mm sieve), and stored in gunny bags. Samples were collected from different gunny bags and stored for laboratory nutrient analysis.

Figure 1: Sun-drying of the guava by-product

Experimental Diets and feeding

Four experimental diets were formulated such that they were iso-nitrogenous and iso-caloric. The control diet had 0% inclusion of guava by-product, and the other three diets had different guava by-product inclusion levels; 2.5%, 5%, and 7.5%. Diet formulation was based on the Kenya Bureau of Standards (KeBS) requirements for the broiler finisher and starter diets with a minimum of 3000 Kcal/kg ME and 22% crude protein content for the starter diets and 3000Kcal/kg ME and an 18% crude protein content for the finisher diets. The dietary constituents were blended as Table 1 and fed to the broiler chicken in mash form.

Table 1: Ingredients nutrient composition

Ingredients	STARTER				FINISHER			
	0	**2.5**	**5**	**7.5**	**0**	**2.5**	**5**	**7.5**
Maize grain	53	49	49	52	56	55	55	55
Pollard	16	10	10	10	21	18	15	12
Guava by-product	0	2.5	5	7.5	0	2.5	5.0	7.5
Fat	0.05	2.5	1.4	0.8	0	0	0	0
Soya bean meal	19.0	27	23	16.7	11.9	13.4	13.9	14.4
Omena	10	6.6	10	10	9	9	9	9
L-Lysine	0.02	0	0	1.28	0	0	0	0
DL-Methionine	0.1	0.08	0.08	0.10	0.20	0.20	0.20	0.20
DCP	0	0.3	0	0	0	0	0	0
Limestone	1.12	1.24	0.86	0.86	1.20	1.20	1.20	1.20

Salt	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Vit/mineral Premix*	0.25	0.25	0.25	0.25	0.2	0.25	0.25	0.25
Mycotoxin Binder	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Coccidiostat	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Enzyme (phytase)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Calculated								
Crude protein CP%	21.3	21.2	21.2	21.3	18.7	17.8	18.1	18
Metabolizable Energy ME Mcal/kg)	2886	2967	2952	2903	2916	2804	2832	2811

**1Vitamin and mineral premix provided the following per kg of diet: vitamin A, 11500IU;cholecalciferol,2100IU;vitaminE(fromdltocopherylacetate),22IU; vitamin B12, 0.60mg; riboflavin, 4.4mg; nicotinamide, 40mg; calcium pantothenate, 35mg; menadione (from menadione dimethyl-pyrimidinol), 1.50mg; folic acid, 0.80mg; thiamine, 3mg; pyridoxine, 10mg; biotin, 1mg; choline chloride, 560mg; ethoxyquin, 125mg; Mn (from $MnSO_4{\cdot}H_2O$), 65mg; Zn (from ZnO), 55mg; Fe (from $FeSO_4{\cdot}7H_2O$), 50mg;Cu (from $CuSO_4{\cdot}5H_2O$),8mg; (from $Ca(IO_3)_2{\cdot}H_2O$),1.8mg;Se,0.30mg;Co(from Co_2O_3),0.20mg;Mo,0.16mg.*

A specific diet was assigned randomly to 1-day old chicks, replicated 4 times with 40 chicks per treatment in a completely randomized experimental design. The experimental chicken were fed in two phases: the growing phase (1-21 days) followed by the finishing phase (22-42nd days). Water and feed and were availed *ad libitum* throughout the experiment.

Experimental birds

One hundred and sixty day-old broilers acquired from Kenchic Ltd® were used for the experiment. The chicks were weighed on arrival and brooded with the aid of infrared bulbs. Temperatures were retained at 32°C during the first week, and reduced by 2 °C every week, by adjusting the height of the infrared bulb. The temperature had been reduced to 26°C at the end of the week three. For the first 3 days, all the chicks were fed on a composite of the 4 experimental diets. On the third day, the birds were feather sexed and randomly allocated into 16 cages (1m width x1m length x 0.9m height), with each cage holding ten birds with an equal number of males and females as shown in Figure 2.

Figure 2: Cages placed in the poultry house

Each cage provided a floor space of $0.1m^2$ per chick. Wood shaving covered the floor to a depth of 10 cm. The birds were housed in a clean, well-lit, and well-ventilated poultry house. The chicks were vaccinated against Infectious Bursal Disease (Gumboro) on the 7^{th} day and New Castle Disease on the 14^{th} day. Any mortality that occurred in the course of the experimental period was recorded.

Data collection

Feed intake and body weight gain

Weight gain and the intake of feed by the chicks was assessed weekly. Weight gain was obtained by the difference in weight between two successive weightings. On every first day of the experimental week, the chicks in each cage were weighed together in a tared plastic bucket using a digital weighing scale to the nearest 0.0g The difference in the bird's current week weight and their previous week's weight was the bodyweight gain.

The feed intake was laid by the weight discrepancy of the initial feed availed at the start of the experimental week and the amount of feed remaining at the conclusion of the experimental week. At the beginning of the experimental week, a known quantity of the experimental diets was weighed for each respective replicate into a plastic bucket, from which feed was transferred into the respective feeding troughs throughout the experimental week. After seven experimental days, the feed remaining in the feeding troughs were scooped and put back into the respective buckets, and weighed. The ratio of the weekly feed intake and weekly weight gain was used to determine the feed conversion ratio.

Carcass characteristics

On day 43, 32 birds, 2 from each replicate were selected on a weight basis (birds that were within the average weight of that cage) and humanely slaughtered at the slaughter chambers at the University of Nairobi poultry unit. The birds were each weighed before slaughter (live weight), after slaughter (carcass weight), the weight of eviscerated carcass, drumstick, the breast, wing, thigh, dorsum, liver, gizzard (with fat), spleen, abdominal fat, heart, and intestinal weight and length were measured and recorded. The weight of the eviscerated carcass with head and feet was used to calculate the relative weight. The pH of the meat was determined immediately after slaughter using a pH meter (Hanna Instruments, Italy), and the meat color was determined using a colorimeter (PCE-CSM 1, Germany). Color traits were showed in u CIE L*a*b* system (lightness-L*, redness and greenness - a*, yellowness, and blueness - b*) (Robertson, 1977; Dzinic *et al.*, 2011).

Sensory analysis

From every cage, one bird was randomly chosen at the tail-end of the experimental feeding, slaughtered, labeled, and taken to the laboratory at the Food Science, Nutrition, and Technology Department where sensory evaluation was done. The sampled chicken carcasses were skinned, deboned, and cut into relatively equal portions then deep fried in a fryer. Cooked meat from different experimental diets was sampled twice and coded. GBO= BN and JD, GB2.5= SF and MQ, GB5= LT and HE, GB7.5= ZC and GY.

The color, odor, oiliness, hardness/tenderness, flavor, juiciness, fibrousness, after-taste, and overall acceptability of the different meat samples were scored by a 7-point hedonic scale: 1 =“strongly disliked”; 2 =“moderately disliked”; 3 =“slightly disliked”; 4 =“neither like nor dislike”; 5 =“slightly liked”; 6 =“moderately liked”; and 7 =“strongly liked.” (Granato et al., 2012; Daniel et al., 2010).

The sensory evaluation exercise was done by forty panelists, both male and female, ranging in age from 20 to 60 years old. They were presented with a sensory evaluation questionnaire. They were requested to score for each attribute listed with the help of a scoring scale provided. The samples were placed in disposable plastic plates. Water and toothpicks were provided to each panelist. They were urged to gargle before and after evaluating a sample and before proceeding to the next one. This was done in a partitioned room.

Digestibility test

On day 43, one bird from each replicate was transferred into a metabolic cage (Figure 3).

Figure 3: Birds placed in the metabolic cages

A total of 16 broilers 4 birds from each experimental diet were selected. Before the transfer of the birds, the cages and the room were disinfected and fumigated. The birds were allowed 3 days to acclimatize to the new environment, and each bird continued on its previous experimental diet. Individual feed intake was determined by the residue between the quantity of feed provided at the start of the experimental period and the amount of feed remaining after 4 days of digestibility data collection.

Total fecal material was collected every day for four days from aluminum trays lined with polythene placed at the base of the cage. The trays were removed, and any material contaminating the fecal material was handpicked. The fecal material from each bird was weighed daily, thoroughly mixed, and sundried (**Error! Reference source not found.**).

Figure 4: Sun-drying of the daily collected fecal material

The fecal material from each cage, collected and dried in the four days, was composited and sampled for chemical analysis.

The digestibility of nutrients was determined as below:

$$nutrient\ digestibility\ \% = \frac{(NF - NE) * 100}{\text{NF}}$$

Where NF = nutrient in feed and NE = Nutrient in Excreta (Mujahid *et al*., 1996)

Chemical analyses

Duplicate samples of the guava by-product, raw materials, and the formulated experimental diets were sampled for laboratory analysis. The analysis for Crude Fiber (CF), Dry Matter (DM), Crude Protein (CP), crude ash, and Ether Extracts (EE) was done as (AOAC, 2002). To determine the DM, samples were oven-dried for 12 hours at 105°C. The crude fiber was the sample fraction that defied digestion by both the 2.04 N H_2SO_4 and 1.78N KOH solutions. The amount of CP was analysed using the Kjeldahl procedure. To determine the crude ash content, the sample was burnt in a muffle furnace at 600°C for 3 hours. The EE was extracted from the sample by diethyl ether. Nitrogen-free Extracts (NFE) were determined by subtracting the percent of the ash content, EE, CF, and CP from 100%. Gross energy determination was done at the Kenya Industrial Research and Development Institute (KIRDI), using an Adiabatic Bomb Calorimeter.

Duplicate samples from the breast and thigh muscle were sampled and assayed for Crude Protein (CP) and Ether Extract (EE).

Fecal samples were also analyzed for dry matter, gross energy, ash, crude protein, crude fiber, and ether extracts as described above.

Data analysis

All data collected on body weight gain, feed intake, FCR, the carcass parts, the meat quality, and digestibility test were subjected to a one-way Analysis of Variance (ANOVA) using Genstat Discovery 14th edition (Payne *et al*, 2011). Significant treatment means were separated using the Bonferroni Multiple Comparison Procedure and the level of significance set at $P \leq 0.05$.

CHAPTER FOUR

RESULTS AND DISCUSSION

Chemical composition

Chemical composition of the guava by-product

The chemical composition of the guava processing by-product (composed of peels and seeds after extraction of the pulp) is demonstrated in Table 2.

Table 2: Chemical composition (%DM) of sundried the guava processing by-product

	(%)
DM (of the sun-dried sample)	88.51
Ash	3.10
Crude fiber (CF)	46.46
Crude protein (CP)	5.41
Ether extracts (EE)	6.32
Nitrogen free extracts (NFE)	38.71

The sun-dried guava by-product had 88.51% DM, 46.46% CF, 5.41% CP, 6.32% EE, 3.1% ash, 38.71% NFE, and an estimated ME of 2320Kcal/Kg. The CF of the guava by-product was less than 56.01% reported by Lira *et al*. (2009) for red guava waste, 55.62% noted by Silva *et al*., (2009) and Pereira *et al*., (2009) and 59.21% reported by Kamel *et al*. (2016). The CF was also higher than 40% documented by El-Deek *et al*. (2009b), and 39.5% reported by El-Deek *et al*. (2009). The variance in the crude fiber amount in the different byproducts can be attributed to different processing techniques, guava varities and ripeness of the by-product. The crude protein content was lower than 10.09% reported by Pereira *et al*., (2009), 7.53% (Kamel *et al*., 2016), and 10.06% (Martins *et al*., 2021). This can be attributed to the different locations with different soil types where the guava fruits are grown (Chiveu, 2018).

The ether extracts (EE) of the guava by-product were lower than 10.86% recorded by Lira *et al*., (2009), 10.0%, and 7.92% documented by Braga *et al*., (2016). It was more than 4.52% recorded by El-Deek *et al*., (2009b). The ash content was lower than 5.62% reported by El-Deek *et al*., (2009b) and higher than 2.52% recorded by El-Deek *et al.*, (2009), and 1.27% by Kamel *et al.*, (2016). The nitrogen-free extracts (NFE) fraction was higher than 33.14 % observed by El-Deek *et al*., (2009b), and 32.97% recorded by El-Deek *et al.*, (2009). The differences in nutrient content with the current experiment can be allotted to the differences in soil types in the areas where the fruits grow and the processing methods (Chiveu, 2018).

Chemical composition of the experimental diets

Table 3 displays the nutrient composition of the experimental diets.

Table 3: Chemical composition (% DM) of experimental formulated broiler feed

	Broiler Starter				Broiler Finisher			
	GB0	**GB2.5**	**GB5**	**GB7.5**	**GB0**	**GB2.5**	**GB5**	**GB7.5**
Dry matter	87.31	87.90	88.07	88.41	88.98	89.06	89.06	89.41
Crude protein (CP)	21.3	21.2	21.2	21.3	18.7	17.8	18.1	18.0
Ether extract (EE)	4.85	6.61	6.41	5.61	6.15	4.43	4.93	4.62
Crude fiber (CF)	6.5	7.6	8.12	8.88	8.32	8.67	9.37	10.95
Ash	6.69	6.13	5.86	5.93	5.61	7.09	5.98	5.90
Nitrogen Free Extracts (NFE)	60.66	58.46	58.41	58.28	61.22	62.01	61.62	60.53

GBO: control, GB2.5: 2.5% inclusion, GB5: 5% inclusion, GB7.5: 7.5% inclusion

During diet preparation, the aim was to have all diets for each feeding phase to be iso-nitrogenous and iso-caloric. The target for the crude protein content in the diets was 21% in the starter diets and 18% in the finisher diets. The crude protein for the starter diets ranged from 21.2 to 21.3%, while in the finisher diet the range was from 17.8 to 18.7%. The slight differences were attributed to the mixing and sampling errors and the inconsistent CP content of the ingredients used in the diet formulation. The diet with the highest guava by-product inclusion had the highest crude fiber content, 8.88% for the starter diet and 10.95% for the finisher diet. This was due to the high fiber amount in the guava by-product.

Growth performance

The feed intake, weight gain, and feed conversion ratio for the starter phase, finisher phase, and the entire feeding period are shown in **Table 4**.

Table 4: Effect of inclusion of guava fruit processing by-product in broiler diets on performance

	Treatments				SEM	*P* value
	GB0	GB2.5	GB5	GB7.5		
Starter phase (d1-d21)						
Final weight (g) d21	868.9^{bc}	820.2^{b}	934^{c}	665.4^{a}	21.6	<.001
BWG[1] g/day	37.91^{bc}	35.53^{b}	40.85^{c}	28.26^{a}	1.004	<.001
ADFI[1] (g/day)	65.5	66.64	71.67	57.52	3.88	0.132
FCR[1]	1.720	1.877	1.758	2.039	0.089	0.102
Finisher phase (d22-d42)						
Initial weight (g) d22	868.9^{bc}	820.2^{b}	934^{c}	665.4^{a}	21.6	<.001
Final weight (g) d42	2447^{b}	2379^{b}	2639^{b}	1990^{a}	70.6	<.001
BWG[1] g/day	75.15^{ab}	74.24^{ab}	81.19^{b}	63.09^{a}	2.85	0.006
ADFI[1] (g/day)	52.56^{b}	51.78^{b}	53.26^{b}	44.88^{a}	1.344	0.003
FCR[1]	1.431	1.434	1.525	1.403	0.041	0.228
Entire Feeding period						
Final weight (g)	2447^{b}	2379^{b}	2639^{b}	1990^{a}	70.60	<.001
BWG[1] g/day	56.53^{b}	54.88^{b}	61.02^{b}	45.68^{a}	1.67	<.001
ADFI[1] (g/day)	59.03^{ab}	59.21^{ab}	62.47^{b}	51.20^{a}	2.17	0.019
FCR[1]	1.576	1.656	1.641	1.721	0.043	0.193

[a]*Means in a row with different superscripts are significantly different (p<0.05)*
[1]*BWG – Body Weight Gain, ADFI – Average Daily Feed Intake, FCR – Feed Conversion Ratio*
GBO: control, GB2.5: 2.5% inclusion, GB5: 5% inclusion, GB7.5: 7.5% inclusion

The ADFI during the starter phase tended to be lower for GB7.5 though not significant (p= 0.132) compared to GB0 and the other experimental diets GB2.5 and GB5. This can be attributed to the high fiber content in this diet. The daily body weight gain was influenced (p<0.05) among the diets with the highest noted in GB5, followed by GB0 (control) then GB2.5, and lowest in GB7.5. This can be ascribed to the lower feed intake and probably reduce digestibility for this diet. The final weight at the termination of the starter period was highest in GB5, followed by GB0 (control), GB2.5, and lowest in GB7.5. This was in agreement with average weight gain throughout the starter period. The FCR was not influenced ($p>0.05$) by the different inclusion levels of guava fruit processing by-product.

During the finisher period, there was a marked difference ($p=0.003$) in feed intake, with GB7.5 having the lowest compared to others which were not different. This was due to the high fiber content in the GB7.5 diet.

The daily body weight gain was influenced significantly ($p=0.006$) by the addition of different levels of guava by-product in the diets. BWG was high in treatment GB5, intermediate in GB2.5 and GB0 (control), and low in GB7.5. This was related to the feed intake during the period. The final weight was similar among birds fed with GB0, GB2.5, and GB5 but low in GB7.5. The level of inclusion did not influence FCR.

During the entire feeding period, the daily feed intake was highest for GB5 (62.47g/d) followed by GB0 and GB2.5 (59.03 and 59.21) and lowest for GB7.5 (51.20). It was significantly more ($p<0.05$) in GB5.0 in comparison to GB7.5. The daily weight gain was similar for GB0, GB2.5, and GB5 (56.53, 54.88, and 61.02 respectively) but significantly lower ($p<0.05$) for GB7.5 (45.68). The FCR was not affected by the different inclusions during the entire period.

The low feed intake observed for GB7.5 can be attributed to the high fiber content that makes the feed bulky compared to the other diets. However, El-Deek *et al*. (2009) reported that broilers fed on feeds with higher levels of guava by-product inclusion (6% and 8%) whether raw or processed greatly increased the amount of feed consumed compared to the diets with lower levels. According to the study, this was owed to the considerably larger amount of crude fiber in the meals having greater levels of guava by-products, which meant the birds were required to eat more to cover their energy needs because fiber content was not fully utilized. Fiber is bulky and quickly fills the stomach limiting feed intake by the birds. In addition, insoluble fiber tends to accumulate a lot of water and forms a gel that slows down the stomach emptying time and overall food transit time through the GIT (Jha & Mishra, 2021). This extends the time an animal feels "full" significantly reducing feed intake.

The results were different from Abiola & Adekunle (2002) who fed chicken a diet containing melon husk as a replacement for maize in different percentages (0, 10, 20, and 30) and reported that the diets with high fiber (10, 20, and 30%) had an increase in feed intake. El-Deek *et al*. (2009b) fed laying hens with diets of differently treated guava by-products at different inclusion levels (5, 10, and 15%) also observed that the diet with the highest inclusion (10 and 15%) of guava by-product had the highest feed intake, an indication that guava by-product improved the diet palatability. This contradicted the finding that the highest guava by-product inclusion reduced intake in this study. According to Lira *et al.* (2009), broiler birds that were fed diets with different inclusions (3, 6, 9, or 12%) of guava waste showed a significant effect on feed intake during the 1st week with the 3% inclusion being the highest and the 12% having the least feed intake. This was attributed to the fact that the birds were trying to cope to the experimental diets during the post-hatch period.

Other studies where guava fruit by-products were fed to birds showed no effect on feed intake; Guimarães (2007) observed that layers fed on feeds with differing amounts of guava waste inclusion (0, 2, 4. 6 and 8 %) from week 30 to 39 had no influence in feed intake. Oliveira *et al*. (2018) fed broiler birds with diets with guava by-product at inclusion levels of 0, 0.5, 1.0, and 1.5% and observed no effect on the feed intake.

The birds with lowest performance for all attributes was observed at 7.5% inclusion of the guava by-product which was arcorded to the high content of fiber in the diet. The high fiber in the diet decreased feed intake resulting in poor weight gain observed in comparison to the other experimental diets and the control. The fiber in guava fruit by-products consists mainly of lignin and pectin (El-Deek *et al.*, 2009b). Pectin is a soluble fiber that tends to form a viscous gel-matrix that reduces the accessibility of products of digestion to the absorptive sites by coating the absorptive lining of the gut (Forman & Schneeman, 1980; El-Deek *et al*., 2009). Further, the gel-matrix can inhibit enzyme activity (Arnal-Peyrot & Adrian, 1974; El-Deek *et al*., 2009; El-Deek *et al*., 2009b). A comparable tendency was observed by El-Deek *et al*., (2009) where there was an improvement in average weight gain for the broilers fed diets containing 4% and 6% guava processing by-products in comparison to those fed the control diet, while those fed diets with 8% processing by-products had a reduced daily weight gain. This was attrubuted the higher fiber content of diets containing 8% inclusion.

Fiber has no energy value for non-ruminant animals because they do not have the necessary enzymes for its digestion. Further, fiber dilutes the energy content of the diet. El-Deek *et al*. (2009b) reported that layers fed on diets containing 10 and 15% of guava by-products had a significant increase in weight gain (159.5g and 153.6g respectively) compared to the control (78.7) with no guava by-product inclusion an indication that there was a higher nutrient availability in feeds with more guava by-product inclusion compared to the diets with no guava by-product inclusion.

A study by Lira *et al.* (2009) however showed no influence on the weight gain for the broilers fed diets containing 3, 6, 9, and 12% guava by-products from the 2nd to the 6th week. There was however a reduction of weight gain with increased guava by-product inclusion in the 1st week that was attributed to the birds being young with an immature digestive system and digestive enzyme production compared to older birds. Guimarães (2007) reported that guava by-product inclusion levels of 0, 2, 4, 6, and 8% did not significantly affect weight gain in layer birds. De Oliveira *et al*. (2018), fed broiler birds with diets containing 0, 0.5, 1.0, and 1.5% of guava byproducts, and observed that the weight gain was raised linearly with the increase of guava by-product inclusion. In the study, the level of inclusion was low which may not have had a negative effect on performance.

From this study, it can be concluded that increased content of guava by-product to a level (5%) in the diet improved the birds' performance in both weight gain and feed intake but a higher increment (7.5%) led to adverse influence on the performance of broiler birds (reduced feed intake and reduced weight gain).

For the entire experiment, there were no effects of guava by-product addition level on feed conversion ratio (FCR) (1.57 to 1.72). This was an indication that the feed consumed by the birds was equally utilized for gain for the different diets. This observation was similar to Lira *et al*., (2009), where broiler chicken were fed on diets with different levels (3, 6, 9 or 12%) of guava waste, had FCR values between 1.67 and 1.72. The results were also in agreement with those by El-Deek *et al*., (2009) where the FCR of broiler finisher diets with different inclusion levels of guava by-product (0, 2, 4, 6, and 8%) was simillar. The values of the FCR were however higher (3.01 for the control and 2.78 for the experimental diets) than those in this study (1.4-1.5) an indication that in the current study diets were more efficiently utilized than those by El-Deek *et al*., (2009).

The trends of the weekly performance of broilers fed diets with different levels of guava by-product are shown in Figures 5, 6 and 7.

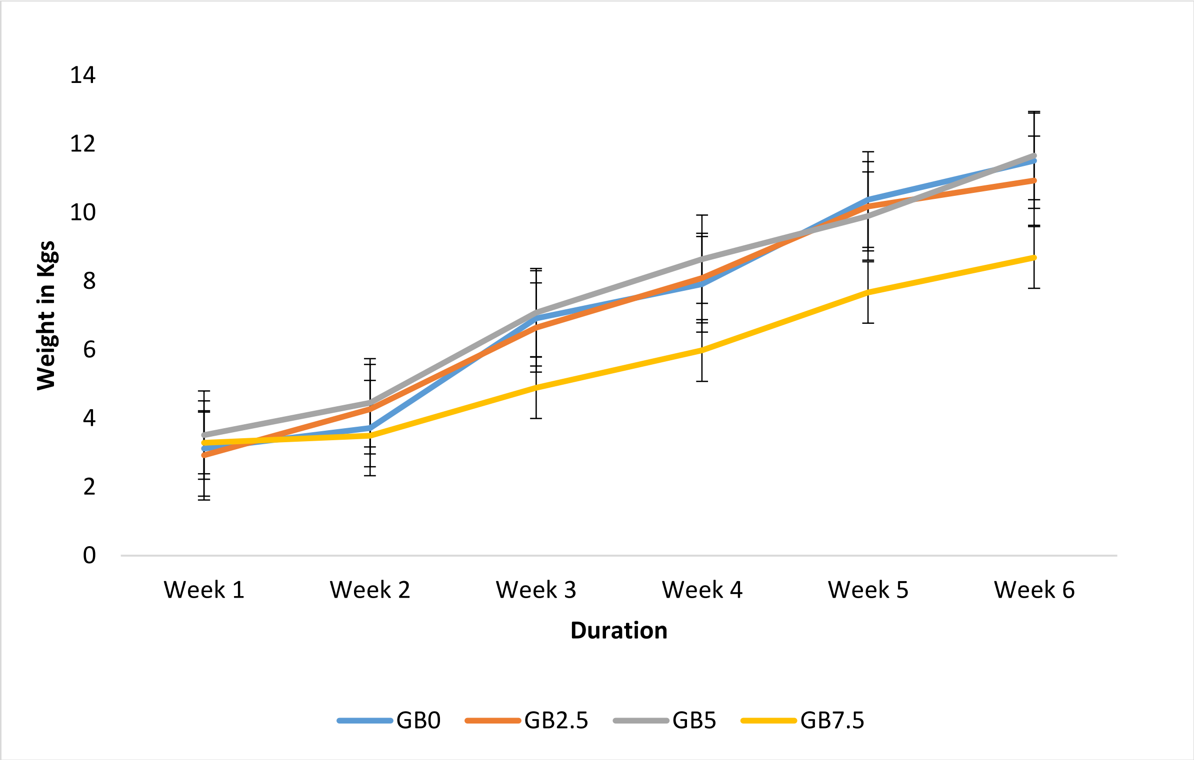

Figure 5: Trends in weekly feed intake of birds fed on broiler diets with different guava fruit processing by-product inclusions. The bars represent the standard error of the mean.

From Figure 5, it was observed that GB7.5 had the least feed intake throughout the experimental period in comparison to the other diets. This was due to the highest amount of crude fiber in the diet. GB5 was observed to have the highest feed intake in comparison to the other diets throughout the experimental period. This revealed that there was an improvement in the feed intake in the diet GB5 in comparison to GB0, the inclusion of the guava by-product at 5% improved the diet making it more palatable.

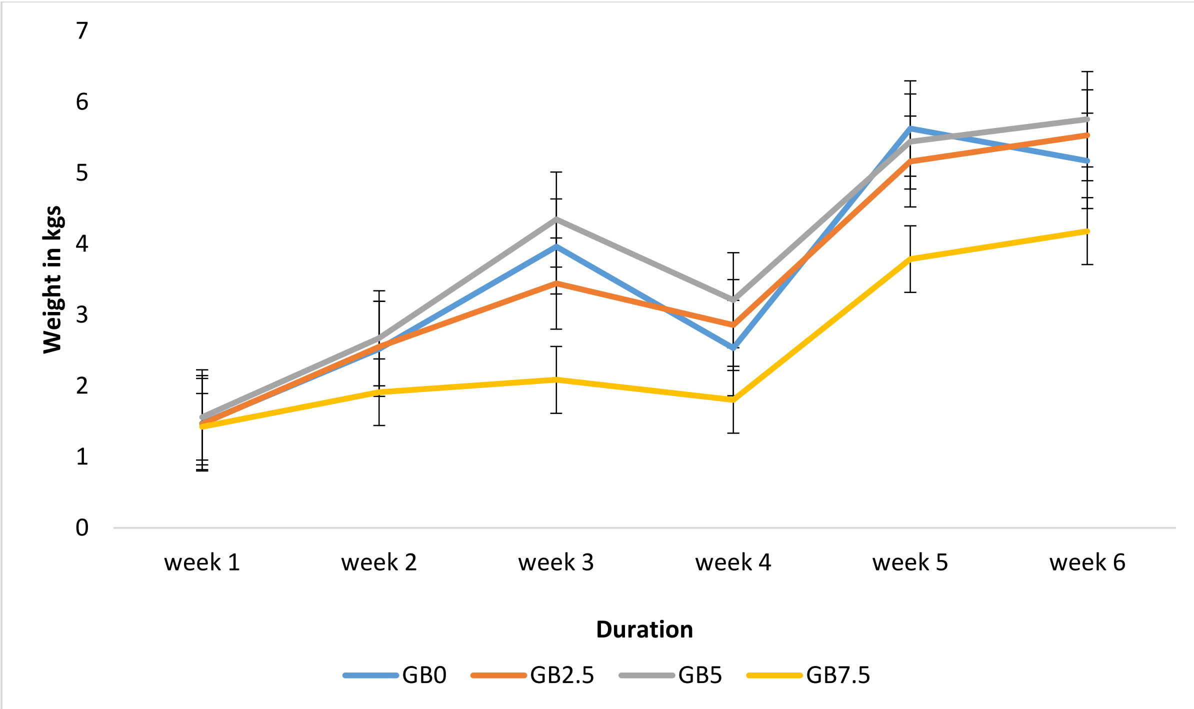

Figure 6: Trends in weekly weight gain of birds fed on broiler diets with different levels of guava fruit processing by-product inclusion. The bars represent the standard error of the mean.

Figure 6 shows weekly trends in weight gain as affected by the different treatments. In the 1st week, the weight gain was high and similar for GB0, GB2.5, and GB5 compared to GB7.5 and this can be due to the high fiber in the GB7.5 that could not be well utilized by the birds at this young age since the digestive tract and the digestive enzymes are not well mature. By the 3rd week, the birds peaked in the weight gain, an indication that the birds were well adapted to the diet. In the 4th week, the weight gain of the birds was observed to markedly reduce and this was attributed to the change of diets from the starter phase diet to the finisher phase diet. By the 5th week, the weight gain had peaked again a sign that the birds had adapted to the finisher feed and by the 6th week, the weight gain reduced for GB0 but with a slight increment in the other diets, a sign that the guava by-product improved the weight gain.

Figure 7 shows weekly trends in the feed conversion ratio (FCR) which was high for GB7.5, though not significant, throughout the experimental period. This showed that the diet was not efficiently utilized for weight gain by the experimental birds. During the 1st two weeks, GB0 (control) was more efficiently utilized compared to the experimental diets. By the 3rd week to end of feeding period, GB5 was the most efficiently utilized diet. At the 4th week, the FCR had a substantial increase, an indication that during this time the diets were not efficiently converted to gain as was shown in Table 4. This was because the finisher feed was being introduced to the broiler chicken.

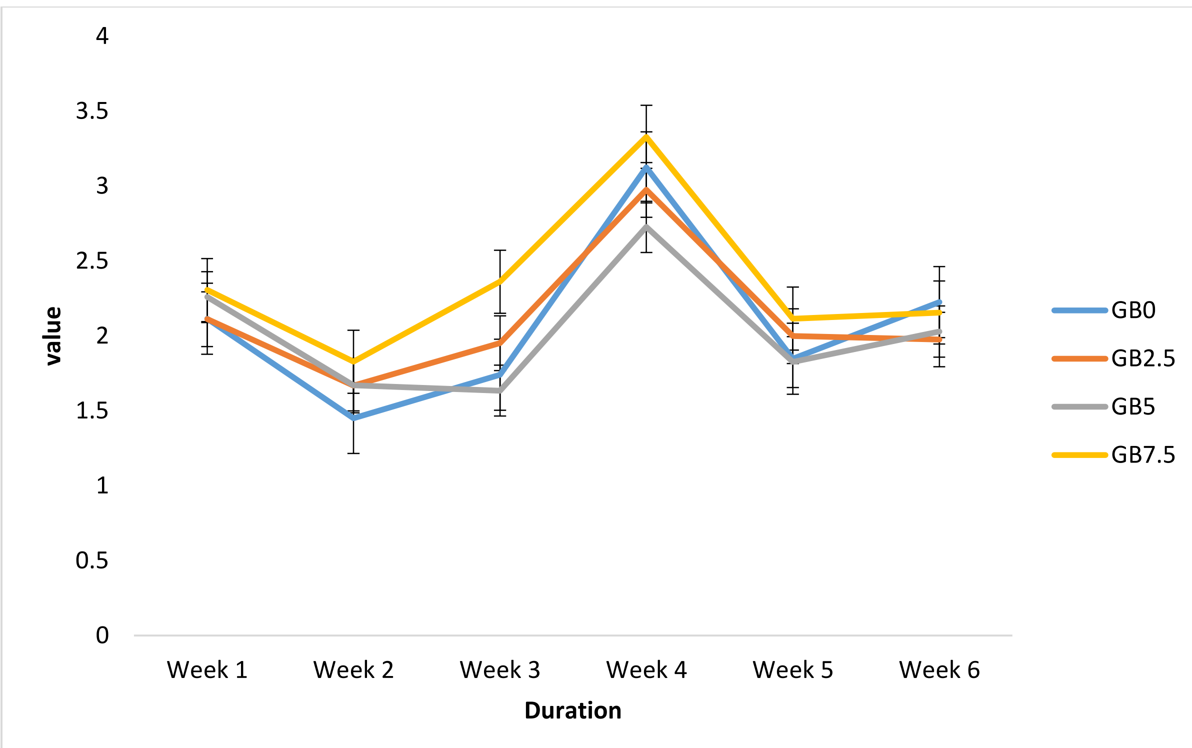

Figure 7: Trends in the weekly feed conversion ratio of birds fed on broiler diets with different levels of guava fruit processing by-product inclusion. The bars represent the standard error of the mean.

Diet digestibility

The apparent digestibility of crude protein (CP), dry matter (DM), crude fiber (CF), and gross energy (GE) are displayed in Table 5

Table 5: Effects of the level of inclusion of the guava by-product on apparent digestibility (%) of dry matter, crude protein, crude fiber, and gross energy in broiler chicken

	Experimental diets				SEM	P-Value
	GB0	GB2.5	GB5	GB7.5		
Dry Matter	65.20	71.03	69.47	61.79	3.42	0.264
Crude protein	57.17	63.56	65.03	54.59	3.89	0.228
Crude fiber	48.77	53.01	40.27	47.82	3.22	0.092
Gross energy(GE)	78.27	82.69	80.85	73.44	5.47	0.312

GBO: control, GB2.5: 2.5% inclusion, GB5: 5% inclusion, GB7.5: 7.5% inclusion

The different inclusion levels of the guava by-product in the broiler finisher diets did not influence the apparent digestibility of the different nutrients in the diets (P > 0.05). The apparent digestibility of dry matter ranged from 61.79 to 71.03, the crude protein % apparent digestibility ranged from 54.59 to 65.03, and crude fiber apparent digestibility ranged from 40.27 and 53.01 and the GE ranged from 73.44 and 82.69. It has been observed that from the ingested feed, broiler birds lose around 30% of dry matter (DM), 50% nitrogen, and 25% of gross energy (FAO, 2013), in agreement to this study. In another study where broilers were fed with guava extract at different levels, the digestibility coefficients of metabolizable energy and nutrients in feed were unaffected (Noleto-Mendonça *et al*., 2021).

The dry matter digestibility was not significantly influenced but the value appeared lower for diet GB7.5 (61.79) in comparison to GB0 (65.20) and the other experimental diets GB2.5 (71.03) and GB5 (69.47). This was reflected in growth performance where the broilers fed on GB7.5 had the least weight gain. Table 5 above showed that the digestibility of crude fiber was low compared to the other nutrients. Crude fiber contains both the insoluble and soluble non-starch polysaccharides and fractions of lignin (Choct, 2015).

Carcass characteristics

A high-quality broiler chicken should have minimal abdominal fat with a high ratio of leg and breast meat (Ogeto, 2017). Consumers have been observed to select against high-fat content due to its link to the risk of heart disease (Micha *et al*., 2010) Other measures of quality are; looks, tenderness and water holding capacity of the meat (Onsongo, 2017).

Absolute and Dressed % weights

Absolute weight is the weight of the bird, the whole carcass, and the different cuts of the carcass while relative weight or dressed percentage is the percentage of the different weights to the weight of the bird.

The absolute weights of the live bird, carcass, eviscerated carcass (with and without feet and head), the abdominal fat, wings, drumstick, thigh, breast, heart, liver, spleen, gizzard without content, and the intestines are shown in Table 6 and 7. The weights of the eviscerated carcass (with or without feet and head), the abdominal fat, thigh, drumstick, spleen, heart liver, and gizzard were not influenced ($P \leq 0.05$) between diets. There was a non significant trend of increased weights with the increase of guava by-product inclusion up to 5% (GB5) then a decrease in weight at GB7.5 which can be attributed to the higher weight gain during the experimental period.

In a study by Lira *et al*., (2009) with 3, 6, 9, or 12% guava by-product inclusion the absolute weight of the eviscerated carcass, thigh, drumstick, breast, dorsum, wings, heart, and spleen were also not affected. However, in this study, the weights of the gizzard, and the intestines were observed to increase with the inclusion of the guava by-product. This increase in intestinal and gizzard weights can be due to the increament in the fiber content in the diets. Increase in fibre content leads to an increment feed retention in the gastro intestinal tract thus more contraction force is needed to aid in digestion, this then leads to higher muscle mass thus the increased weight. Similarly Lira *et al*., (2009) reported a linear increament in gizzard weight as the guava waste addition (3, 6, 9, or 12%) increased. The study attributed this to the increase of the seed content in the gizzard that caused it to contract more thus increasing its muscle mass. However, El-Deek *et al*. (2009) observed that the gizzard weights were not significantly affected while the intestinal weights were influenced significantly by the inclusion of the guava by-product.

The absolute weight of the bird and the weight of the carcass were influenced ($P \leq 0.05$) by the diet with GB7.5 being lower in both (2266g) (2086.4) compared to the other 3 diets (Table 6). The birds from GB5 had the highest weights compared to the control GB0 which was similar to GB2.5. These differences are in line with the earlier observed higher feed intake and weight gain where the high fiber content of GB7.5 was incriminated. The absolute weight of the wings was significantly affected by the diet with the highest weight being of birds fed on GB2.5. The dorsum weights were significantly different as the absolute weight reduced with the rise in the amount of guava inclusion in the diet. In a comparable experiment by Camelo *et al*. (2015) where European quails were fed a diet that had corn partially substituted with guava residues up to 10%, the carcass characteristics were not affected. El-Deek *et al*., (2009) also included guava byproducts of up to 8% in the feeds of broiler birds and concluded the carcass traits were not affected by the inclusions. Evaluation of the effect of inclusion of guava in diets of other types of livestock diets showed no effect on carcass characteristics, in pigs fed up to 30% (Rao et al., 2004), New Zealand rabbits with guava waste at 20% (Kamel *et al*., 2016) and growing lambs (Mosaad & Hassan, 2016; Costa *et al*., 2019)).

Table 6: The effects of level of inclusion of the guava fruit processing by-product in broiler chicken diets on the absolute and dressed % weights (g) of carcass and main carcass cuts

	MEAN+ SE				SEM	P-Value
	GB0	GB2.5	GB5	GB7.5		
Weight of live bird	2369.98[ab]	2437.9[b]	2404.03[b]	2266.73[a]	24.9	0.002
Weight of the carcass	2173.63[ab]	2245.68[b]	2228.63[b]	2086.4[a]	26.4	0.005
Eviscerated carcass with head and feet	1910.45	1969.18	1843.43	1815.88	59.9	0.313
Eviscerated carcass without head and feet	1787.63	1792.35	1711.3	1676.08	62.4	0.494
Breast	660.6	683.38	684.98	605.5	24.2	0.124
Thigh	150.13	154.31	154.45	148.68	5.09	0.802
Drumstick	105.83	113.66	112.09	102.56	3.31	0.11
Wings	85.61[ab]	90.51[b]	89.48[ab]	81.64[a]	1.826	0.019
Dressing %						
Carcass	91.71	92.11	92.7	92.05	0.37	0.34
Breast	27.88	28.01	28.5	26.67	0.85	0.5
Thigh	6.33	6.33	6.43	6.56	0.2	0.84
Drumstick	4.47	4.66	4.66	4.53	0.14	0.7
Wings	3.61	3.71	3.72	3.6	0.79	0.6

[ab] *means are significantly different within diets (*$P \leq 0.05$)
means in a row with no letter superscript are no significantly different (p>0.05)
GBO: control, GB2.5: 2.5% inclusion, GB5: 5% inclusion, GB7.5: 7.5% inclusion

Table 7: The effect of level of inclusion of the guava fruit processing by-product in broiler chicken diets on the absolute and dressed % weight (g) of internal viscera and other parts of the chicken carcass

	Mean±SE				SEM	P-value
	GB0	GB2.5	GB5	GB7.5		

Weight of live bird	2369.98[ab]	2437.9[b]	2404.03[b]	2266.73[a]	24.9	0.002
Abdominal fat	25.4	23.55	30.3	20.2	3.55	0.288
Dorsum	437.23[b]	427.65[b]	415.53[b]	388.93[a]	10.91	0.044
Heart	12.65	12.18	12.55	12.18	0.643	0.928
Liver	38.98	41.38	40.45	40.55	1.828	0.826
Spleen	2.28	2.15	2	1.75	0.285	0.61
Gizzard without content	36.63	37.78	41.55	41.18	2.59	0.472
Weight of intestines	83.75	95.38	89.68	95.65	6.14	0.497
Dressed %						
Abdominal fat	1.07	0.97	1.26	0.89	0.15	0.37
Dorsum	18.45	17.54	17.28	17.17	0.41	0.17
Heart	0.53	0.5	0.52	0.54	0.02	0.79
Liver	1.65	1.7	1.68	1.79	0.08	0.63
Spleen	0.1	0.09	0.08	0.08	0.01	0.71
Gizzard without content	1.55	1.55	1.73	1.82	0..12	0.33
Weight of intestines	3.53	3.92	3.72	4.23	0.26	0.32

[ab] means are significantly different between diets ($P \leq 0.05$)

means in a row with no letter superscript are no significantly different (p>0.05)

GBO: control, GB2.5: 2.5% inclusion, GB5: 5% inclusion, GB7.5: 7.5% inclusion

Meat quality

Chemical analysis

The crude protein, moisture and ether extract (crude fat) content of meat from the thigh and the breast are depicted in Table 8.

Table 8: The effect of level of inclusion of guava fruit processing by-product on the moisture, crude protein and fat content (%) of thigh and breast muscle of broiler chicken

		Mean±SE				SEM	P-value
		GB0	GB2.5	GB5	GB7.5		
Moisture	Thigh	74.73	76	73.92	73.93	0.879	0.342
	Breast	72.47	73.54	74	74.46	0.502	0.081
Crude Protein	Thigh	17.2	16.25	15.53	16.5	1.086	0.754
	Breast	19.56	17.8	18.64	16.26	0.79	0.066
Ether Extract	Thigh	2.5	2.11	2.51	2.83	0.209	0.171
	Breast	2.24	1.67	1.58	1.68	0.489	0.768

GBO: control, GB2.5: 2.5% inclusion, GB5: 5% inclusion, GB7.5: 7.5% inclusion means in a row with no letter superscript are not significantly different (p>0.05)

The crude protein content of the thigh meat ranged from 15.53 to 17.2%, and 16.26 to 19.56 for the breast meat, ether extracts ranged from 1.58 to 2.24 in the breast meat and 2.11 to 2.83 in the thigh meat. Moisture was the highest constituent of the meat ranging from 73.92 to 76 for thigh and from 72.47 to 74.46 for breast muscle.

The inclusion levels had no influence on the moisture content, crude protein (CP) and ether extracts (EE) of both the thigh and breast muscle of the experimental birds. The EE content of the thigh muscle was higher than that of the breast regardless of the diet in agreement with De Oliveira *et al* (2016). In a review by Culioli *et al* (2003), the crude protein ranged 18.4 and 23.4%, and lipids ranged between 1.3 and 6.0% in breast meat of broiler meat comparable to those in this study. The findings also agree with Castellini *et al*., (2002) who recorded a range of 60 to 80% moisture, 15 to 25% protein, and 1.5 to 5.3% lipids in chicken that were fed organically. De Oliveira *et al*. (2016) reported that the ether extracts make the most variable component of the meat as it is influenced by some factors; diet, age, the anatomical cut, and the breeding environment.

Dzinic *et al*. (2011) reported a moisture content of 74.04%, the protein content of 23.35%, and free fat content of 1.40 % from the breast of chicken fed on extruded corn and slaughtered at 49 days. They argued that chicken meat contained more protein (23%) compared to other meat types and less fat (1-5%) thus considered as a dietetic food. da Silva *et al.* (2017) analysed the composition of the thigh and breast of free-range and commercial broilers and reported a higherprotein (18%, 20.1%) in the free-range broiler compared to the commercial broiler (15.7, 19.9%). The total fat content was high in the commercial broiler (3.4, 1.3%) than in the free-range broiler (2.2, 0.92%).

There was no variance in the meat composition of the birds on different guava inclusion levels which can be attributed to the diets being isocaloric and isonitrogenous.

Meat pH

Meat pH is considered as the measure of how basic or acidic the meat is and is a pointer for the overall quality of the meat, the freshness of the meat and the taste of the meat, and it can range between 5.2 to 7.0 (Glamoclija *et al.*, 2015). According to Hertanto *et al*. (2018), the acidity or development of rigor time of chicken flesh may be affected by pre and postmortem treatment, which changes the pH quality of the meat. The pH has effects on different aspects of the meat; color, water holding capacity, weight lost on cooking, tenderness, juiciness, and the stability of microbes (Fletcher, 2002). When the pH is more than 6.2 after 24hrs the meat will have high water retention that will translate to short conservation and dark color formation referred to us the dark firm dry (DFD) meat while when the pH is below 5.8 in less than 4hrs there will be pale soft and exudate (PSE) meat that has poor water retention with a pale and soft appearance (Bridi *et al*., 2012; De Oliveira *et al*., 2018).

The influence of the level of addition of guava by-product on meat (breast and thigh) pH 30 minutes after the humane slaughter is displayed in Table 9.

Table 9: The effect of level of inclusion of the guava fruit processing by-product on the pH of thigh and breast meat taken within 30 minutes of slaughter.

	Mean±SE				**SEM**	**P-value**
	GB0	**GB2.5**	**GB5**	**GB7.5**		
Breast	6.35	6.43	6.3	6.29	0.0883	0.67
Thigh	6.32	6.37	6.36	6.39	0.0656	0.89

GBO: control, GB2.5: 2.5% inclusion, GB5: 5% inclusion, GB7.5: 7.5% inclusion
Means with no superscripts within a row are not significantly different ($P > 0.05$)

The thigh and breast meat pH was not influenced by the different additional levels. The pH of the breast meat ranged between 6.29 and 6.43 while that of the thigh meat ranged from 6.32 to 6.39. The values were bigger compared with those recorded by De Oliveira *et al*. (2018) for broiler birds fed different levels of guava by-product (0, 0.5, 1.0, and 1.5%).They reported breast meat pH ranging 5.90 to 5.96 while the thigh pH ranged between 6.02 and 6.09. The study attributed the varince in pH between the breast and thigh meat to the dissimilar types of muscle fibers in each. There were no significant effects observed in the pH within the different diets. The pH value in this study lay within the range (6.29-6.48) reported by Glamoclija *et al*., (2015) at 15 minutes after slaughter for the different breeds at 42 days of age.

Guava by-product addition in the diet did not influence the pH of broiler meat (De Oliveira *et al*., 2018) and lambs (Nobre *et al*., 2020). Likewise, in this study, the the inclusion level did not affect the pH..

Meat color

Color has a vital impression on the quality of meat and is the most crucial factor while purchasing meat (Nobre *et al*., 2020). The color of poultry carcasses and meat products is an important sensory characteristic by which consumers often base product selection and judge quality (Petracci & Fletcher, 2002). Some of the most important factors affecting the color of broiler meat include the pre-slaughter conditions, the haem pigments, the slaughter process and the condition of processing (Mir *et al*., 2017a).

The feed ingredient source can influence meat colour. Some ingredients contain pigments that are lipid-soluble (like carotenoids pigments) which the animal can deposit under the skin affeceting meat color (Mir *et al*., 2017). Guava by-product is reported to contain carotenoids (Omayio *et al*., 2019). Meat color and color abnormalities are influenced by both myoglobin concentration and muscle pH (Mir *et al*., 2017b). The characteristics of the meat color for different guava inclusion levels are shown in Table 10.

Guava by-product inclusion level had no significant effect on any of the color aspects on both the thigh and breast. From Table 10, the lightness (l*) of the breast meat ranged between 48.48- 50.34 while that of the thigh meat ranged between 53.36- 56.66. The breast meat redness ranged from 3.68 to 6.02 while that of the thigh meat was 3.17-4.11. The breast meat yellowness ranged between 2.29-5.42 while the thigh meat ranged between 0.13-3.65. The meat redness (a^*), yellowness (b^*), and lightness (L^*) were all similar between the different diets. These findings were alike to those noted reported by De Oliveira *et al.* (2018) where the lightness (L*), yellow content (b*), and red content (a*) of both the thigh and breast meat were unaffected by the addition of the guava by-product. The l*ranged between 39.65 and40.89, (40.67-42.22) a* ranged between (4.05-4.81), (9.03-9.45), and b* ranged between 5.36 and 6.68, (6.30-7.59) for the breast and thigh meat respectfully.

Table 10: The impact of different inclusion levels of the guava processing by-product in broiler feed on the of the thigh and breast meat colour

		Mean±SE				SEM	P-Value
		GB0	GB2.5	GB5	GB7.5		
a*	breast	6.02	5.04	3.99	3.68	0.8	0.203
	thigh	4.01	3.9	4.11	3.17	0.62	0.699
b*	breast	5.42	3.71	2.68	2.29	1.03	0.193
	thigh	3.46	3.2	3.65	0.13	1.02	0.094
l*	breast	50.34	48.48	49.8	50.24	1.67	0.826
	thigh	55.09	55.64	56.66	53.36	2.24	0.769

GBO: control, GB2.5: 2.5% inclusion, GB5: 5% inclusion, GB7.5: 7.5% inclusion
*Means with no superscripts within a row are not significantly different (*P>0.05)
a*=redness, b*=yellowness and l*= lightness.

The amounts of guava by-product used in this study might not have contributed enough content of carotenoids to influence color change. The results were in agreement with De Oliveira *et al*., (2018) where the guava by-product did not influence the lightness (l*) yellowness (b*) and redness content (a*) of both the thigh and breast meat.

Sensory analysis

Sensory analysis of meat is an important aspect of quality determination as it evaluates the color, odor, structure, texture, and flavor (Baston & Barna, 2010). The effect of guava inclusion level on different sensory attributes is displayed in Table 11.

Table 11: The effect of level of inclusion of the guava fruit processing by-product on the sensory attributes of broiler meat.

	Mean±SE				SEM	P-value
	GB0	GB2.5	GB5	GB7.5		
After taste	5.09	4.81	4.9	4.39	0.1386	0.09

Color	5.56^{ab}	5.84^{b}	5.05^{a}	5.38^{ab}	0.1097	0.029
Fibrousness	5.05	4.84	4.81	4.61	0.1736	0.447
Flavor	5.25^{b}	4.59^{a}	4.65^{a}	4.53^{a}	0.0752	0.007
Hardness	5.13	4.05	4.81	4.39	0.188	0.054
Juiciness	4.74	4.28	4.71	4.18	0.1196	0.059
Odor	5.23^{ab}	5.56^{b}	4.75^{a}	5.10^{ab}	0.1077	0.026
Oiliness	5.24	4.91	5.14	4.66	0.1146	0.076
Overall	5.40^{b}	4.90^{a}	4.91^{a}	4.58^{a}	0.0656	0.004

^{abc} means are significantly different within diets ($P \leq 0.05$)
GBO: control, GB2.5: 2.5% inclusion, GB5: 5% inclusion, GB7.5: 7.5% inclusion
The score scale: 1 =“strongly disliked”; 2 =“moderately disliked”; 3 =“slightly disliked”; 4 =“neither like nor dislike”; 5 =“slightly liked”; 6 =“moderately liked”; and 7 =“strongly liked

Guava by-product inclusion level had no significant effect ($P > 0.05$) on sensory traits of the cooked meat. Meat after taste ranged between 4.39 to 5.09, fibrousness between 4.62-5.05, a hardness between 4.39 and 5.13, juiciness between 4.18- 4.74, and oiliness ranging between 4.66 and 5.24. All the scores for these attributes were between 4 and 6, which is acceptable as they lie between the score neither like nor dislike to moderately liked. The diets significantly affected the overall acceptability of the chicken meat with GB0 scoring the highest and low in GB2.5, GB5, and GB7.5.

Flavors in chicken meat are a result of lipid degeneration, maillard reaction, or the interaction of both to produce volatile compounds after cooking (Onsongo, 2017). Meat flavor is influenced by a variety of elements, including the chicken's diet, meat pH, and cooking (Jayasena *et al*., 2013). In this study, meat from the control diet was more acceptable than from all the diets, which scored similarly.

CONCLUSIONS AND RECOMMENDATIONS

The goal of the study was to explore how incorporating the by-products from guava fruit processing in broiler chicken feeds affected performance. Four diets with different inclusions, 0%, 2.5%, 5%, and 7.5% of guava fruit processing by-product were formulated. One hundred and sixty day-old broiler birds were used in the study. The four diets were replicated four times with ten birds randomly allocated in each replicate. The broiler birds' weekly feed intake, weekly weight gain, and feed conversion ratio were determined. The digestibility of the different formulated finisher diets was determined. The birds were sampled from each treatment diet at the end of the trial, and the varied carcass features and quality were examined.

Conclusion

It was concluded that:

1. The incorporation of of up to 5% guava fruit processing by product in broiler diets did not influence feed conversion ratio (FCR), feed intake, and weight gain.
2. The incorporation of different levels of guava fruit processing of by-product in broiler diets did not influence diet digestibility.
3. The incorporation of guava fruit processing by-product in broiler feed at different levels did not affect the weight of the main cuts (thigh, drumstick, breast), meat pH, meat colour and the nutrient constituents of the meat.

Recommendations

Guava fruit processing by-products (peels and seeds) can be incorporated in broiler rations up to 5% in order to lower the cost of production and maintain carcass quality.

Areas for further research

There is a need to document more on the effects of guava by-product inclusion on the sensory evaluation, meat colour, meat pH ofbroiler chicken.

1. More research should be done on the utilization of by-product from guava fruit processing as animal feeds in layers swine and ruminants performancewhile encouraging the growing and processing of guava fruit.
2. Evaluate the effect of inclusion of an exogenous enyme to enhance CF degradation

REFERENCES

Abdollahi, M. R., Ravindran, V., & Svihus, B. (2013). Pelleting of broiler diets : An overview with emphasis on pellet quality and nutritional value. *Animal Feed Science and Technology*, *179*(1–4), 1–23. https://doi.org/10.1016/j.anifeedsci.2012.10.011

Abiola, S. S., & Adekunle, A. O. (2002). Nutritive value of melon husk in the diet of chickens. *Bioresource Technology*, *81*(3), 265–267. https://doi.org/10.1016/S0960-8524(01)00132-8

Arnal-Peyrot, F., & Adrian, J. (1974). THE GUMS AND MUCILAGES ON DIGESTIBILITY: Case of the baobab leaf (“Adansonia digitata”). In *Annals of Nutrition and Food* (pp. 505–521).

Atchade, G. S. T., Houndonougbo, F. M., Chrysostome, C. A. A. M., & Mensah, G. A. (2019). Digestibility of feeds in broiler chicken (*Galus galus* linnaeus, 1758) in Africa: a review. *International Journal of Biological and Chemical Sciences*, *13*(2), 1127. https://doi.org/10.4314/ijbcs.v13i2.43

Ayala-Zavala, J. F., Vega-Vega, V., Rosas-Domínguez, C., Palafox-Carlos, H., Villa-Rodriguez, J. A., Siddiqui, M. W., … González-Aguilar, G. A. (2011). Agro-industrial potential of exotic fruit byproducts as a source of food additives. *Food Research International*, *44*(7), 1866–1874. https://doi.org/10.1016/j.foodres.2011.02.021

Bakshi, M., Angad, G., & Veterinary, D. (2016). Waste to worth : fruit wastes and by-products as animal feed . Commonwealth Agriculture Waste to worth : fruit wastes and by-products as animal feed y, (January 2015). https://doi.org/10.1079/PAVSNNR201510031

Baston, O., & Barna, O. (2010). Raw Chicken Leg and Breast Sensory Evaaluation. *Annals. Food Science and Technology*, *11*(1), 25–30.

Bhuvaneswari, S., & Tiwari, R. B. (2007). Pilot scale processing of red flesh guava RTS beverage, *2*(1), 50–52.

Braga, A. P., De Andrade Ferreira Amâncio, A. V., De Souza Gonçalves, J., Da Silva Lagos Cortes Assis, L. C., De Souza, C. M. S., Da Silva Maia, I. S. A., & Gerra, D. G. F. (2016). Ruminal degradability of agro-industrial fruit residues. *Semina:Ciencias Agrarias*, *37*(1), 279–292. https://doi.org/10.5433/1679-0359.2016v37n1p279

Bridi, A. M., Fonseca, N. A. N., Da Silva, C. A., Balarin, M. R. S., Da Costa Flaiban, K. K. M., Costantino, C., … De Almeida Bitencourt Cardoso, T. (2012). Indicators of stress and quality meat in broilers slaughtered by the "Halal." *Semina:Ciencias Agrarias*, *33*(6), 2451–2459. https://doi.org/10.5433/1679-0359.2012v33n6p2451

BUDIÑO, F. E. L., PREZZI, J. A., RODRIGUES, D. J., MONFERDINI, R. P., & OTSUK, I. P. (2015). Desempenho e digestibilidade de leitões alimentados com rações contendo feno de alfafa e frutoligossacarídeo na fase inicial1. *Revista Brasileira de Saúde e Produção Animal*, *16*(4), 796–810. https://doi.org/10.1590/s1519-99402015000400004

Camelo, L. C. L., Lana, G. R. Q., Dos Santos, M. J. B., Camelo, Y. A. R. P., Marinho, A. L., & Rabello, C. B. V. (2015). Inclution of guava wastes in the diet of European Quails. *Ciencia Animal Brasileira*, *16*(3), 343–349. https://doi.org/10.1590/1089-6891v16i324342

Castellini, C., Mugnai, C., & Dal Bosco, A. (2002). Effect of organic sysytem on broiler carcass and meat quality. *Meat Science*, *60*, 219–225. Retrieved from www.elsevier.com/locate/meatsci

Chang, Y. P., Tan, M. P., Lok, W. L., Pakianathan, S., & Supramaniam, Y. (2014). Making Use of Guava Seed (Psidium guajava L): The Effects of Pre-treatments on Its Chemical

Composition. *Plant Foods for Human Nutrition*, *69*(1), 43–49. https://doi.org/10.1007/s11130-013-0396-3

Chiveu Chemulanga Josiah. (2018). *assessment of genetic and nutritional diversity, and salinity tolerance of Kenya guava (Psidium guajava L.): an underutilized naturalized fruit species*.

Chiveu, J. (2018). *Assessment of genetic and nutritional diversity, and salinity tolerance of Kenyan guava (Psidium guajava L.): an underutilized naturalized fruit species*.

Chiveu, J., Naumann, M., Pawelzik, E., & Kehlenbeck, K. (2016). Morphological Diversity of the Underutilised Fruit Species Guava (Psidium guajava L .) in Kenya, 1.

Choct, M. (2015). Fibre - Chemistry and Functions in Poultry Nutrition. *LII Simposio Cientifico de Avicultura*, 113–119. Retrieved from https://www.wpsa-aeca.es/aeca_imgs_docs/16478_fibra_mingan.pdf

Culioli, J., Berri, C., & Mourot, J. (2003). Muscle foods: Consumption, composition and quality. *Sciences Des Aliments*, *23*(1), 13–34. https://doi.org/10.3166/sda.23.13-34

da Silva, D. C. F., de Arruda, A. M. V., & Gonçalves, A. A. (2017). Quality characteristics of broiler chicken meat from free-range and industrial poultry system for the consumers. *Journal of Food Science and Technology*, *54*(7), 1818–1826. https://doi.org/10.1007/s13197-017-2612-x

Daily, M. (2012). Guavas: Common in homesteads but hardly on the market - Daily Monitor.

de Groote, H., Nyanamba, T., & Wahome, R. (2010). Quality protein maize for the feed industry in Kenya. *Outlook on Agriculture*, *39*(4), 291–298. https://doi.org/10.5367/oa.2010.0022

De Oliveira, J., Avanço, S. V., Garcia-Neto, M., & Ponsano, E. H. G. (2016). Composition of broilers meat. *Journal of Applied Poultry Research*, *25*(2), 173–181. https://doi.org/10.3382/japr/pfv095

de Oliveira, S. D., Araújo, C. M., Borges, G. da S. C., Lima, M. dos S., Viera, V. B., Garcia, E. F., … de Oliveira, M. E. G. (2020). Improvement in physicochemical characteristics, bioactive compounds and antioxidant activity of acerola (Malpighia emarginata D.C.) and guava (Psidium guajava L.) fruit by-products fermented with potentially probiotic lactobacilli. *Lwt*, *134*(June). https://doi.org/10.1016/j.lwt.2020.110200

Dzinic, N., Okanovic, D., Jokanovic, M., Tasic, T., Tomovic, V., Ikonic, P., & Filipovic, S. (2011). Carcass and breast meat quality of broilers feed with extruded corn. *Biotechnology in Animal HusbandryBiotehnologija u Stocarstvu*, *27*(4), 1697–1703. https://doi.org/10.2298/bah1104697d

E Cheptarus Kirwa, E. N. M. and A. J. N. N. (2010). Pastoral chicken production trends: the case of Mashuru and Loitoktok Divisions in Kajiado district, Kenya.

El-Deek, A. A., Hamdy, S. M., Attia, Y. A., & El-Shahat, A. M. (2009a). Guava by-product meal processed in various ways and fed in differing amounts as a component in laying hen diets. *International Journal of Poultry Science*. https://doi.org/10.3923/ijps.2009.866.874

El-Deek, A. A., Hamdy, S. M., Attia, Y. A., & El-Shahat, A. M. (2009b). Guava by-product meal processed in various ways and fed in differing amounts as a component in laying hen diets. *International Journal of Poultry Science*, *8*(9), 866–874. https://doi.org/10.3923/ijps.2009.866.874

El-Deek, A., Asar, M., Hamdy, S., & Abdalla, A. (2009). Utilization of Guava By Products in Broiler Finisher Diets. *Egyptian Poultry Science*, *29*(1), 53–75.

FAO. (2013). *POULTRY DEVELOPMENT*.

Farid, A. S., & Kamel, E. R. (2016). Effect of feeding guava waste on growth performance, diet digestibility, carcass characteristics and production profitability of ossimi lambs., *19*, 463–475.

Fiaboe, K., & Nakimbugwe, D. (2017). Insfeed – Integrating Insects in Poultry and Fish Feed in Kenya and Uganda, (OCTOBER 2014), 25.

Fletcher, D. L. (2002). Poultry meat quality. *World's Poultry Science Journal*, *58*(2), 131–145. https://doi.org/10.1079/WPS20020013

Fontanari, G. G., Souza, G. R., Batistuti, J. P., Neves, V. A., Pastre, I. A., & Fertonani, F. L. (2008). DSC studies on protein isolate of guava seeds Psidium guajava. *Journal of Thermal Analysis and Calorimetry*, *93*(2), 397–402. https://doi.org/10.1007/s10973-007-8576-8

Forman, L. P., & Schneeman, B. O. (1980). Effects of dietary pectin and fat on the small intestinal contents and exocrine pancreas of rats. *Journal of Nutrition*, *110*(10), 1992–1999. https://doi.org/10.1093/jn/110.10.1992

García, M., Lázaro, R., Latorre, M. A., Gracia, M. I., & Mateos, G. G. (2008). Influence of enzyme supplementation and heat processing of barley on digestive traits and productive performance of broilers. *Poultry Science*, *87*(5), 940–948. https://doi.org/10.3382/ps.2007-00266

Gautam, N. N., Singh, K., Singh, B., Seal, S., Goel, A., & Goel, V. L. (2010). Studies on clonal multiplication of Guava (Psidium guajava L.) through cutting under controlled conditions. *Australian Journal of Crop Science*, *4*(9), 666–669.

Gehlhar, M., & Regmi, A. (2014). Factors Shaping Global Food Markets, (May).

Gerland, P., Raftery, A. E., Šev, H., Li, N., Gu, D., Spoorenberg, T., … Heilig, G. K. (2014). Reports World population stabilization unlikely this century, (September), 1–5. https://doi.org/10.1038/42935

Glamoclija, N., Starcevic, M., Janjic, J., Ivanovic, J., Boskovic, M., Djordjevic, J., … Baltic, M. Z. (2015). The Effect of Breed Line and Age on Measurements of pH-value as Meat Quality Parameter in Breast Muscles (m. Pectoralis Major) of Broiler Chickens. *Procedia Food Science*, *5*, 89–92. https://doi.org/10.1016/j.profoo.2015.09.023

González-Alvarado, J. M., Jiménez-Moreno, E., Lázaro, R., & Mateos, G. G. (2007). Effect of type of cereal, heat processing of the cereal, and inclusion of fiber in the diet on productive performance and digestive traits of broilers. *Poultry Science*, *86*(8), 1705–1715. https://doi.org/10.1093/ps/86.8.1705

Granato, D., Masson, M. L., & Ribeiro, J. C. B. (2012). Sensory acceptability and physical stability evaluation of a prebiotic soy-based dessert developed with passion fruit juice | Aceitação sensorial e avaliação da estabilidade física de uma sobremesa prebiótica à base de soja desenvolvida com suco de maracu. *Ciencia e Tecnologia de Alimentos*, *32*(1), 119–125. https://doi.org/10.1590/S0101-20612012005000004

Granato, Daniel, Castro, I. A. De, Ellendersen, L. S. N., & Masson, M. L. (2010). Physical Stability Assessment and Sensory Optimization of a Dairy-Free Emulsion Using Response Surface Methodology. *Journal of Food Science*, *75*(3), S149–S155. https://doi.org/10.1111/J.1750-3841.2010.01514.X

Guimarães, A. A. D. S. (2007). Utilização do resíduo de goiaba (Psidium guajava L.) na alimentação de poedeiras comerciais, 42. https://doi.org/616.89-008.47:616-

Hasan, M. R., Hecht, T., De Silva, S. S., & Tacon, A. G. J. (2007). *Study and analysis of feeds and fertilizers for sustainable aquaculture development*. *FAO. Fisheries Technical Paper*. Retrieved from http://www.fao.org/documents/card/en/c/6fac3b12-1277-5363-a4ce-baaf6a7546d3/

HCD. (2014). Horticultural Validated Report, 61.

HCD. (2016). VALIDATED REPORT 2015-2016.

Hertanto, B. S., Nurmalasari, C. D. A., Nuhriawangsa, A. M. P., Cahyadi, M., & Kartikasari, L. R. (2018). The physical and microbiological quality of chicken meat in the different type of enterprise poultry slaughterhouse: A case study in Karanganyar District. *IOP Conference Series: Earth and Environmental Science*, *102*(1). https://doi.org/10.1088/1755-1315/102/1/012051

Horticultural Crops Directorate (HCD). (2017). Horticulture validated report 2016-2017. *Agriculture and Food Authority (AFA)*, 1–61.

http://farmbizafrica.com. (2018). KALRO gives Busia farmers 55,000 free guava, gooseberry and jack fruit seedlings.

Hussain, Z., Sajjad, W., Khan, T., & Wahid, F. (2019). Production of bacterial cellulose from industrial wastes: a review. *Cellulose*, *26*(5), 2895–2911. https://doi.org/10.1007/s10570-019-02307-1

Industries, A. G. R. O., & Development, F. O. R. D. (2009). *Agro-industries for development*. *Agro-industries for development*. https://doi.org/10.1079/9781845935764.0000

Jacob, J. P., Mitaru, B. N., Mbugua, P. N., & Blair, R. (1996). The feeding value of Kenyan sorghum, sunflower seed cake and sesame seed cake for broilers and layers. *Animal Feed Science and Technology*, *61*(1–4), 41–56. https://doi.org/10.1016/0377-8401(96)00957-1

Jarrett, S., & Ashworth, C. J. (2018). The role of dietary fibre in pig production, with a particular emphasis on reproduction. *Journal of Animal Science and Biotechnology*, *9*(1), 1–11. https://doi.org/10.1186/s40104-018-0270-0

Jayasena, D. D., Ahn, D. U., Nam, K. C., & Jo, C. (2013). Flavour chemistry of chicken meat: A review. *Asian-Australasian Journal of Animal Sciences*, *26*(5), 732–742. https://doi.org/10.5713/ajas.2012.12619

Jha, R., & Mishra, P. (2021). Dietary fiber in poultry nutrition and their effects on nutrient utilization, performance, gut health, and on the environment: a review. *Journal of Animal Science and Biotechnology*, *12*(1), 1–16. https://doi.org/10.1186/s40104-021-00576-0

Jorge, N. (2005). Characterization of some seed oils of fruits for utilization of industrial residues, 1008–1014.

Justus, O., Owuor, G., & Bebe, B. O. (2013). Management practices and challenges in smallholder indigenous chicken production in western Kenya. *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, *114*(1), 51–58.

Kamel, E., AbdelFattah, F., ElQaliouby, H., & EAA, and. (2016). Response of New Zealand Rabbits to Diet Containing Guava Waste (Psidium Guaijava L.): 1. Effect on Growth Performance, Diet Digestibility and Economic Efficiency. *Alexandria Journal of Veterinary Sciences*, *50*(1), 24. https://doi.org/10.5455/ajvs.232098

Kochhar, S. L. (2018). Fruits and Nuts. *Economic Botany*. https://doi.org/10.1017/9781316286098.009

Kowalska, H., Czajkowska, K., Cichowska, J., & Lenart, A. (2017). What's new in biopotential of fruit and vegetable by-products applied in the food processing industry. *Trends in Food Science and Technology*, *67*, 150–159. https://doi.org/10.1016/j.tifs.2017.06.016

Kumari, K. Usha, Rishitha, G., Prasad, K. Rajendra, Kumar, P. S. (2017). Value added products of guava K., *12*. https://doi.org/10.15740/HAS/AU/12.TECHSEAR(8)2017/2270-2276.K

Kwambai, K., & Wambani, H. N. (2000). Assessing the Status of Underutilized Fruit Species in Northwest Kenya, (1999), 643–650.

Leeson, S., J. D. S. (2005). Commercial poultry nutrition. Retrieved July 4, 2022, from https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=Leeson%2C+S.+and+J.D.+Summers%2C+2005.+Commercial+poultry+nutrition.+Published+by+Nottingham+University+Press%2C+Manor+Farm%2C+Church+Lane%2C+Thrumpton%2C+Nottingham%2C+England%2C+3rd+Edn.&btnG=

Lira, R. C., Rabello, C. B.-V., Ferreira, P. V., Lana, G. R. Q., Lüdke, J. V., & Dutra Junior, W. M. (2009). Inclusion of guava wastes in feed for broiler chickens. *Revista Brasileira de Zootecnia*, *38*(12), 2401–2407. https://doi.org/10.1590/S1516-35982009001200016

Litz, F. H., Fernandes, E. A., Bueno, J. P. R., Silva, M. C. A., Carolino, A., Martins, J. M. S., … Nascimento, D. V. (2017). Digestibility, determination of metabolizable energy and bone mineralization of broilers fed with nutritionally valued phytase. *Revista Brasileira de Ciencia Avicola*, *19*(Special Issue), 67–74. https://doi.org/10.1590/1806-9061-2016-0325

Longo, F. A., Menten, J. F. M., Pedroso, A. A., Figueiredo, A. N., Racanicci, A. M. C., Gaiotto, J. B., & Sorbara, J. O. B. (2005). Different Sources of Protein in the Diet of Newly Hatched Chicks. *Revista Brasileira de Zootecnia*, *34*(1), 112–122. https://doi.org/10.1590/s1516-35982005000100015

Lukuyu, B., Franzel, S., Mudavadi, P. O., & Duncan, A. J. (2011). Livestock feed resources: Current production and management practices in central and Northern rift valley provinces of Kenya East Africa Dairy Development Project: Feed Development Component View project Nile Basin Development Challeneg (NBDC) programme V, (May), 1–17. Retrieved from https://www.researchgate.net/publication/287168075

M. Kadam, D., Kaushik, P., & Kumar, R. (2012). Evaluation of Guava Products Quality. *International Journal of Food Science and Nutrition Engineering*, *2*(1), 7–11. https://doi.org/10.5923/j.food.20120201.02

Macagnan, F. T., Santos, L. R. Dos, Roberto, B. S., De Moura, F. A., Bizzani, M., & Da Silva, L. P. (2015). Biological properties of apple pomace, orange bagasse and passion fruit peel as alternative sources of dietary fibre. *Bioactive Carbohydrates and Dietary Fibre*, *6*(1), 1–6. https://doi.org/10.1016/j.bcdf.2015.04.001

Mahmoud, R. El-Sayed; Ibrahim, Doaa; Badawi, M. E.-S. (2013). Effect of Supplementation of Broiler Diets With Guava leaves and/or olive oil on growth, meat composition, blood metabolites and immune response. *Benha Veterinary Medical Journal*, *25*(2), 23–32.

Maria, C., Omena, B., Barros, I., Guedes, S., Rabelo, L. A., Marinho, C., … Goulart, F. (2012). Antioxidant , anti-acetylcholinesterase and cytotoxic activities of ethanol extracts of peel , pulp and seeds of exotic Brazilian fruits Antioxidant , anti-acetylcholinesterase and cytotoxic activities in fruits. *FRIN*, *49*(1), 334–344. https://doi.org/10.1016/j.foodres.2012.07.010

Marquina, V., Araujo, L., Ru\'\iz, J., Rodr\'\iguez-Malaver, A., & Vit, P. (2008). Composition and antioxidant capacity of the guava (Psidium guajava L.) fruit, pulp and jam. *Archivos Latinoamericanos de Nutricion*, *58*(1), 98–102.

Martins, J. S., Genova, J. L., Leal, I. F., Barbosa, K. A., Santos, L. B. de A., Rupolo, P. E., … Bruno, L. D. G. (2021). Potential impacts of guava seed meal on piglet feeding as a dietary fibre alternative. *Journal of Applied Animal Research*, *49*(1), 330–339. https://doi.org/10.1080/09712119.2021.1961780

McMullin, S., Ngethe, E., Gachuiri, A., Njogu, K., & Jamnadass, R. (2016). Fruit tree portfolios for improved diets and nutrition in Machakos. *Www.Worldagroforestry.Org*, 1–15. https://doi.org/978-92-9059-381-2

Micha, R., Wallace, S. K., & Mozaffarian, D. (2010). Red and processed meat consumption and risk of incident coronary heart disease, stroke, and diabetes mellitus: A systematic review and meta-analysis. *Circulation*, *121*(21), 2271–2283. https://doi.org/10.1161/CIRCULATIONAHA.109.924977

Mir, N. A., Rafiq, A., Kumar, F., Singh, V., & Shukla, V. (2017a). Determinants of broiler chicken meat quality and factors affecting them: a review. *Journal of Food Science and Technology*, *54*(10), 2997–3009. https://doi.org/10.1007/s13197-017-2789-z

Mir, N. A., Rafiq, A., Kumar, F., Singh, V., & Shukla, V. (2017b, September 1). Determinants of broiler chicken meat quality and factors affecting them: a review. *Journal of Food Science and Technology*. Springer India. https://doi.org/10.1007/s13197-017-2789-z

MoLD. (2008). Republic of Kenya Ministry of Livestock Development. Session Paper NO: 2 of 2008 on November 2008, (2), 1–53.

MoLD. (2019). Republic of KenyaMinistry of Agriculture, Livestock,Fisheries and Irrigation-State Department for Livestock Draft National Livestock Policy Kenya., (February).

Mosaad, T., & Hassan, M. (2016). Effect of feeding guava waste on growth performance, diet digestibility, carcass characteristics and production profitability of ossimi lambs., (december).

Mudgil, D. (2017). *The Interaction Between Insoluble and Soluble Fiber*. *Dietary Fiber for the Prevention of Cardiovascular Disease: Fiber's Interaction between Gut Micoflora, Sugar Metabolism, Weight Control and Cardiovascular Health*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-805130-6.00003-3

Mujahid, A., Asif, M., Haq, I., Abdullah, M., & Gilani, A. H. (2003). Nutrient Digestibility of Broiler Feeds Containing Different Levels of Variously Processed Rice Bran Stored for Different Periods 1 Processing of Rice Bran, 1438–1443.

Murangiri, M., Amwata, D., & Kanui, T. (2016). Extension Support Services among Poultry Farmers, a Case of Katulani District, Kitui County. *International Journal of Livestock Research*, *6*(3), 8. https://doi.org/10.5455/ijlr.20160313125928

Mutua, F., Lindahl, J., & Grace, D. (2019). Availability and use of mycotoxin binders in selected urban and peri-urban areas of Kenya. *Food Security*, *11*(2), 359–369. https://doi.org/10.1007/s12571-019-00911-4

Nikhanj, P., Kocher, G. S., & Boora, R. S. (2017). Fermentative production of guava wine from pectinase treated and untreated juice of ‘punjab pink’ cultivar of *Psidium guajava* L. *Agricultural Research Journal*, *54*(2), 244. https://doi.org/10.5958/2395-146X.2017.00044.8

Nobre, P. T., Munekata, P. E. S., Costa, R. G., Carvalho, F. R., Ribeiro, N. L., Queiroga, R. C. R. E., … Lorenzo, J. M. (2020). The impact of dietary supplementation with guava (Psidium guajava L.) agroindustrial waste on growth performance and meat quality of lambs. *Meat Science*, *164*(February), 108105. https://doi.org/10.1016/j.meatsci.2020.108105

Noleto-Mendonça, R. A., da Silva Martins, J. M., Carvalho, D. P., de Araújo, I. C. S., Stringhini, J. H., da Conceição, E. C., … Leandro, N. S. M. (2021). Performance, nutrient digestibility, and intestinal histomorphometry of broilers fed diet supplemented with guava extract standardized in phenolic compounds. *Revista Brasileira de Zootecnia*, *50*, 1–10. https://doi.org/10.37496/rbz5020210026

Ochieng, P. E., Scippo, M. L., Kemboi, D. C., Croubels, S., Okoth, S., Kang’ethe, E. K., … Antonissen, G. (2021). Mycotoxins in poultry feed and feed ingredients from sub-saharan africa and their impact on the production of broiler and layer chickens: A review. *Toxins*, *13*(9). https://doi.org/10.3390/toxins13090633

Ogeto Onsongo, V. (2017). PERFORMANCE AND MEAT QUALITY OF BROILER CHICKEN FED DIETS ENRICHED WITH BLACK SOLDIER FLY (Hermetia illucens) LARVAE MEAL, 1–57. Retrieved from https://pdfs.semanticscholar.org/63a5/bd41b72d7686df8d68c0057dc65d4f292c85.pdf

Oliveira, M. D. De, Helena, H., Mello, D. C., & Stringhini, J. H. (2018). Antioxidant effect of the guava byproduct in the diet of broilers in the starter phase. *Revista Brasileira de*

Zootecnia.

Omayio, Duke G., Abong, G. O., Okoth, M. W., Gachuiri, C. K., & Mwang'ombe, A. W. (2019). Current Status of Guava (Psidium Guajava L) Production, Utilization, Processing and Preservation in Kenya: A Review. *Current Agriculture Research Journal*, *7*(3), 318–331. https://doi.org/10.12944/carj.7.3.07

Omayio, Duke Gekonge, Abong', G. O., Okoth, M. W., Gachuiri, C. K., & Mwang'ombe, A. W. (2020). Trends and Constraints in Guava (Psidium Guajava L.) Production, Utilization, Processing and Preservation in Kenya. *International Journal of Fruit Science*, *00*(00), 1–12. https://doi.org/10.1080/15538362.2020.1791304

Omiti, J. M., & Okuthe, S. O. (2008). An overview of the poultry sector and status of highly pathongenic avian influenza (HPAI) in Kenya - Background paper. *Collaborative Research on Pro-Poor HPAI Risk Reduction*, 1–107.

Ondwasy, H., Wesonga, H., & Okitoi, L. (2006). Indigenous chicken production manual. *KARI Technical Note*, (18).

Onsongo, V. O., Osuga, I. M., Gachuiri, C. K., Wachira, A. M., Miano, D. M., Tanga, C. M., … Fiaboe, K. K. M. (2018). Insects for Income Generation Through Animal Feed : Effect of Dietary Replacement of Soybean and Fish Meal With Black Soldier Fly Meal on Broiler Growth and Economic Performance. *Veterinary Entomology*, (May), 1–8. https://doi.org/10.1093/jee/toy118

Payne, R.W., Harding, S.A., Murray, D.A., Soutar, D.M., Baird, D.B., Glaser, A.I., Channing, I.C., Welham, S.J., Gilmour, A.R., Thompson, R. and Webster, R. (2011). The guide to GenStat release 14. *VSN International, Hemel Hempstead, UK*.

Pereira, E., Arabutan, D., Bôa-viagem, C., Lima, R. B., Lima, M. B., & Ludke, J. V. (2009). Physicochemical composition and energy and nutritional characteristics of guava and tomato residues for free range broilers, *3598*.

Petracci, M., & Fletcher, D. L. (2002). Broiler skin and meat color changes during storage. *Poultry Science*, *81*(10), 1589–1597. https://doi.org/10.1093/ps/81.10.1589

Phani Deepthi, V., Chandra Sekhar, R., Srihari, D., & Siva Sankar, A. (2016). Guava fruit quality and storability as influenced by harvest maturity and postharvest application of calcium salts. *Plant Archives*, *16*(1), 174–182.

Pius, L. O., Strausz, P., & Kusza, S. (2021). Overview of poultry management as a key factor for solving food and nutritional security with a special focus on chicken breeding in east african countries. *Biology*, *10*(8). https://doi.org/10.3390/biology10080810

Pommer, C. V, Murakami, K. R. N., & Production, W. (2009). Breeding Guava (Psidium guajava L .).

Rana, S., Siddiqui, S., & Goyal, A. (2015). Extension of the shelf life of guava by individual packaging with cling and shrink films. *Journal of Food Science and Technology*, *52*(12), 8148–8155. https://doi.org/10.1007/s13197-015-1881-5

Rao, T., Ravi, A., & Rao, D. (2004). Effect of Inclusion of Guava (Psidium guajava) Pomace in Pig Diets on Growth Performance, Nutrient Utilization and Carcass Characteristics. *Indianjournals.Com*, *4*(1), 43–52. Retrieved from http://www.indianjournals.com/ijor.aspx?target=ijor:anft&volume=4&issue=1&article=005

Ravinadan, V. (2009). Poultry feed availability and nutritionin developing countries. *Green*

Farming, *2*(10), 694–695.

Riise, J. C., Permin, A., Kryger, K. N., & Faso, B. (2005). Strategies for developing family poultry production at village level - Experiences from West Africa and Asia, *61*(March), 15–22. https://doi.org/10.1079/WPS200437

Robertson, A. R. (1977). The CIE 1976 Color-Difference Formulae. *Color Research & Application*, *2*(1), 7–11. https://doi.org/10.1002/j.1520-6378.1977.tb00104.x

Rosa Martha , Sylvia Mitchel, R. V. (2008). Psidium guajava : A review of its traditional uses , phytochemistry and pharmacology, *117*(16), 1–27. https://doi.org/10.1016/j.jep.2008.01.025

Sadh, P. K., Duhan, S., & Singh Duhan, J. (2018). Agro-industrial wastes and their utilization using solid state fermentation: a review. *Bioresources and Bioprocessing*, *5*, 1. https://doi.org/10.1186/s40643-017-0187-z

Silva, E. P. da, Silva, D. A. T. da, Rabello, C. B.-V., Lima, R. B., Lima, M. B., & Ludke, J. V. (2009). Physico-chemical composition and energy values of guava and tomato residues for slow growing broilers. *Revista Brasileira de Zootecnia*, *38*(6), 1051–1058. https://doi.org/10.1590/S1516-35982009000600012

Singh, G. (2007). Recent Development in Production of Guava, 161–176.

Uchôa-thomaz, A. M. A., Sousa, E. C., Carioca, J. O. B., Morais, S. M. De, Lima, A. De, Martins, C. G., … Rodrigues, L. L. (2014). Chemical composition, fatty acid profile and bioactive compounds of guava seeds (Psidium guajava L.). *Food Science and Technology*, *34*(3), 485–492. https://doi.org/10.1590/1678-457x.6339

Van Huis, A. (2013). Potential of insects as food and feed in assuring food security. *Annual*

Review of Entomology, *58*, 563–583. https://doi.org/10.1146/annurev-ento-120811-153704

Verma, A. K., Rajkumar, V., Banerjee, R., Biswas, S., & Das, A. K. (2013). Guava (Psidium guajava L.) powder as an antioxidant dietary fibre in sheep meat nuggets. *Asian-Australasian Journal of Animal Sciences*, *26*(6), 886–895. https://doi.org/10.5713/ajas.2012.12671

Wadhwa, M., & Bakshi, M. P. S. (2013). *Utilization of fruit and vegetable wastes as livestock feed and as substrates for generation of other value added products. RAP Publication 2013/04* (Vol. 105). https://doi.org/10.1111/j.1471-4159.2007.05137.x

Wadhwa, Manju, Bakshi, M. P. S., & Makkar, H. P. S. (2015). Waste to worth: Fruit wastes and by-products as animal feed. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, *10*. https://doi.org/10.1079/PAVSNNR201510031

Wainaina, P. W., Okello, J. J., & Nzuma, J. (2012). Impact of Contract Farming on Smallholder Poultry Farmers' Income in Kenya. *Selected Paper Prepared for Presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz Do Iguaçu, Brazil, 18-24 August, 2012.*, 18–24.

Wasilwa L, Wayua F , Wasilwa T, Wasike V W, Omari F, N. J. and O. N. (2018). Preferences of Guava (Psidium guajava L.) types amongst school Children in Western Kenya.

Zarei, A., Jaberzadeh, V., & Hemmati, B. (2014). Determination of Apparent and True Digestibility of Poultry by Product Meal in Broiler Chickens. *Iranian J. Appli. Anim. Sci.*, *4*(3), 587–590.

Zhang, C., Xu, T., Feng, H., & Chen, S. (2019). Greenhouse gas emissions from landfills: A review and bibliometric analysis. *Sustainability (Switzerland)*, *11*(8), 1–15. https://doi.org/10.3390/su11082282

Zootecnica international. (2016). *The poultry sector in Kenya*. *zootecnica international*.