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The nutritive value of macadamia oil cake meal and wood ash as alternative feed ingredients for chickens in rural areas

By

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Declaration

I, Mashilo Alpheus Phosa, declare that this thesis, for the degree M. Inst. Agrar (Animal Production) at the University of Pretoria, has not been submitted by me for a degree at any other University.

…………………………

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ABSTRACT

The majority of South African household live in poverty with a limited variety of foods available in their home. In most rural villages domestic poultry plays an important role in improving household food security, but is limited by shortage of feed and high feed costs. Using non-conventional feed ingredients in poultry diets may ease the situation of malnutrition in rural populations, providing the family with high quality animal protein at more affordable prices. Macadamia oil cake meal (MOCM) is an inexpensive by-product from the macadamia oil industry of the Limpopo Province. Although it is relatively high in crude protein (20-25%), MOCM has never been considered as a feed ingredient for poultry feeds. The high and varying fibre content (up to 25%, depending on the extrusion method applied) of MOCM may render it unsuitable as an ingredient for high producing poultry such as broilers. The question, however, arouse whether the inclusion of MOCM in the growing diet of meat-producing chickens typically found in rural areas, would be cost-effective. Calcium (Ca) in poultry rations is usually supplied as calcium carbonate from limestone. Wood ash (WA) from fireplaces at homestead in rural villages was found to be rich in Ca (approximately 26%) and has the potential of being a free and readily available Ca supplement that could easily be added to the diet. The purpose of this study was to evaluate the effects of MOCM and WA as alternative feed ingredients in growth rations for chickens in rural areas. New Hampshire chickens were randomly divided into eight treatment groups with four replicates per treatment and twelve chicks in each replicates. The chicks were housed in an environmentally controlled broiler house from day-old to 15-weeks of age. Four diets were formulated, one without MOCM and the other three containing different levels of MOCM, viz. 10, 50 and 100% plus salt and a trace nutrient mixture. Each of these treatments was split in two with one receiving limestone ($CaCO_3$) and the other WA, as Ca sources, giving eight treatments in total. All the treatments received diets with a Ca level close to 1 %. Parameters measured on weekly basis were body weight (BW), feed intake (FI), and body weight gain (BWG) and feed conversion efficiency (FCE) was determined. The analysis of the carcass composition and tibia bone strength was done at the end of the 15 week period. An analysis of variance with the ANOVA model (SAS) was used to determine the significance between different treatments for the balanced data. Significance of difference (5%) between means was determined by multiple

comparisons using Tukey t-test. The treatment of 100% MOCM was terminated at eight weeks since the chickens had retarded growth and low body weight gains, demonstrating that the 100% MOCM diet both with and without Ca were not feasible. The BW and feed intake of the diet of 100% MOCM plus WA was, however, significantly higher than the diet of 100% MOCM plus lime. However, the inclusion level of up to 50% MOCM had no significant differences in (muscle and fat), except for FI, BWG and FCE between treatment diets. In conclusion, the results prove that MOCM can be added to the ration at a 10% concentration level without any adverse effect on growth. Higher inclusion levels of MOCM might also be beneficial, especially when included at an older age of the bird. Wood ash proved to be an efficient Ca source, as the substitution of limestone with WA showed no negative effect on the tibia bone parameters measured.

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CHAPTER 1 - LITERATURE REVIEW

1.1 By-products as alternative feed ingredients in chickens reared in small-scale farming system

A definition of a by-product feedstuff is a product that has value as an animal feed and is obtained during the harvesting or processing of a commodity in which human food or fibre is derived. By-product feedstuffs can be of either plant or animal origin. Growing interest in technologies of identifying and quantifying by-product feedstuffs is due to the desire to understand and monitor environmental waste in developed and developing countries. The worldwide use of by-product feedstuffs is common practice yet few published reports document the amounts of plant by-product feedstuffs generated (Grasser et al., 1995; Van Horn and Hall, 1997).

Many by-products feedstuffs cannot be quantified because no standard equivalent is available in the literature to make this conversion from a processed food to a by-product feedstuff. Some by-products feedstuffs that are not easily quantified include almond hulls, bagasse, beet pulp, and brewer's grains. However, knowing the amount of by-product feedstuffs generated is critical in defining the integral role of animals in the food and fibre system. General information is known about animal by-product feedstuffs that are recycled back to the animal (Romans et al., 1994).

Maize, wheat, barley and oats are the most commonly used energy-rich feedstuffs in conventional poultry diets. Their production in countries such as Asia, Africa and Pacific nations has never been adequate, both for human consumption and agricultural use. Hence, there is a severe shortage of cereals for use in poultry feeds. Similarly the cost of conventionally employed vegetable oil meals or cakes (soybean, peanut, sunflower, sesamum and rape) and animal proteins such as fish and meat meal are becoming scarce, making them very expensive and with an inconsistent supply (Reddy & Quadratullah, 1996).

As an example, in Kenya the expansion of the commercial poultry industry is limited by the supply of reasonably priced, good quality feeds. Although there is sufficient milling capacity, there is a shortage of appropriate feedstuffs. Maize is the principal ingredient used in Kenyan poultry diets but, because it is also a staple food in the diet of most Kenyans, the quantity of maize available for use in animal feeds is limited and expensive (Jacob *et al.,* 1996). On the other hand, Ogunfowora (1984) stated that the most logical step to take in the face of the increasing human population and dwindling raw material supplies is to formulate livestock feeds from non-conventional ingredients, such as by-products and wastes from plant processing procedures, which are not directly utilized by man.

Not much has yet been published on macadamia oil cake meal (MOCM) as a feed ingredient for poultry diets. However, over the decades, research has been conducted worldwide on the use of non-conventional feed ingredients as feedstuffs for poultry diets. The results of these studies showed that various unconventional feedstuffs can serve as a viable alternative to maize in poultry diets (Damron *et al.,* 1966, Day & Dilworth, 1968, Daguro & Rivas, 1987, Saleh *et al.,* 1996, Attia *et al.*, 1997) and can lead to reduced cost/kg of live weight of the birds, and consequently greatly reduce the total cost of production (Eruvbetine & Afolami, 1996). There is a continuous search for alternatives to reduce poultry feed costs and improve the efficiency of small-scale poultry production units. An effort is thus being made to study the possibility of utilising agricultural, animal and industrial by-product for the nutrition of poultry (Fetuga and Olufemi, 1976; Dominguez, 1992;, El Boushy 2000).

By using non-conventional feed sources of energy in poultry diets, it could possibly alleviate the situation of malnutrition in rural populations of South Africa and worldwide by providing the family with high quality protein at low cost, thereby decreasing the high incidence of protein deficiency.

Marketing by-products as animal feeds can help reduce pollution and minimise waste treatment costs. If by-product recovery is feasible in a given situation, it is critical that the material be kept free of contaminants, that inventory (if wet) be turned over rapidly and that moisture and nutrient content be as consistent as possible. With effective quality control, many livestock feeders can benefit from using food processing by-products.

1.2 Nutrient composition of conventional feed

It is common practice to feed chickens a ration that is a mixture of economically available ingredients so as to provide every known nutritional need in quantities necessary for their daily well-being. Commercial poultry rations today are known as “complete rations”; that is, they contain all the essential ingredients for the bird to perform effectively, whether in growth, egg production or meat production (North, 1984).

Most of these feeds come from the common and major feed ingredients such as cereal grains, protein and fat supplements, certain mill by-products and major minerals. However, in most cases, a mixture of the ingredients would either not satisfy the bird’s nutritional requirements, or be economically feasible. Certain vitamins, minerals, by-products and other ingredients must be added to balance the diet.

1.2.1 Energy in broiler ration

The energy content of the ration will govern the chicken’s daily feed consumption. The amount of each of the other nutrients in the ration must be related to the feed’s caloric content. This recommendation is based on the premise that the bird has a daily requirement of each nutritional factor, when there is a variation in feed consumption as a result of dietary changes in the caloric value of the ration or environmental or other factors causing the bird to eat more or less feed, an adjustment must be made in the non-energy portion of the diet (North, 1984).

The energy requirements may be defined as the amount of available energy that will provide for growth or egg production at a high enough level to permit maximal economic return for the production unit. Each primary energy source i.e., carbohydrates, fats and protein, has a specific function: all of them can be used to provide energy for maintenance and production of poultry. From the standpoint of providing the normal energy needs, however, carbohydrates are by far the most important, whereas fats rank next as an energy source (North, 1984). The major energy sources of poultry feeds are the cereal grains and their by-products and fats. Maize is the most important grain used in poultry feeds in South Africa making up at least half of the total feed which they consume. While the bulkiness of feed can alter feed intake, the bird, for the most part will eat to satisfy its need for the most limiting nutrient in the diet, which would normally be energy. Because of this, special attention must be given to nutrient ratios, especially the ratio of energy to various nutrients such as amino acids and minerals (North, 1984).

1.2.2 Protein in broiler ration

From the standpoint of poultry nutrition, the amino acids that make up proteins are really the essential nutrients, rather than the protein molecule itself. Hence, protein content as a measure of the nutritional value of a feed is becoming less important, and each amino acid is being considered individually. The usefulness of a protein feedstuff depends upon its ability to furnish the essential amino acids required by the bird, the digestibility of the protein and the presence or absence of toxic substances. As a general rule, several different sources of protein produce better results than single protein sources (North, 1984).

1.2.3 Amino acids

When formulating poultry rations, they must be so designed as to supply all the essential amino acids in ample amounts. Special attention needs to be given to supplying the amino acids lysine (most limiting), arginine, methionine and cystine, and tryptophan, which are sometimes referred to as the "critical amino acids" in poultry nutrition, as others are usually supplied adequately by a combination of feedstuffs (North, 1990b).

Table 1 Amino acid specification (%) for broiler diets (North, 1990b)

	Ration		
Amino Acids (%)	Starter	Grower	Finisher
Arginine	1.44	1.20	1.00
Glycine + Serine	1.50	1.00	0.70
Lysine	1.20	1.00	0.85
Methionine	0.50	0.38	0.32
Methionine + Cystine	0.93	0.72	0.62
Tryptophan	0.23	0.20	0.17

1.3 Nutrient composition of by-products (non-conventional feed) as animal feeds

A definition of a by-product feedstuff is a product that has value as an animal feed and is obtained during harvesting and or processing of a commodity in which human food is derived. Many by-products have a substantial potential value as animal feedstuff, though more in ruminant than monogastric nutrition. The main reason is that ruminants have the unique ability to utilise fibre because of their rumen microbes. This means that cereals can largely be replaced by the by-products (Boucqué & Fiems, 1988) and thus reducing the competition between human and animals for cereal products.

The use of by-products and waste as sources of nutrients for domesticated animals has always reflected the ability of these animals to scavenge. From the early days of domestication those parts of plants that were unsuitable for human consumption because they were too fibrous, had undesirable taste or carried a high risk of infection, were given to animals which lived nearby. With the development of organised crop and animal production, the process of feeding animals on crop by-products developed to a considerable extent (Wilkinson, 1988). In recent years, by-products are receiving increasing attention from livestock producers and nutritionists. The growth of the animal feed industry has allowed considerable use to be made of by-products and wastes, some of which, although containing potentially toxic components, can be safely included in compounded feeds in relatively low proportions (Wilkinson, 1988).

1.4 Macadamia nut as a by-product

1.4.1 Macadamia nut background

Australian botanists discovered and named the macadamia nut in 1843, but it was only 125 years later, when it was successfully cultivated in Hawaii, that it actually became known. The macadamia nut is a rarity-a "new" crop, which was domesticated for the first time in 1858 in Australia. It is the only native Australian plant ever developed as a commercial food crop (Rosengarten, 1984). The edible nuts are produced by two species of the genus *Macadamia* i.e. *Macadamia intergrifolia*, known as the smooth-shelled type, and *M. tetraphylla*, commonly referred to as the rough-shell type. The macadamia tree under favourable conditions begins to produce in six to seven years. It is a long-lived tree, which may have a productive life of 60 years or more (Rosengarten, 1984). The first large-scale plantings were at Keauhou and Kona, where 7 000 trees were established. The Hawaii Agricultural Experiment Station (HAES) undertook research on the cultivation of macadamia. The first processing factory was established in 1931 (ARC Bulletin, 426).

1.4.2 Macadamia oil cake meal

Macadamia oil cake meal is an inexpensive by-product, produced from the macadamia oil industry. The high varying fibre content of MOCM may render it unsuitable as an ingredient for high producing poultry such as commercial layers or broilers. The nutritive value of MOCM depends on the processing i.e. the extrusion process applied by the oil producing industries. It is therefore highly recommended that the user of the by-product must be informed about the processing and that the nutrient composition is known before it can be included in chicken rations.

1.4.3 Production in South Africa

It is not exactly known when the first macadamia trees were established in South Africa, but the Durban Botanical Garden already had a tree in 1915. The Citrus and Subtropical Fruit Research Institute (CSFRI, currently the ITSC) established the first trees from seed imported in 1931, one of which is still bearing fruit. The CSFRI started doing research on this new crop in 1963. As a result the industry is now well established in the subtropical areas. Commercial orchards have been established in the Soutpansberg area and in the vicinity of Tzaneen, Nelspruit, White River, Barberton, Komatipoort, Rustenburg, Pietermaritzburg and Port Shepstone. The orchard containing the largest variety of cultivars in South Africa was established on the farm, Cheviot, near Tzaneen (ARC Bulletin 426).

Macadamia is a large evergreen tree indigenous to the coastal rainforest of Australia. While 10 species have been identified, only two *(Macadamia tetraphylla and M. integrifolia)* are grown commercially in Hawaii, Australia and New Zealand. When fresh, these nuts have a moisture content of up to 30 %; they are dried to a moisture content of 2 % for storage (Kaijser *et al*., 2000). Very little research has been carried out on their composition but initial data on the composition of NZ-grown macadamia nuts suggested that a wide variation of fatty acid profiles exists (Dawson and Savage, 1997).

Agro-industrial by-products (by-product feedstuffs, BPF) and crop residues have been identified as possible alternative feed resources for farmers, as the conventional feedstuffs are expensive. The nutrient content and any other potential limitations must be known in order to identify the best way to use these feedstuffs (Skenjana *et al*., 2003, unpublished).

1.5 Wood ash (WA) as alternative calcium source

Mineral supplements are required to fortify animal diets in order to meet the mineral needs for optimum health and production of livestock. However, use of mineral supplements without proper appraisal of the composition of dietary ingredients may be detrimental, possibly because of mineral antagonism (Mertz, 1997).

Various calcium (Ca) sources differ in their origin (animal or plant), particle size (Guinotte *et al*., 1991) and structure (Ajakaiye *et al*., 1996). While Ca is usually supplied as calcium carbonate from limestone in poultry rations, other sources, such as marine shells can be used as a substitute (Guinotte *et al*., 1991). As a consequence, their physico-chemical characteristics are different (Reid and Weber, 1976). Calcium and phosphorus are essential for bone formation, and numerous skeletal pathologies are associated with dietary deficiency in these minerals (Williams *et al.,* 2000). Nutrient requirements, including mineral requirements, change with age (NRC, 1994), and are likely to vary with the potential growth performance of a strain. In spite of the large volume of research conducted on Ca nutrition over the years, little information has been published on the comparative biological availability of Ca from different Ca sources available in tropical climates for chickens and most of the published works were conducted using conventional Ca sources available in temperate climates (Ajakaiye *et al*, 2003). Mineral supplements are not readily available in the rural areas to improve productivity, especially for small village farmers. Therefore, it is necessary to identify cheap, readily available local mineral sources to supplement the feed of livestock on small farms.

Wood ash may be one such material. Ochetim (1988) suggested the use of wood ash as a source of minerals for poultry. Wood ash has been used to treat straws to improve their digestibility (Nolte *et al.*, 1987; Ramirez *et al.*, 1991, 1992) and their mineral contents (Ramirez et al., 1991, 1992).

1.5.1 Wood ash characteristics

Wood ash is the inorganic and organic residue remaining after the combustion of wood. The ash content and chemical composition are variable among tree species and also depend on soil type and climate. Temperate-climate woods yield 1-10 g ash/kg ash, while tropical and subtropical woods yield up to 50 g/kg. Hardwoods, in general, contain more ash than softwoods (Campbell, 1990). Campbell (1990) stated that the ash content is highly variable within trees, being highest in the foliage and then decreasing in the bark, twigs, roots, branches and stems. Within the stem, ash is highest in the pith, early wood (spring wood), and juvenile wood. Barks contain much higher ash content than wood, as indicated by the 10-30 g ash/kg content in hog fuel.

Analyses of wood ash have shown the complex and heterogeneous nature of this material, though, the physical and chemical properties of wood ash are largely unexplored and more data are needed in order to develop recycling processes, which could expand the use of ash. The micrographs obtained by a scanning electronic microscope indicate that wood ash contains large porous particles of carbon and several inorganic particles of irregular shape (Etiegni and Campbell, 1991). X-diffraction and the infrared spectra methods have shown that the calcite ($CaCO_3$) is the major compound of wood ash (Etiegni and Campbell, 1991; Ohno, 1992). Lime (CaO) and calcium silicate (Ca_2SiO_4) among others, were identified as additional constituents (Etiegni and Campbell, 1991).

The alkalinity or neutralization capacity of wood ash is high. This characteristic is largely influenced by the temperature of combustion and the period of storage, the alkalinity decrease with increasing temperature of combustion and with period of storage (Etiegni and Campbell, 1991).

It is well documented that wood ash is rich in Ca and has been used successfully as a fertilizer especially to ameliorate the acidity in soils (Demeyer *et al*., 2001). The product also showed promise as a mineral supplement to livestock in the tropics (Imbeah, 1999) and the treating of low quality fibres to improve fibre utilization by ruminants (Nolte *et al*., 1987; Ramirez *et al*., 1992). The calcium in the wood ash used for this research was mainly in the form of $CaCO_3$. This agrees with the results found by Van Ryssen and Ndlovu (2003).

Several methods can enhance the feeding value of straw by biological, physical or chemical treatments, or their combinations. Chemical treatment increases lignin solubility, reduce cell wall volume and increase cell content digestibility. The most common alkalis used are NaOH, $Ca(OH)_2$ and urea-ammonia (Trung and Devendra, 1987). Another economical alkaline source is wood ash. Nolte et al. (1987) found that treatment of wheat straw with a 30% solution of wood ash for 6 hours increased digestibility of dry matter (DM), organic matter (OM), neutral detergent fibre (NDF) and acid detergent fibre (ADF) in goats.

Wood ash has been known to be an important source of potash and lime for many years (Agee, 1919; Yearbook of Agric., 1938), although recent comprehensive reference makes little reference to it. In the Yearbook of Agriculture (1938), wood ash was suggested to "rate as a potash material with comparatively high lime content, some phosphoric acid and magnesium, and small amounts of other elements". Several research studies had been carried out on the utilisation of wood ash in agriculture and forestry. It is generally accepted that wood ash can serve as a liming agent and its application to the soil is a convenient way to recycle exported nutrient elements (Demeyer et al., 2001). Wood ash has also been recommended to correct forest nutrient deficiencies or imbalance due to acid deposition and leaching (Cronan and Grigal, 1995).

Low digestibility is one of the several traits of many crop residues. Consequently, such residues need to be treated before they can be used as unconventional feed resources in animal nutrition. Grinding and alkali treatment have been used in various countries to improve the nutritive value of fibrous residues. The effects of sodium hydroxide on the nutritive value of maize cobs (Escobar et al., 1984), wheat, barley, and oat straws (Moss et al., 1990) have been evaluated in previous studies.

1.6 Hypothesis

Macadamia oil cake meal (MOCM) and wood ash (WA) can be used as alternative feed ingredients to rear chickens in rural small-scale production systems.

1.7 Motivation

Feed represents a major cost of producing poultry meat and eggs, and farmers often cannot cope with feed cost, forcing them to close their farms. Insufficient food supplies at both national and global level hinder food security at household level by providing less production and stocks that cannot meet the nutritional needs or proper diets for household consumption in general (McCalla *et al.* 1999). Smallholder farming globally had often demonstrated that it can be efficient in the use of resources and can spread the benefits from agricultural growth more widely than other production systems. Smallholder farming on its own would not be a solution for food insecurity and rural underdevelopment, but as part of a diverse sector which also allows space for other types of farming, has a great deal to offer (Duncan, 1998).

Because of the relationship between malnutrition and infection its combined effect is more severe than the independent actions alone and children in particular are susceptible to viral, bacterial and parasitic infections when undernourished. Their resistance to diseases decreases and simultaneously nitrogen losses occur from the body. An increased level of intake for animal products would significantly add to their health through increased energy, protein, iron and vitamin A consumption (Latham, 1997).

By using non-conventional feed sources of energy in poultry diets, it will be possible to alleviate the situation of malnutrition in rural population of South Africa and worldwide by providing the family with high quality protein at low cost, thereby decreasing the high incidence of protein deficiency. Maize is mostly the principal feed ingredient used in poultry feeds, but because it is also a staple in the diet of most people in under-developed countries, the quantity of maize available for use in animal feeds is limited and expensive (Jacob et al., 1996). Therefore, the use of non-conventional ingredient like MOCM as feed ingredient could be a resultant solution to the problem of limited and expensive supply of conventional diet to poultry. The question, however, arouse whether the use or inclusion of MOCM in chicken diet would be cost effective for the raising of chickens typically found in rural areas.

Macadamia oil cake is an inexpensive by-product from the oil producing industry. The by-product is very cheap to obtain and can be used by rural people as feed ingredient for chickens in small-scale production systems. Research has been conducted worldwide on the use of non-conventional feedstuffs as feed ingredient, but no published data are available yet on the use of MOCM as feed ingredient for chickens yet. One of the objectives of the study is to evaluate the use of MOCM as non-conventional feed ingredient for chickens found in rural areas taking into consideration the extrusion process applied and its nutrient composition.

On the other hand, calcium sources in poultry diets are mainly supplied through limestone. As limestone as source of calcium might be scares and not easily available to rural small scale farmers, there is a need to develop locally produced sources of Ca. Wood ash was found to have high calcium content (Van Ryssen and Ndlovu, 2003). As it is very cheap and highly available to rural communities, it was thought to be necessary to conduct a study to evaluate the use of wood ash as an alternative supplement.

1.8 Objectives

The objective of this study was to evaluate the nutritive value of MOCM and WA as alternative ingredients for chicken diets used in small-scale production systems in rural areas.

CHAPTER 2 – MATERIALS AND METHODS

2.1 Introduction

The experiment was conducted to evaluate the effect of MOCM and WA as alternative feed ingredients in growth and layer diets for chickens found in rural areas.

This study was conducted in two phases. Firstly, a growth study was conducted with dual-purpose chickens over a period of 15 weeks. After that, the cockerels were slaughtered and the hens were used in a subsequent 4-week layer study.

2.2 Materials

2.2.1 Experimental animals

A total of 384 day-old New Hampshire chicks were obtained from "Fowls for Africa" at the ARC-Livestock Business Division (Private Bag X2 Irene, 0062, Pretoria, South Africa). The New Hampshire breed originated in the United States of America, and has been used in developing many of the synthetic lines of meat-type chickens and is still used for this purpose. The ability of the breed to produce a large number of eggs that hatch well has made it a valuable asset to many breeding combinations (North, 1984). The New Hampshire breed was chosen for this experiment to represent the type of chickens commonly found under rural situations.

Seventy two of the New Hampshire hens from the growth trial were used in the layer phase of the study, which lasted for a period of four weeks. The experimental period started at an age of 20 weeks and was terminated at an age of 23 weeks.

2.2.2 Treatments

2.2.2.1 Growth study

The research was conducted as a 4x2 factorial design and 48 'as hatched' chicks were randomly allocated per treatment, with four replications of 12 chicks per replicate, and randomly distributed through the house. Four diets were formulated, one without MOCM and the other three containing different levels of MOCM, viz. 10, 50 and 100% plus salt and a trace nutrient mixture. Each of these treatments was split in two with one receiving limestone ($CaCO_3$) and the other WA, as Ca sources, giving eight treatments in total (Table 2.1). All the treatments received diets with a Ca level close to 1 %.

2.2.2.2 Layer study

The hens used for the layer study were randomly assigned to individual cages and divided into six treatment groups with four replicates per treatment and three hens per replicate. An empty cage was left between each replicate so that no cross feeding could have taken place. Three diets were formulated, one without MOCM and the other two containing varying levels of MOCM, viz. 10 and 50 % plus salt and a trace nutrient mixture. Each of these treatments was split in two with one receiving limestone ($CaCO_3$) and the other WA, as Ca sources, resulting in six treatments in total (Table 2.2). The 12 hens used for each of the 4 treatments were randomly selected from their corresponding treatment group of the growth study.

Table 2.1 Number of birds per replicate for the different treatments of the grower trial

Rep.*	Number of birds in each treatment group								Total no. of birds
	0% MOCM		10% MOCM		50% MOCM		100% MOCM		
	Lime	WA	Lime	WA	Lime	WA	Lime	WA	
1	12	12	12	12	12	12	12	12	**96**
2	12	12	12	12	12	12	12	12	**96**
3	12	12	12	12	12	12	12	12	**96**
4	12	12	12	12	12	12	12	12	**96**
Total	**48**	**48**	**48**	**48**	**48**	**48**	**48**	**48**	**384**

[*] Replicates, MOCM = Macadamia Oil Cake Meal, WA = Wood ash

Table 2.2 Number of birds per replicate for different treatments of the layer trial

Rep.*	Number of birds in each treatment group						Total no. of birds
	0% MOCM		10% MOCM		50% MOCM		
	Lime	WA	Lime	WA	Lime	WA	
1	3	3	3	3	3	3	**18**
2	3	3	3	3	3	3	**18**
3	3	3	3	3	3	3	**18**
4	3	3	3	3	3	3	**18**
Total	12	12	12	12	12	12	**72**

* Replicates, MOCM = Macadamia Oil Cake Meal, WA = Wood ash

2.2.3 Experimental terrain

The growth study was conducted using an environmentally controlled broiler house at the experimental farm of the University of Pretoria, Hatfield, Pretoria, South Africa. Both the growth and the layer study were conducted with the approval of the Ethics Committee (EC 030722-021) of the Faculty of Natural and Agricultural Sciences of the University of Pretoria.

Inside the broiler house the replicate groups of chickens were placed randomly in pens (3 x 1.5 m) enclosed with chicken mesh, and sawdust was used as litter material. The sawdust was left in the pens for the duration of the trial. Light was provided for 24 hours per day and infrared bulbs were used as heating equipment. House temperature was kept at 32 °C during the early stages and gradually reduced to 22 °C.

A naturally ventilated laying house on the experimental farm of the University of Pretoria, Hatfield, Pretoria, South Africa was used for the layer experiment. Inside the layer house the hens were placed randomly in cages measuring 400 mm x 500 mm x 420 mm with one hen per cage. Light was provided for 23 hours and 1-hour darkness. Normal light bulbs were used as the light source.

2.3 Diet formulation and feeding facilities

A least cost feed formulation programme was used to formulate the six treatment diets containing the 0%, 10% and 50% inclusion levels of MOCM. These diets were formulated to meet or exceed nutrient specification levels for poultry starter, grower and layer diets as given in the NRC (1994). In the treatments containing 100% MOCM only the different calcium sources plus a salt and trace nutrient mixture were added to the MOCM. The Ca level in WA was determined in advance and was found to be 257 Ca/kg compared to the 380 g Ca/kg in limestone. The level of inclusion of WA was therefore slightly higher than when limestone was used.

During the grower trial flat tray feeders were used for the first three weeks after which tube feeders replaced flat tray feeders. Water was provided *ad libitum* using bell drinkers that were adjusted to breast height of the chicks. The chickens were fed a starter diet from 1 to 4 weeks of age and a grower diet from 4 to 15 weeks. After 15 weeks the growth trial was terminated and the cockerels were slaughtered. All hens were kept in the broiler house until they reached 19 weeks of age. At 19 weeks, 12 hens from each treatment (except the 100% MOCM group) were randomly selected and moved to a layer house for commencement of the layer trial.

The formulation of the starter, grower and layer rations are shown in Tables 2.3 to 2.5. The analysed nutrient levels of these diets are shown in Tables 3.4 to 3.6.

During the layer trial feed troughs were used and *ad libitum* water was provided through nipple drinkers. The hens were fed layer diets for a period of four weeks.

2.4 Source of macadamia oil cake

Macadamia oil cake was obtained from the Royal Macadamia processing plant for both the growth and the layer trial. The macadamias originated from the Green Farm and Royal Macadamia farms at Makhado (Louis Trichardt) in the Limpopo Province. The MOCM was milled in a hammer mill. Samples were collected for laboratory analysis and the balance was used to prepare the experimental diets.

2.5 Preparation of the ash

Dry wood from a variety of tree species was collected on the University experimental farms. The wood was burned in a furnace and the ash was collected. Initially the ash was sifted through a 5 mm sieve and the coarse material returned to burn further to ash. After that the residue was sifted through a 1 mm sieve to remove any coarse material. A sample of ash was analysed in the laboratory for mineral composition.

Table 2.3. Ingredient composition of the starter diets used in the growth trial

	Treatment Group							
	0% MOCM		**10% MOCM**		**50% MOCM**		**100% MOCM**	
	Lime	**WA**	**Lime**	**WA**	**Lime**	**WA**	**Lime**	**WA**
Ingredient (g/kg 'as fed')								
Yellow Maize	499	480	528	530	250	240	-	-
Wheat bran	132	140	110	110	66	70	-	-
Soya oil-cake meal	188	183	152	155	94	92	-	-
Sunflower oil cake meal	80	81	97	91	40	41	-	-
Fish meal	73	73	80	81	36	36	-	-
Macadamia oil cake	-	-	110	110	483	483	680	570
Limestone	19	-	23	-	19	-	19	-
Wood ash	-	33	-	26	-	27	-	30
Salt	10	10	10	10	10	10	10	10
Premix*	3	3	3	3	3	3	3	3

*Premix / kg, MOCM= Macadamia Oil Cake Meal, WA= Wood Ash

Table 2.4. Ingredient composition of the grower diets used in the growth trial

	Treatments							
	0% MOCM		**10% MOCM**		**50% MOCM**		**100% MOCM**	
	Lime	**WA**	**Lime**	**WA**	**Lime**	**WA**	**Lime**	**WA**
Ingredient (g/kg 'as fed')								
Yellow Maize	551	584	659	657	276	292	-	-
Wheat bran	221	168	-	-	110	84	-	-
Soya oil-cake meal	111	120	143	140	56	60	-	-
Fish meal	86	86	76	78	43	43	-	-
Macadamia oil cake	-	-	97	97	493	493	650	570
Limestone	22	-	16	-	11	-	22	-
Wood ash	-	33	-	19	-	17	-	30
Salt	10	10	10	10	10	10	10	10
Premix *	3	3	3	3	3	3	3	3

*Premix / kg, MOCM= Macadamia Oil Cake Meal, WA= Wood Ash

Table 2.5. Ingredient composition of the layer diets used in the layer trial

	Treatments					
	0% MOCM		**10% MOCM**		**50% MOCM**	
	Lime	**WA**	**Lime**	**WA**	**Lime**	**WA**
Ingredient (g/kg 'as fed')						
Yellow Maize	650	635.3	597.4	567.1	325.0	317.6
Wheat bran	80	60	-	-	-	-
Soya oil-cake meal	150	159.5	183.8	191.4	75.0	79.8
Mono Calcium Phosphate	13.5	17.7	15.9	19.0	6.80	8.8
Macadamia oil cake	-	-	100	100	446.8	436.2
Limestone	100	-	96.2	-	100	-
Wood ash	-	121.1	-	115.9	-	121.1
Salt	4	4	4	4	4	4
Premix *	2.5	2.5	2.5	2.5	2.5	2.5

*Premix / kg, MOCM= Macadamia Oil Cake Meal, WA= Wood Ash

2.6 Vaccination programme

The chickens were vaccinated against most common diseases. The vaccination programme is given in Table 2.6.

Table 2.6. The vaccination programme of the birds during the growth trial

Age	Disease	Vaccine	Application route	Date of Application
1 Day	Mareks	Mareks	Injection	15/07/2003
12 Days	Newcastle	ND La Sota	Fine Spray	27/07/2003
19 Days	Gumboro	TAD G	Fine Spray	3/08/2003
23 Days	Gumboro	TAD G	Fine Spray	7/08/2003
26 Days	Newcastle	ND La Sota	Fine Spray	11/08/2003

The supplier vaccinated the chicks for Marek's disease before the birds were collected. The other vaccinations were done during the trial.

2.7 Slaughter procedure

At the end of the growth trial at 15 weeks, 48 cockerels per pen from the remaining six treatments were humanely slaughtered. The slaughtered birds were dipped in scalding warm water (60 °C) for ±1 min before defeathering. The carcasses were dissected into two equal halves, and the right half was frozen until further analyses.

2.8 Measurements taken

2.8.1 Growth study

2.8.1.1 Feed intake

Feed intake was recorded every Monday morning on a weekly basis. Feed intake, was calculated by subtracting feed leftovers from total feed offered.

2.8.1.2 Body weight

Total body weights of the birds per pen were recorded on a weekly basis every Monday morning, and the mean body weight per bird per pen was determined.

2.8.1.3 Feed conversion efficiency

Feed conversion efficiency was calculated weekly as body weight (kg) gain per pen over feed intake (kg).

2.8.1.4 Mortalities

Mortalities were recorded over the 15-week period. Dead birds were removed and incinerated. Post mortems were not conducted because of financial constrains. The 100% MOCM treatments were terminated at nine weeks because of their poor growth and high mortality rate.

2.8.2 Parameters determined after slaughtering

2.8.2.1. Carcass composition

Half carcasses (without the tibia, intestine, head and the neck) were weighed to record the slaughter weight and taken for analysis of carcass composition. The carcasses were stored in a freezer between –10 °C and –20 °C for further analyses. The half carcass was thawed (at room temperature) weighed and carefully dissected into fat, muscles (lean meat) and bone to calculate carcass composition as a percentage of carcass weight.

2.8.2.2 Preparation of the tibiae

Both legs with tibia bones from each chicken were collected, labelled, wrapped, sorted (by treatment number), and stored in a freezer at between –10 °C and –20 °C for determination of bone strength. The legs were thawed and cleaned of adhering tissues, and the tibiae were removed. The tibiae were wrapped in a Para film paper and placed in the refrigerator. Before the breaking strength test was done, the bones were dried in an oven at a temperature of between 60-80 ^{o}C. Both the dry tibiae from each bird were weighed.

2.9. Layer study

Mortalities were recorded daily over a four- week period and dead birds were removed and incinerated. Post-mortems were not conducted due to financial constrains. Feed intake (g), egg weight (g) and egg production expressed in percentage units (%) were determined daily. Feed conversion ratio was calculated from the feed intake, egg weight and egg production. This was done for all the treatments and their replicates. On the fourth week six eggs were randomly collected from each of the six treatments for determination of shell breaking strength (Instron, model 1011 Canton Massachusetts, USA).

2.10 Chemical analyses of feeds

The same procedure of chemical analyses of the feeds was done for both the growth and layer study.

2.10.1 Dry matter content

The DM content analysis was done according to the AOAC (1995) methods. A porcelain crucible was put into an oven for about one-hour in order to dry it completely after which it was put into a desiccator to cool. One gram of each sample of the by-product was weighed into a porcelain crucible, and then placed in an oven at 100 ^{o}C for 24 hours. The crucibles were then put in a desiccator that contained silica gel for 30 minutes to cool before weighing. The DM content (%) was calculated as recommended by AOAC (1995).

% DM = (dry sample mass/wet sample mass) x 100

2.10.2 The ash content

The ash content analysis was done according to the AOAC (1995) methods. Oven-dried samples of the by-products in porcelain crucibles from the DM procedure were incinerated in a muffle furnace for four hours at 600 ^{o}C. The furnace was then allowed to cool down to approximately 250 ^{o}C. The crucibles were placed in a desiccator for 30 minutes and weighed. The ash content of the samples was calculated as follows:

% Ash = (ash mass/wet sample mass) x 100

2.10.3 Crude protein determination

The determination of the crude protein was done as described in the A.O.A.C. (2000), using the Dumas' method, with the Leco FP-428 version 2.40 of the Leco Corporation St. Joseph MI USA.

Sample preparation:

1. Weigh out 4 standards, approximately 0.2 g of EDTA (note the exact mass) into "cups". Fold up the cups carefully into drumstick shape.
2. Weigh out samples, approximately 0.2 g, in duplicate, note the exact mass. If the sample is extremely bulky reduce the sample mass to either 0.15 g or 0.1 g, as appropriate. Fold up the cups carefully into drumstick shape. The results are printed out after they have been analysed.

2.10.4 Amino acids

The amino acid composition of the samples was determined using the Pico tag method (Bidlingmeyer *et al*., 1984), courtesy of Ms Exley from the Department of Biochemistry, University of Pretoria. A 10 mg defatted sample was weighed into a hydrolysis flask and 1 mL of 6N HCl plus 1 % phenol was added. The flask was evacuated and blown with N_2 to remove O_2 and then sealed off under vacuum (0.01 mm Hg). They were then placed in an oven for 24 hours at a temperature of 110 ºC. After cooling, deionised water was added up to 5 mL. The samples were then derivatized. After that, they were filtered and placed in WSIP (automatic loader). The amino acids were separated by pumping the solution through a reverse fase column. Tow pumps were used to form a gradient for optimum separation. SYSTEM GOLD was used for calculations.

2.10.5 Crude fibre (Proximate analysis method)

The crude fibre (CF) concentration of the by-product samples was determined using the same method followed by Goering & Van Soest (1970) using the Tecator fibretec system. One gram of each sample was weighed into a filter crucible and placed on the hot extraction units of the system. The extraction was carried with a 30 mL of 98 % sulphuric acid H_2SO_4 (following Weende method) for 14 minutes, by boiling. The H_2SO_4 was removed by switching on the vacuum pump and washed out (three times) with warm distilled water. Sequential to the H_2SO_4 removal, 100 mL of sodium hydroxide (NaOH) was added and boiled for 14 minutes and removed as with H_2SO_4. The residue in the crucibles were dried at 100 °C overnight, then cooled in a desiccator for 30 minutes and weighed. After weighing they were ashed in a muffle furnace at 600 °C for 3 hours. The furnace was allowed to cool to at least 250 °C, and then the crucibles were cooled in a desiccator for 30 minutes and weighed.

Percentage CF was calculated as follows:

$$\% \text{ Crude fibre} = \frac{Wrd - Wra}{Ws}$$

Wrd = weight of residue after drying in crucible

Wra = weight of residue after ashing in crucible

Ws = weight of initial sample

2.10.6 Neutral detergent fibre determination

The NDF concentration of the by-product samples was determined according to Goering & Van Soest (1970) using the Tecator fibretec system. One gram of each sample was weighed into a filter crucible and placed on the hot extraction units of the system. The extraction was carried with a 100 mL of neutral detergent solution (NDS) (following alpha amylase method) for one hour, after boiling has commenced. The NDS was removed by washing out with hot distilled water. The residues in the crucibles were dried at 100 °C overnight, then cooled in a desiccator for 30 minutes and weighed. After weighing they were ashed in a muffle furnace at 600 °C for 3 hours. The furnace was allowed to cool to at least 250 °C, and then the crucibles were cooled in a desiccator for 30 minutes and weighed.

Percentage NDF was calculated as follows:

$$\% \text{ NDF} = \frac{Wrd - Wra}{Ws}$$

Wrd = weight of residue after drying in crucible

Wra = weight of residue after ashing in crucible

Ws = weight of initial sample

2.10.7 Fat determination

Total fat content was determined according to the ether extraction method (AOAC, 1995) using the Soxtec HT6 Model. Three g of sample was weighed onto a filter paper and then put into a thimble. The thimble was then placed on an extraction unit. Petroleum ether of 60 ^{o}C - 80 ^{o}C was used for extraction. The extracts were collected into extraction cups for two hours of boiling. The extraction cups were then dried in a 70 ^{o}C oven overnight, and removed and placed in a desiccator for 30 minutes to cool and then weighed. The total fat was calculated as follows:

$$\% \text{ Crude Fat} = \frac{(\text{Mass of flask plus residue} - \text{Mass of flask})}{\text{Sample mass}} \times 100$$

2.10.8 Minerals

The concentration of minerals, Ca, phosphorus (P), and magnesium (Mg) were determined in all the diet samples. A sample of 1 gram was digested in a block digester at 230 ^{o}C using the wet digestion technique. One gram of sample was weighed and put into a test tube together with 25 mL nitric acid (HNO_3) (65 %) and heated afterwards and 5 mL perchloric acid (HOCl) was added into the tubes after about 10 minutes when almost half of the HNO_3 had evaporated. The solution was further allowed to boil for another 40 minutes until the solution was clear. The solution was then allowed to cool down and up to 50 mL with distilled water. Each sample was prepared in duplicates and analysed for the different minerals. Ca and Mg were determined using the atomic absorption spectrophotometer (Perkin Elmer 2380 Model). P concentration was determined using a Technicon auto analyser and the concentration obtained from a calibration curve.

2.10.9 Determination of metabolisable energy

The metabolisable energy (ME MJ/kg) values of the experimental diets were calculated using the equation adapted from the National Research Council (NRC, 1994), in nutrient requirements for domestic animals, as shown:

$$ME= (((protein*194.7) + (fibre*13.1) + (fat*275.1) + (NFE*147.9))/1000)*0.96$$

2.10.10 Nitrogen free extract

Nitrogen free extract (NFE) is determined by subtracting from 100 the sum of the amounts of ash, crude protein, ether extract, crude fibre and moisture (expressed in g/kg) and is considered to be a measure of the digestible carbohydrates (Scott *et al.,* 1982).

NFE = 100-(ash + protein + fibre + fat + moisture)

2.11 Breaking strength of the tibia bone and egg shell

The same machine and procedure were used for the breaking strength of both the tibia bones and eggshells, with the difference being with the applied load range. For the eggshells and tibia bones a load range varying from 50 to 100 loads, respectively were used.

2.11.1 Measurements on tibia bones

The major and minor exterior diameters were measured at the thinnest part of the tibia diaphysis with a veneer calliper. All the bones were kept dry until the time of the breaking test. Strength of the tibia was determined with an Instron Universal Testing machine (Model No. 1011, Instron Corporation, Canton, MA, USA) using the standard bending test (ASAE, 1993). Each tibia was placed horizontally on a three-point bend fixture. The length of the tibia was measured and the plunger was placed in the centre for breaking of the bone. The plunger mounted on the crosshead of the testing machine was adjusted until it has touched the bone at the centre. The test was done on both the right and left tibia. A set crosshead speed of 30 mm/min was used for both the tibiae.

2.11.2 Breaking strength and Instron calibration

Method:

Calibration was done as follows:

Attach the compression probe before calibrating; make sure that the washer is used.

Switch the machine on 15 minutes beforehand.

Press function: Units [Enter]

SI [Enter]

Press transducer: 50 kg/500 N [Enter]

Balance knobs to zero

Load Range: Must be 10 % of max load

- 5 kg for 50 kg
- 50 N for 500 N

Speed: Set to 100 mm/min [Enter]

Balance knobs to zero and lock.

Hang 5 kg weight to attachment (using wire loop).

Use yellow screwdriver to adjust setting:

Set to 50 N

Remove 5 kg weight and set the gauge length

Set compression

Break action: set to return

Unlock balance knobs again and set to zero and lock again.

Date selection set/adjust to break to read the force on screen

The bone is placed horizontal with the three-point bend fixture before breaking

Breaking strength is red on the Instron screen in Newton

Printer:

- Start knob down
- Prop time knob down
- 1:20 knob down
- 10 X knob down
- Power on, Input knob on
- Each column on the paper will then represent 10 Newton
- Pen cap off and in down position

2.11.3 Egg breaking strength

Method:

The Instron Model 1011 was used to determine the breaking strength.

Calibration was done as follows:

Attach the compression probe before calibrating; make sure that the washer is used.

Switch the machine on 15 minutes beforehand.

Press function: Units [Enter]

SI [Enter]

Press transducer: 50 kg/500N [Enter]

Load Range: Must be 10% of max load

- 5 kg for 50 kg
- 50 N for 500 N

Speed: Set to 100 mm/min [Enter]

Balance knobs to zero and lock.

Hang 5 kg weight to attachment.

Use screwdriver to adjust setting: set to 50 N

Remove 5 kg weight and set the gauge length

Set compression

Break action: set to return

Unlock balance knobs again and set to zero, and lock.

Date selection: set to break

The egg was placed with its sharp end up before breaking

Breaking strength is red on the Instron screen in Newton

2.12 Chemical analyses of tibia bones

After determination of breaking strength, the bones were crushed and milled for mineral analyses. Bones were further defatted by soxhlet extraction apparatus using petroleum ether and chemical analysis were done according to the methods as described in the AOAC (2002).

2.13 Procedure to determine mineral crystalline composition of wood ash

The analysis for the form in which Ca is available was done using X-ray diffraction (XRD) (King & Alexander, 1974). The sample was prepared using standard Siemens sample holders and the powder pressed into the holder using a glass slide.

The instrument used and data collection parameters:

- Instrument Siemens D-501
- Radiation Cu K*a* (1.5418 Å)
- Temperature 25 ºC

• Specimen	flat-plate, rotating (30 RPM)
• Power setting	40 kV, 40 mA
• Soller slits	2º (diffracted beam side)
• Divergence slits	1º
• Receiving slits	0.05º
• Monochromator	secondary, graphite
• Detector	scintillation counter
• Range of 2θ	4-70º 2θ
• Speed width	0.04º 2θ
• Time per step	1.5 s

2.14 Statistical analyses

An analysis of variance with the ANOVA model (Statistical Analysis Systems, 1994) was used to determine the significance between different treatments for the balanced data, with the mortalities taken into consideration. Means and standard deviations (SD) were calculated. The data was analysed for a 15 weeks period and the last two treatments (100% MOCM plus limestone and WA) were excluded from the data of a 15-week period because they were terminated at an age of eight weeks due to their poor growth performance.

Significance difference of (5%) between means was determined multiple comparisons using the Tukey t-test (Samuels, 1989). Significance between repeated weeks was analysed. Least square means (LSM) and standard errors (SE) were calculated. Significance difference of (5%) between least square means for a week was determined using the Bonferroni test (Samuels 1989).

CHAPTER 3 – RESULTS

3.1 CHEMICAL COMPOSITION

The results of the chemical composition of MOCM on "as is" and DM basis are presented in Table 3.1. while the amino acid composition is presented in Table 3.2. The chemical compositions were all analysed on as fed full-fat basis.

Table 3.1 Chemical composition of the macadamia oil cake meal (g/kg) used in the study

Composition	As is	DM
Dry matter	940	1000
Moisture	60	0
Ash	28	30
Crude Protein	132	140
Crude Fibre	365	385
Neutral detergent fibre	394	419
Crude fat	228	243
Calcium	1.6	1.8
Phosphorus	2.3	2.4
NFE*	186	202
NFC*	217	168

* NFC – Non-fibre carbohydrates, NFE – Nitrogen-free Extract Calculated

Table 3.2 Amino acid composition* (g/kg) of macadamia oil cake on as is and dry matter basis

Amino acid	% As is	/100 g DM	/100 g true protein **	As % of lysine
Aspartic acid	1.02	1.08	8.99	163
Glutamic acid	2.27	2.41	20.07	365
Serine	0.69	0.73	6.08	111
Glycine	0.70	0.74	6.16	112
Histidine	0.25	0.27	2.25	41
Arginine	1.17	1.24	10.32	188
Threonine	0.49	0.52	4.33	79
Alanine	0.67	0.71	5.91	107
Proline	0.65	0.69	5.75	105
Tyrosine	0.43	0.46	3.83	70
Valine	0.53	0.56	4.66	85
Methionine	0.19	0.20	1.67	30
Isoleucine	0.41	0.44	3.66	67
Leucine	0.77	0.82	6.83	124
Phenylalanine	0.45	0.48	4.00	73
Lysine	0.64	0.66	5.50	100
Total		12.01	100	

* Tryptophan not determined, ** Based on sum of amino acids, i.e. 12.1 g/100 g

3.2 WOOD ASH

The crystalline forms of the elements in WA are presented in Table 3.3 and Figure 3.1. The results show that calcite ($CaCO_3$) is the major compound of WA constituting 58.8% of the DM concentration, and then followed by periclase (MgO) at a concentration of 19.30%. The other element *viz*. hydroxylapatite ($Ca_5 (PO_4)_3(OH)$) to sylvite (KCI) ranged from 7.4 % to 1.2%, respectively.

Table 3.3 Approximate proportions of crystalline forms (XRD analysis) of minerals in wood ash

Crystalline form	Symbol	Percentage
Calcite	$CaCO_3$	58.8
Periclase	MgO	19.4
Hydroxylapatite	$Ca_5(PO_4)_3(OH)$	7.4
Quartz	SiO_2	1.4
Ankerite	$Ca(Fe+_2,Mg)(CO_3)_2$	1.8
Halite	KO_4NaO_6Cl	1.3
Fairchildlite	$K_2Ca(CO_3)_2$	6.5
Lime	CaO	2.2
Sylvite	KCl	1.2

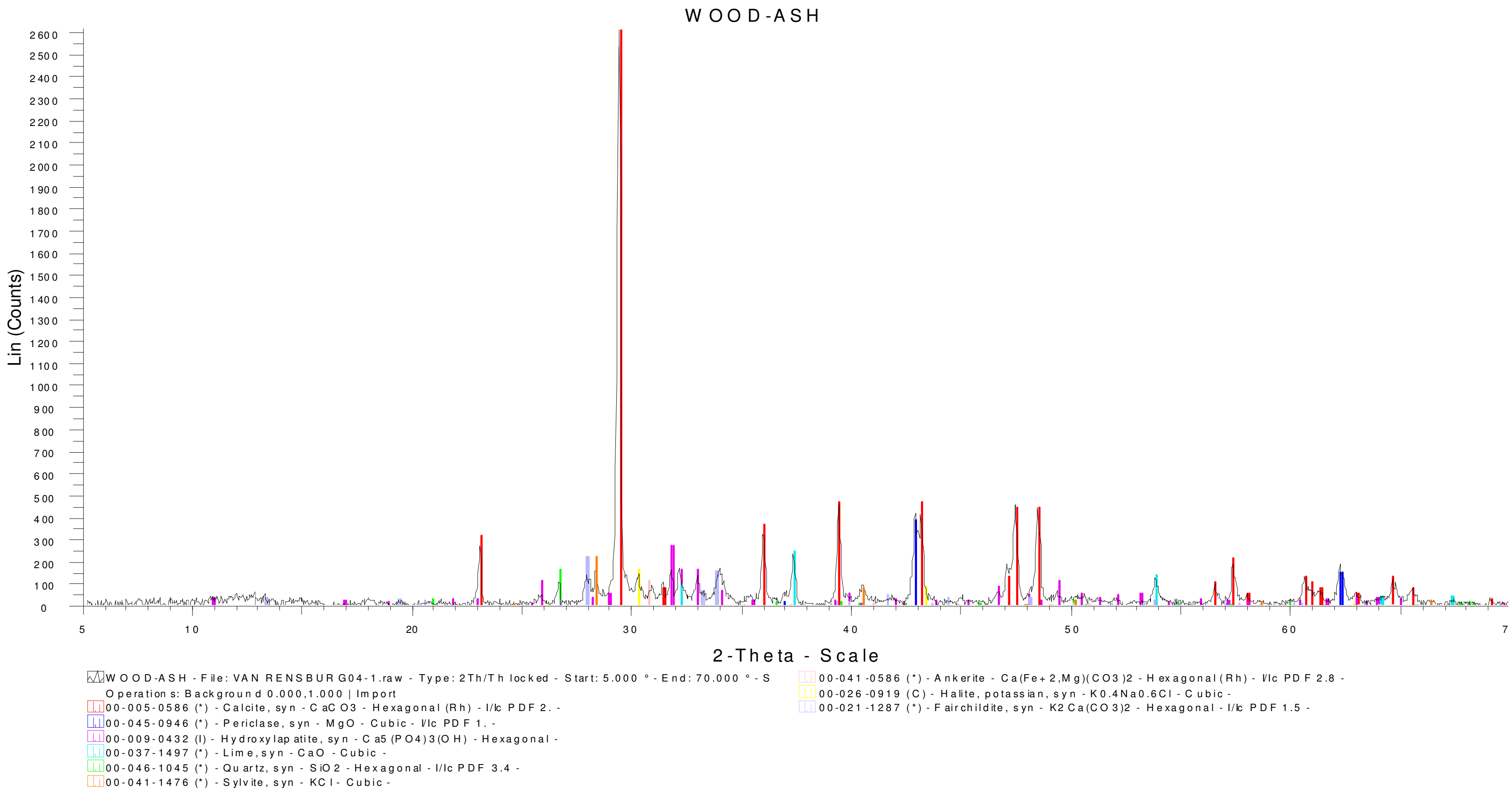

Figure 3.1 Graphical presentations of the crystalline forms in wood ash

3.3 The chemical composition of the experimental diets

The chemical compositions of the starter, grower and layer diets for the different treatment diets are presented in Tables 3.4, 3.5 and 3.6, respectively. The diets were formulated according to feed specification to conform to the standard of the NRC (1994) for poultry. In general, the 50% MOCM diet had a slightly higher fat content and much higher fibre content than the 0% and 10% MOCM diets.

Table 3.4 Chemical composition (g/kg) of the different treatments of the starter diets on an as fed, full fat basis

Treatments

	0%MOCM		**10%MOCM**		**50%MOCM**	
Composition	**L**	**W**	**L**	**W**	**L**	**W**
Dry matter	900	900	900	900	920	920
Crude protein	210	230	230	230	190	180
Fat	60	40	50	50	80	100
Crude fibre	60	70	90	90	220	220
Calcium	10	10	10	10	10	10
Total phosphorus	5	7	6	6	4	4
Neutral detergent fibre	220	220	230	230	370	350

MOCM – Macadamia oil cake meal, L – Lime, W – Wood ash

Table 3.5 Chemical compositions of different treatments of the grower diets, as fed, full fat basis (g/kg)

	Treatments					
	0%MOCM		10%MOCM		50%MOCM	
Composition	**L**	**W**	**L**	**W**	**L**	**W**
Dry matter	910	910	910	910	930	930
Crude protein	190	190	180	180	180	160
Fat	30	30	40	40	80	80
Crude fibre	40	40	50	50	160	190
Ash	70	70	60	60	70	80
Calcium	10	10	9	8	10	10
Total phosphorus	6	7	5	5	4	5
Magnesium	2	3	2	2	2	4
NDF	170	150	150	170	280	340
ME (MJ/kg)*	120	120	130	130	120	110

*ME – Metabolisable energy (calculated), NDF – Neutral detergent fibre, MOCM – Macadamia oil cake meal, L – Lime, W – Wood ash

* ME= (((protein*194.7) + (fibre*13.1) + (fat*275.1) + (NFE*147.9))/1000)*0.96

Table 3.6 Chemical compositions of different treatments of the layer diets on as fed, full fat basis (g/kg)

	Treatments					
Composition	**0%MOCM**		**10%MOCM**		**50%MOCM**	
	L	**W**	**L**	**W**	**L**	**W**
Dry matter	910	910	910	920	920	930
Crude protein	130	130	140	150	130	120
Fat	20	20	30	20	60	50
Ash	110	140	110	140	100	120
Calcium	30	30	30	30	30	30
Total phosphorus	7	8	6	9	6	7
Magnesium	2	7	2	8	2	7
Neutral detergent fibre	140	120	130	130	280	280
ME (MJ/kg)*	120	110	120	110	110	110

*ME – Metabolisable energy (calculated), MOCM – Macadamia oil cake meal, L – Lime, W – Wood ash

* ME= (((protein*194.7) + (fibre*13.1) + (fat*275.1) + (NFE*147.9))/1000)*0.96

The amino acid profiles of the grower and layer diets are presented in Tables 3.7 and 3.8.

Table 3.7 Amino acid concentrations (g/kg) of different treatment diets in the grower experiment on an as fed, full fat basis

Treatments

Composition	**0%MOCM**		**10%MOCM**		**50%MOCM**	
	L	**W**	**L**	**W**	**L**	**W**
Aspartic acid	10	10	11	10	9	9
Glutamic acid	26	26	25	24	26	23
Serine	7	7	7	7	6	6
Glycine	8	8	8	7	7	7
Histidine	3	3	3	3	3	3
Arginine	9	9	10	9	12	11
Threonine	6	6	6	5	5	5
Alanine	9	8	7	7	6	5
Proline	9	10	9	8	7	7
Tyrosine	5	5	5	5	5	5
Valine	8	6	7	7	6	6
Methionine	3	9	3	3	2	3
Cystine	6	2	0.3	0.0	0.2	0.2
Isoleucine	9	6	6	6	5	5
Leucine	5	11	11	11	8	9
Phenylalanine	5	6	6	6	5	5
Lysine	7	8	7	7	6	6

MOCM – Macadamia oil cake meal, L – Lime, W – Wood ash

Table 3.8 Amino acid concentrations (g/kg) of different treatment diets in the layer experiment as fed, full fat basis

	Treatments					
Composition	0%MOCM		10%MOCM		50%MOCM	
	L	W	L	W	L	W
Aspartic acid	3.6	3.5	5.5	3.7	4.1	3
Glutamic acid	17.1	17.8	21.2	19.8	18	16.5
Serine	5.2	5.5	6.3	6.2	5.4	4.9
Glycine	4.7	5	5.8	5.7	5.7	5.4
Histidine	2.4	2.7	2.8	2.9	2.2	2.2
Arginine	6.7	8.1	9.1	9.4	10.1	8.8
Threonine	3.6	3.9	4.5	4.4	3.7	3.6
Alanine	4.9	5	5.4	5.5	4.2	4
Proline	7.6	7.7	8.3	8.3	6.8	6.6
Tyrosine	3.6	4.1	4.8	4.8	4.1	4.2
Valine	5.3	5.8	6.2	6.3	4.9	4.9
Methionine	0.7	1.4	2	1.9	1.2	1.7
Cystine	0.0	0.0	0.0	0.0	0.0	0.0
Isoleucine	4.3	4.8	5.4	5.5	3.9	4
Leucine	9.5	9.9	10.8	10.3	7.7	7.9
Phenylalanine	4.9	5.4	5.8	6	4.3	4.3
Lysine	4.5	5.4	6.1	6.4	5	4.7

MOCM – Macadamia oil cake meal, L – Lime, W – Wood ash

The order of limiting amino acids for both the grower and layer experimental diets is presented in Table 3.9. The results of limiting order of amino acids below, shows the limiting amino acid at different inclusion level of MOCM for the grower and laying experimental diets.

Determining the limiting order of amino acid was done by calculating the "desired feed intake" (DFI) by the chickens, based on each of the amino acid in the feed. The DFI is calculated as a ratio of nutrients requirements to nutrients content in the feed i.e. the daily requirements and the contents of each amino acid in the test feed. The amino acid giving the highest DFI will be the first limiting.

Table 3.9 The order of limiting amino acids (g/kg) on as fed, full fat basis for both the grower and layer diets

Composition	Grower diets			Layer diets		
	0% MOCM	10% MOCM	50% MOCM	0% MOCM	10% MOCM	50% MOCM
Arginine	75.1	60.8	42.3	94.7	59.9	57.4
Histidine	49.0	49.0	49.0	47.9	38.5	66.9
Isoleucine	34.5	61.4	88.4	83.4	58.3	110.3
Leucine	100.0	52.9	79.0	59.8	50.1	92.5
Lysine	49.0	64.0	87.1	96.0	60.5	100.0
Methionine	14.7	58.8	58.8	364.5	110.3	196.0
Phenylalanine	49.0	49.0	70.6	53.4	36.4	60.1
Threonine	78.0	78.0	112.4	134.1	95.6	141.4
Valine	49.0	49.0	66.7	59.0	46.6	77.0

MOCM – Macadamia oil cake meal

3.4 The results of the performance parameters for the growth experiment study

3.4.1 Feed Intake

Results of the weekly feed intake (FI) of the treatment diets over a 15 – week period are presented in Table 3.10. Feed intake of the 50% MOCM diet with WA was significantly higher (P < .0.05) than for the diet containing 0% MOCM with WA. Over a 15 – week period, the 50% MOCM diet had a higher (P < 0.05) FI compared to the other diets, but the differences were not significant in some of the weeks. Also, the diet of 10% MOCM had a higher (P < 0.05) FI compared to the 0% MOCM diet, even though the differences were significant only in some weeks.

Table 3.10 The effect of dietary level of macadamia oil cake meal (MOCM) and calcium source on the weekly feed intake (g) per bird for the grower trial

	Treatments						
	0% MOCM		10% MOCM		50% MOCM		
	L	W	L	W	L	W	(±SEM)
Weeks							
1	23.1[ab]	19.5[b]	20.8[b]	23.7[ab]	23.8[ab]	25.7[a]	(±1.6)
2	26.6	27.1	27.0	30.2	30.1	28.9	(±2.2)
3	42.4	42.6	44.2	43.5	44.3	44.6	(±2.4)
4	46.0[a]	40.5[b]	46.2[a]	40.5[b]	41.4[a]	40.2[b]	(±1.9)
5	66.4	68.9	72.2	72.2	67.7	75.9	(±5.3)
Sub-Total	**204.5**	**198.5**	**210.5**	**210.1**	**207.2**	**215.3**	**(±7.1)**
6	65.3[a]	66.5[a]	68.8[a]	70.5[a]	72.2[b]	70.9[a]	(±1.9)
7	66.5[a]	66.5[a]	73.1[ab]	76.9[b]	78.8[b]	75.9[b]	(±2.5)
8	88.3[a]	84.2[a]	79.9[ac]	54.7[b]	51.3[b]	70.2[c]	(±4.6)
9	81.3[a]	67.4[b]	86.7[a]	78.3[ab]	76.0[ab]	84.5[a]	(±3.7)
10	93.2[a]	91.4[a]	92.0[a]	96.8[a]	97.4[a]	107.3[b]	(±2.4)
Sub-Total	**394.6[abc]**	**376.1[bc]**	**400.6[a]**	**377.2[bc]**	**375.6[c]**	**408.8[a]**	**(±7.2)**
11	115.9	107.1	112.1	114.3	112.3	121.1	(±11.9)
12	96.3[a]	101.4[ab]	95.3[a]	96.7[a]	106.9[b]	116.1[c]	(±2.9)
13	103.4[a]	105.5[ab]	105.9[ab]	114.4[ab]	120.4[b]	118.9[ab]	(±5.7)
14	97.4[a]	96.8[a]	95.8[a]	95.5[a]	116.9[b]	125.2[b]	(±4.8)
15	120.6	114.1	114.8	123.6	127.7	147.9	(±11.7)
Sub-Total	**533.5[b]**	**524.8[b]**	**524.0[b]**	**544.5[b]**	**584.2[ab]**	**629.2[a]**	**(±20.8)**
Total FI over 15 weeks	**1132.5[b] (±58.42)**	**1099.4[b] (±34.29)**	**1135.1[b] (±54.29)**	**1131.7[b] (±24.89)**	**1167.1[ab] (±83.69)**	**1253.3[a] (±35.87)**	

[abc] Means with different superscripts, within rows, differed significantly (P < 0.05)

MOCM – Macadamia oil cake meal, L – Lime, W – Wood ash

The sub-total feed intake i.e. from week 1 to 5, for the first phase showed no (P>0.05) difference between treatment diets. However, the second phase (week 6 to 10) showed a difference (P<0.05) between treatment diets. Birds on diets 10% MOCM + lime and 50% MOCM + WA had a higher (P<0.05) FI compared to the other treatment diets, except for the diet of 0% MOCM + lime. In the third phase (week 11 to 15), the diet of 50% MOCM + WA had a higher FI (P<0.05) compared to the other treatment diets, except the diet of 50% MOCM + lime. The results in Table 3.10 also show the total feed intake over a period of 15 weeks. There was an overall difference (P<0.05) between the diet of 50% MOCM + WA and the other treatment diets except the diet of 50% MOCM + lime.

3.4.2 Body Weight

The results of weekly and different phases on body weights (BW) of the birds for treatment diets 0% MOCM to 50% MOCM over a period of 15 weeks are presented in Table 3.11. The diet of 50% MOCM had a lower (P<0.05) BW compared to the other treatment diets throughout the experimental period, the exception was in weeks 14 and 15 as the diet of 50% MOCM plus WA had no difference (P>0.05) with the diets of 0% and 10% MOCM.

The results of BW for the different phases are also presented in Table 3.11. The diet on 50% MOCM had a lower (P<0.05) BW compared to the other treatment diets for the first phase (week 1 to 5). Also, the same was observed in the second phase (week 6 to 10) as in the first phase. In the third phase (week 11 to 15), the diet of 50% MOCM differed from (P<0.05) the diet of 10% MOCM. Lastly, there was an overall difference (P<0.05) between the diet of 10% MOCM as compared to the diet of 50% MOCM.

Table 3.11 The effect of dietary level of macadamia oil cake meal (MOCM) and calcium source on the weekly body weight (g) per bird over the 15-week growth trial

Treatments

	0% MOCM		10% MOCM		50% MOCM		
	L	W	L	W	L	W	(±SEM)
Weeks							
1	8.0	8.6	8.8	8.0	8.2	8.3	(±0.3)
2	15.9	17.4	16.9	16.8	15.8	15.9	(±0.6)
3	26.6[bc]	28.3[ab]	28.9[a]	28.3[ab]	24.5[c]	24.9[c]	(±0.7)
4	38.9[bc]	44.5[a]	42.6[ab]	37.0[c]	31.5[d]	32.1[d]	(±1.7)
5	60.4[b]	63.1[ab]	64.6[a]	62.9[ab]	52.5[c]	50.5[c]	(±1.4)
Sub-Total	**149.9[a]**	**161.9[a]**	**161.8[a]**	**153.1[a]**	**132.5[b]**	**131.7[b]**	**(±3.8)**
6	79.9[a]	81.9[a]	83.4[a]	84.6[a]	69.5[b]	65.3[b]	(±1.8)
7	103.8[a]	107.4[a]	109.2[a]	111.1[a]	88.3[b]	86.0[b]	(±2.6)
8	121.9[b]	123.7[b]	131.3[a]	132.1[a]	109.6[c]	103.4[c]	(±2.3)
9	151.6[a]	150.4[a]	159.2[a]	155.9[a]	138.4[b]	136.0[b]	(±3.3)
10	170.9[a]	171.3[a]	176.7[a]	177.7[a]	152.9[b]	153.4[b]	(±3.6)
Sub-Total	**628.1[a]**	**634.7[a]**	**659.9[a]**	**661.5[a]**	**558.7[b]**	**554.2[b]**	**(±11.1)**
11	196.9[a]	195.8[a]	205.2[a]	204.7[a]	181.2[b]	181.9[b]	(±3.7)
12	214.4[a]	225.1[a]	225.3[a]	227.6[a]	203.3[b]	203.4[b]	(±4.9)
13	240.3[a]	237.5[a]	248.8[a]	255.4[a]	224.9[b]	233.8[b]	(±7.1)
14	265.7[a]	266.8[a]	264.7[a]	276.2[a]	252.9[b]	266.7[a]	(±8.3)
15	277.7[ab]	277.1[ab]	282.4[ab]	296.9[a]	261.8[b]	279.6[ab]	(±10.3)
Sub-Total	**1194.9[abc]**	**1202.4[abc]**	**1226.5[ab]**	**1260.9[ab]**	**1124.1[c]**	**1165.3[c]**	**(±28.3)**
Total BW/15 weeks	**1972.9[abc] (±59.86)**	**1998.9[ab] (±62.65)**	**2048.2[a] (±62.72)**	**2075.5[a] (±92.24)**	**1815.3[c] (±79.02)**	**1841.2[bc] (±115.64)**	

[abc] Means with different superscripts, within rows, differed significantly ($P < 0.05$)
MOCM – Macadamia oil cake meal, L – Lime, W – Wood ash

The effect of dietary level of MOCM and Ca source using regression analysis of the growth curve equation fitted for each treatment diet is presented in Table 3.12. The objective was to determine the effect of level of inclusion of MOCM, lime and WA for all the treatment diets. However, there was no (P>0.05) difference between treatment diets.

Table 3.12 The effect of dietary level of macadamia oil cake meal (MOCM) and calcium source using the regression analysis growth curve equation fitted for each treatment diets

MOCM	Ca Sources	a	b	Correlation Index
0%	Lime	351.2	-0.0068	0.9994
10%	Lime	342.8	-0.0073	0.9990
50%	Lime	338.2	-0.0078	0.9996
0%	WA	376.6	-0.0067	0.9993
10%	WA	366.7	-0.0057	0.9992
50%	WA	470.0	-0.0041	0.9990

Means between treatments are not significantly different (P > 0.05)

MOCM – Macadamia-oil cake meal, Ca – Calcium, a – Max or Min values, b – slope, y – weight

Growth curve equation (using regression analysis):

$$\mathbf{y = a\,(1-e^{b\wedge 2})}$$

y = weight (g)

a = maximum and minimum values

b= slope

The results of the BW for the birds on the 0% MOCM to 50% MOCM diets are presented in Figure 3.2 to indicate the trends of growth through the growth curve. Graphically, the BW for all the treatment diets shows a similar growth trend, with slight, but not significant (P>0.05) differences throughout the trial period.

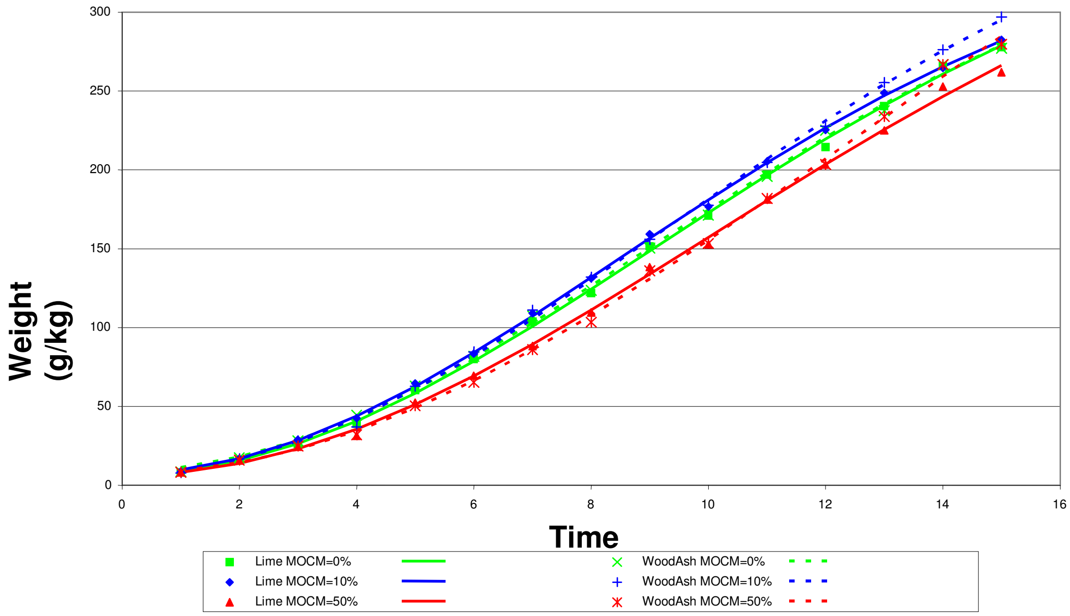

Figure 3.2 The effect of macadamia oil cake meal (MOCM) and calcium source on body weight for the grower trial over a period of 15 weeks

3.4.3 Body weight gain

The results of the body weight gain (BWG) for the birds on the 0% MOCM to 50% MOCM diets over a period of 15 – weeks are presented in Table 3.13. The BWG of the birds on the 50% MOCM diet was lower (P<0.05) than that of the other treatment diets up to eight weeks of age. From 9 to 14 weeks of age, the chickens in 50% MOCM diets experienced a higher (P<0.05) BWG than those in the other treatments. In week 15 the 0% MOCM diet had a lower (P<0.05) BWG than the other treatment diets.

The birds fed on diet of 10% MOCM + lime in the first phase had a highest (P<0.05) subtotal BWG compared to other treatment groups. In the 2^{nd} phase, birds fed on diet of 50% MOCM had a lowest (P<0.05) BWG compared to the other treatment groups, however, did not (P>0.05) differ from the 10% MOCM + WA diet. There were no (P>0.05) difference between treatment diets for the overall or total BWG for the 15 week period.

Table 3.13 The effect of dietary level of macadamia oil cake meal (MOCM) and calcium source on weekly body weight gain (g) per bird during the grower trial

	Treatments						
	0% MOCM M		10% MOCM		50% MOCM		
	L	W	L	W	L	W	(±SEM)
Weeks							
2	7.9	8.8	8.0	8.8	7.6	7.6	(±0.5)
3	10.3^{b}	10.9^{ab}	11.4^{a}	11.1^{ab}	8.7^{c}	8.9^{c}	(±0.4)
4	12.3^{b}	16.2^{a}	13.6^{ab}	9.3^{c}	7.0^{c}	7.3^{c}	(±1.3)
5	21.5^{ac}	18.6^{ab}	22.9^{ab}	25.9^{b}	20.9^{ac}	18.3^{c}	(±1.6)
Sub-Total	**51.9^{b}**	**54.5^{ab}**	**56.1^{a}**	**55.2^{ab}**	**44.3^{c}**	**42.1^{c}**	**(±1.3)**
6	19.8^{ab}	18.8^{ab}	18.9^{ab}	20.7^{a}	17.0^{bc}	14.9^{c}	(±1.1)
7	23.9^{ab}	25.6^{ab}	25.8^{a}	25.8^{a}	18.8^{b}	20.7^{b}	(±1.7)
8	18.0^{b}	16.2^{b}	22.1^{a}	21.9^{a}	21.3^{a}	17.4^{b}	(±2.3)
9	29.7^{ab}	26.8^{ab}	27.9^{ab}	24.2^{b}	28.8^{ab}	32.6^{a}	(±2.3)
10	19.4^{a}	20.8^{a}	17.5^{b}	21.7^{a}	14.5^{b}	17.4^{b}	(±1.2)
Sub-Total	**110.6^{a}**	**108.2^{ab}**	**112.1^{a}**	**114.2^{a}**	**100.4^{b}**	**102.9^{b}**	**(±2.7)**
11	25.9^{ab}	24.6^{b}	28.6^{a}	27.0^{ab}	24.9^{ab}	28.4^{ab}	(±1.4)
12	15.0^{a}	25.5^{b}	20.1^{ab}	22.9^{ab}	21.5^{ab}	21.6^{ab}	(±2.8)
13	22.4^{ab}	16.7^{a}	19.8^{a}	24.9^{ab}	22.3^{ab}	30.4^{b}	(±3.4)
14	21.8^{ab}	16.9^{a}	19.9^{ab}	23.9^{ab}	27.9^{ab}	32.9^{b}	(±4.7)
15	5.3^{c}	4.7^{c}	11.9^{ab}	7.9^{b}	8.9^{b}	12.9^{a}	(±1.4)
Sub-Total	**90.5^{b}**	**88.3^{b}**	**100.4^{b}**	**106.7^{ab}**	**108.9^{ab}**	**126.2^{a}**	**(±7.1)**
Total BWG over 15 weeks	**253.1 (±20.82)**	**250.9 (±17.99)**	**268.6 (±13.25)**	**276.1 (±12.00)**	**253.6 (±18.88)**	**271.3 (±13.80)**	

^{abc} Means with different superscripts, within rows, differed significantly (P < 0.05)

MOCM – Macadamia oil cake meal, L – Lime, W – Wood ash

3.4.4 Feed conversion efficiency

The results of weekly feed conversion efficiency (FCE) as measured in (kg gain/kg feed) for the birds on the 0% MOCM to 50% MOCM diets over a 15 – week period are presented in Table 3.14. Birds on the 50% MOCM diet had a lower (P < 0.05) FCE than those on the other treatment diets up to the 11th week. The 0% MOCM and

10% MOCM + WA treatments also resulted in lower (P < 0.05) FCE compared to the diet of 10% and 50% MOCM with lime and WA, respectively on the 15th week.

Table 3.14 The effect of dietary level of macadamia oil cake meal (MOCM) and calcium source on weekly feed conversion efficiency (g gain/ g feed) per bird for the grower trial over a period of 15 – weeks

Treatments

	0% MOCM		10% MOCM		50% MOCM		
	L	W	L	W	L	W	(±SEM)
Weeks							
2	0.30	0.32	0.30	0.30	0.25	0.26	(±0.02)
3	0.24^{ab}	0.26^{a}	0.26^{a}	0.25^{a}	0.19^{c}	0.20^{bc}	(±0.01)
4	0.26^{b}	0.40^{a}	0.29^{b}	0.23^{bc}	0.16^{c}	0.18^{c}	(±0.03)
5	0.32	0.27	0.32	0.36	0.35	0.24	(±0.04)
Sub-Total	**1.14^{a}**	**1.26^{a}**	**1.18^{a}**	**1.15^{a}**	**0.97^{b}**	**0.89^{b}**	**(±0.05)**
6	0.30^{a}	0.28^{a}	0.27^{ab}	0.29^{a}	0.23^{bc}	0.21^{c}	(±0.01)
7	0.36^{a}	0.38^{a}	0.35^{a}	0.33^{a}	0.24^{b}	0.27^{b}	(±0.02)
8	0.21^{b}	0.19^{b}	0.27^{b}	0.40^{a}	0.42^{a}	0.24^{b}	(±0.05)
9	0.36	0.39	0.32	0.32	0.38	0.38	(±0.03)
10	0.20^{ab}	0.22^{a}	0.18^{bc}	0.22^{a}	0.15^{d}	0.16^{dc}	(±0.01)
Sub-Total	**1.45^{b}**	**1.48^{b}**	**1.42^{b}**	**1.59^{a}**	**1.43^{b}**	**1.28^{c}**	**(±0.04)**
11	0.22	0.22	0.36	0.23	0.22	0.23	(±0.06)
12	0.15^{b}	0.25^{a}	0.21^{ab}	0.23^{a}	0.20^{ab}	0.18^{ab}	(±0.02)
13	0.21^{ab}	0.16^{b}	0.18^{ab}	0.22^{ab}	0.18^{ab}	0.25^{a}	(±0.03)
14	0.21	0.16	0.20	0.25	0.24	0.26	(±0.04)
15	0.04^{c}	0.04^{c}	0.10^{ab}	0.06^{bc}	0.07^{abc}	0.08^{ab}	(±0.01)
Sub-Total	**0.86^{ab}**	**0.85^{b}**	**1.07^{a}**	**1.01^{ab}**	**0.92^{ab}**	**1.03^{ab}**	**(±0.08)**
Total FCE over 15 weeks	**3.45^{ab} (±0.14)**	**3.59^{ab} (±0.17)**	**3.67^{a} (±0.31)**	**3.75^{a} (±0.17)**	**3.32^{ab} (±0.22)**	**3.20^{b} (±0.14)**	

^{abcd} Means with different superscripts, within rows, differed significantly (P < 0.05)

MOCM – Macadamia oil cake meal, L – Lime, W – Wood ash, SD – Standard deviation

The diet of 50% MOCM had a lower (P<0.05) difference in FCE as compared to the other treatment diets in first phase (week 1 to 5). In the 2nd phase, the diet of 10% MOCM + WA had a higher (P<0.05) difference in FCE compared to other diets, while the diet of 50% MOCM + WA had a lower (P<0.05) FCE as compared to the other treatment diets. The diet of 0% MOCM + WA in the 3rd phase had a (P<0.05) different FCE when compared to the diet of 10% MOCM + lime. The overall results showed a (P<0.05) difference FCE between the diet of 10% MOCM and 50% MOCM + WA diet.

3.5 The carcass parameters

The results of the carcass mass, muscle, fat and bone as percentage of carcass weight of the treatment diets from 0% MOCM to 50% MOCM are presented in Table 3.15. There was no (P > 0.05) difference in carcass weight between the treatment diets. Muscle as percent of carcass mass in the treatment, 50% MOCM plus lime, was higher (P < 0.05) than that in the 10% MOCM treatment diet. There was no (P > 0.05) difference in muscle as percent carcass mass between the diets of 0%, 10% and 50% MOCM plus WA.

The fat as percentage of carcass mass differed significantly between treatments. The diet of 10% MOCM with lime had a higher (P < 0.05) fat content as percentage of carcass mass as compared to the other treatment diets. There was no (P > 0.05) difference in fat percentage between the diets of 10% MOCM plus WA with the other treatment diets.

There was no (P > 0.05) difference in bone as percentage of carcass weight between treatments.

The result of the bone breaking strength (BBS) of the right and left tibia of the chickens are presented in Table 3.16. There was no (P > 0.05) difference in BBS between the treatments. The combined results of the means for the two sources of Ca on BBS are presented in Table 3.17.

The results of tibia weight, volume and density for both the right and left tibia of the grower experiment are presented in Table 3.18. There was no ($P > 0.05$) difference in tibia weight, volume and density between treatments for both the right and the left tibia.

The results of the diameter of the right and the left tibia are presented in Table 3.22. There was no ($P > 0.05$) difference in diameter between all treatments for both the right and the left tibia. The combined results of the means for the two sources of Ca on BBS are presented in Table 3.19.

Table 3.15 The effect of dietary level of macadamia oil cake meal (MOCM) and calcium source on carcass mass and muscle, fat and bone as percent carcass weight at 8 – weeks of age

	Carcass mass (g)		Muscle (%)		Fat (%)		Bone (%)	
	Mean	**(±SEM)**	**Mean**	**(±SEM)**	**Mean**	**(±SEM)**	**Mean**	**(±SEM)**
Treatment								
0% MOCM (L)	817.3	(±46.5)	77.1[ab]	(±0.42)	1.9[b]	(±0.97)	19.5	(±1.27)
0% MOCM (W)	865.6	(±75.6)	77.8[ab]	(±1.76)	2.2[b]	(±1.02)	19.1	(±2.32)
10% MOCM (L)	869.5	(±69.7)	74.8[b]	(±1.81)	4.8[a]	(±0.63)	18.9	(±1.93)
10% MOCM (W)	852.2	(±24.4)	75.4[b]	(±1.22)	3.3[ab]	(±1.48)	19.3	(±0.84)
50% MOCM (L)	805.9	(±46.9)	79.6[a]	(±2.11)	1.4[b]	(±0.31)	17.9	(±2.14)
50% MOCM (W)	784.7	(±39.7)	75.7[ab]	(±2.45)	2.4[b]	(±1.04)	19.7	(±0.86)

[ab] Means within columns and within parameters with different superscripts, differed significantly ($P < 0.05$)

MOCM – Macadamia oil cake meal, L – Lime, W – Wood ash

Table 3.16 The effect of dietary level of macadamia oil cake meal (MOCM) and calcium source on bone breaking strength (BBS), Newton (N) of the right and left tibia as interpreted separately at the age of 8 – weeks old

	Right Tibia		Left Tibia	
	Mean	(±SEM)	Mean	(±SEM)
Treatments				
0% MOCM (L)	-235.0	(±78.9)	-267.3	(±101.9)
0% MOCM (W)	-234.4	(±67.9)	-202.6	(±41.0)
10% MOCM (L)	-236.6	(±37.1)	-220.9	(±64.3)
10% MOCM (W)	-240.5	(±52.6)	-208.8	(±7.0)
50% MOCM (L)	-220.5	(±54.2)	-221.7	(±52.7)
50% MOCM (W)	-169.2	(±24.6)	-175.7	(±15.8)

Means between treatments are not significantly different (P > 0.05)

MOCM – Macadamia oil cake meal, L – Lime, W – Wood ash

Table 3.17 The effect of dietary level of macadamia oil cake meal (MOCM) and calcium source on combined means of the two sources of calcium for the bone breaking strength, Newton (N) of the right and left tibia as the age of 8 – weeks old

	MOCM Level			Ca sources	
	0%	10%	50%	Lime	WA
Mean	-234.8	-226.7	-196.8	-233.8	-205.2
(±SEM)	(±69.0)	(±36.3)	(±43.8)	(±60.4)	(±39.8)

Means between treatments are not significantly different (P > 0.05)

MOCM – Macadamia oil cake meal, L – Lime, W – Wood ash

Table 3.18 The effect of dietary level of macadamia oil cake meal (MOCM) and calcium source on both the right and left tibia weight (g), volume (l) and density (g/l) on a wet bone basis of the birds at 8 weeks of age

	Weight (g)				Volume (L)				Density (g/L)			
	Right Tibia		Left Tibia		Right Tibia		Left Tibia		Right Tibia		Left Tibia	
	Mean	(±SEM)	Mean	(±SEM)	Mean	(±SEM)	Mean	(±SEM)	Mean	(±SEM)	Mean	(±SEM)
Treatments												
0% MOCM (L)	5.7	(±0.66)	5.8	(±0.61)	4.3	(±0.80)	4.3	(±0.75)	1.4	(±0.14)	1.4	(±0.18)
0% MOCM (W)	5.8	(±0.49)	5.8	(±0.59)	4.7	(±0.43)	4.6	(±0.66)	1.2	(±0.02)	1.3	(±0.07)
10% MOCM (L)	5.1	(±0.13)	5.4	(±0.27)	4.2	(±0.24)	4.4	(±0.13)	1.2	(±0.05)	1.2	(±0.07)
10% MOCM (W)	5.5	(±0.72)	5.7	(±0.77)	4.4	(±0.75)	4.6	(±0.66)	1.3	(±0.09)	1.2	(±0.03)
10% MOCM (L)	5.8	(±0.77)	5.7	(±0.69)	4.6	(±0.78)	4.6	(±0.59)	1.3	(±0.08)	1.3	(±0.02)
50% MOCM (W)	5.3	(±0.59)	5.1	(±0.60)	4.3	(±0.47)	4.4	(±0.55)	1.2	(±0.06)	1.2	(±0.04)

Differences between means within columns and parameters are not significant ($P > 0.05$)

MOCM – Macadamia oil cake meal, L – Lime, W – Wood ash

Table 3.19 The combined effect of dietary level of macadamia oil cake meal (MOCM) and calcium source on tibia weight (g), volume (l) and density (g/l) of both right and left tibia bones on a wet bone basis of the birds at 8 weeks of age

	Weight		Volume		Density		Diameter major		Diameter minor	
	Mean	(±SEM)	Mean	(±SEM)	Mean	(±SEM)	Mean	(±SEM)	Mean	(±SEM)
MOCM										
0%	5.8	(±0.5)	4.5	(±0.6)	1.3	(±0.1)	0.6	(±0.02)	0.3	(±0.03)
10%	5.4	(±05)	4.4	(±0.5)	1.2	(±0.04)	0.6	(±0.05)	0.3	(±0.06)
50%	5.5	(±0.7)	4.5	(±0.5)	1.2	(±0.05)	0.6	(±0.05)	0.3	(±0.06)
Calcium source										
Lime	5.6	(±0.6)	4.4	(±0.5)	1.3	(±0.1)	0.6	(±0.03)	0.3	(±0.05)
WA	5.5	(±0.6)	4.5	(±0.5)	1.2	(±0.04)	0.6	(±0.04)	0.3	(±0.05)

Differences between means within columns and parameters are not significant ($P > 0.05$)

L – Lime, W – Wood ash

Table 3.20 The effect of dietary level of macadamia oil cake meal (MOCM) and calcium source on the diameters (mm) of the right and left tibia of the birds at 8 weeks of age

	Right Tibia				Left Tibia			
	Major		Minor		Major		Minor	
	Mean	(±SEM)	Mean	(±SEM)	Mean	(±SEM)	Mean	(±SEM)
Treatments								
0%MOCM (L)	0.62	(±0.04)	0.27	(±0.04)	0.60	(±0.02)	0.29	(±0.07)
0%MOCM (W)	0.65	(±0.02)	0.28	(±0.03)	0.63	(±0.02)	0.30	(±0.02)
10%MOCM (L)	0.65	(±0.08)	0.27	(±0.04)	0.61	(±0.03)	0.27	(±0.05)
10%MOCM (W)	0.61	(±0.03)	0.28	(±0.07)	0.63	(±0.01)	0.28	(±0.11)
50%MOCM (L)	0.63	(±0.04)	0.34	(±0.12)	0.62	(±0.06)	0.32	(±0.04)
50%MOCM(W)	0.58	(±0.06)	0.25	(±0.07)	0.60	(±0.04)	0.27	(±0.04)

Means between treatments are not significantly different ($P > 0.05$)

L – Lime, W – Wood ash

3.6 Mineral analysis of the tibia bones

The results of the mean (±SEM) of the elemental composition of analysed tibia bones on ash basis for the treatment diets of 0% MOCM to 50% MOCM are presented in Tables 3.21. The tibia bones in the 0% MOCM treatment had a lower ($P < 0.05$) DM content compared to the other treatment diets. The bones in the 50% MOCM treatment also had a lower ($P < 0.05$) percentage of ash compared to the other treatment diets. The 50% MOCM diet again, was lower ($P < 0.05$) in Ca and P compared to the other treatment diets.

Table 3.21 The effect of dietary level of macadamia oil cake meal (MOCM) and calcium source on the means (g/kg) on the elemental composition of tibia bones (dry, fat-free basis) and as percentage of bone ash

	Dry matter (g/kg)		Ash (g/kg)		Calcium (g/kg) bone ash			Phosphorus (g/kg) bone ash			Magnesium (g/kg) bone Ash		
	Mean	**(±SEM)**	**Mean**	**(±SEM)**	**Mean**	**(±SEM)**	**% in ash***	**Mean**	**(±SEM)**	**% in ash***	**Mean**	**(±SEM)**	**% in ash***
Treatments													
0% MOCM (L)	91.8[dc]	(±0.5)	58.0[a]	(±0.5)	20.6[ab]	(±0.3)	35.5	10.2[a]	(±0.2)	17.6	0.36	(±0.01)	0.62
0% MOCM (W)	91.4[d]	(±0.2)	57.7[a]	(±0.3)	20.1[b]	(±0.1)	34.8	10.4[a]	(±0.1)	18.0	0.38	(±0.01)	0.66
10% MOCM (L)	92.5[ab]	(±0.6)	58.9[a]	(±1.3)	20.9[a]	(±0.4)	35.5	10.6[a]	(±0.3)	17.9	0.36	(±0.02)	0.61
10%MOCM (W)	92.6[ab]	(±0.4)	58.1[a]	(±1.1)	20.1[b]	(±0.6)	34.6	10.3[a]	(±0.5)	17.7	0.38	(±0.01)	0.65
50% MOCM (L)	92.9[a]	(±0.3)	58.3[a]	(±0.7)	19.5[c]	(±0.2)	33.4	9.3[b]	(±0.1)	16.0	0.37	(±0.02)	0.63
50%MOCM (W)	92.2[bc]	(±0.4)	55.7[b]	(±1.7)	19.4[c]	(±0.2)	34.8	9.3[b]	(±0.1)	16.7	0.37	(±0.02)	0.66

[abcd]Means within columns with different superscripts are significantly different ($P < 0.05$)

L – Lime, W – Wood ash

* Calculated from means

Table 3.22 The effect of dietary level of macadamia oil cake meal (MOCM) and calcium source on the combined means (g/kg) on the elemental composition of tibia bones (dry, fat-free basis)

	Dry Matter (g/kg)		Ash (g/kg)		Calcium (g/kg)		Phosphorus (g/kg)		Magnesium (g/kg)	
	Mean	(±SEM)	Mean	(±SEM)	Mean	(±SEM)	Mean	(±SEM)	Mean	(±SEM)
MOCM Level										
0%	91.6[b]	(±0.4)	57.8[ab]	(±0.4)	20.4[a]	(±0.3)	10.3[a]	(±0.2)	0.4	(±0.01)
10%	92.6[a]	(±0.5)	58.6[a]	(±1.2)	20.5[a]	(±0.6)	10.4[a]	(±0.4)	0.4	(±0.01)
50%	92.6[a]	(±0.5)	56.9[b]	(±1.8)	19.5[b]	(±0.2)	9.3[b]	(±0.1)	0.4	(±0.01)
Calcium source										
Lime	92.4	(±0.7)	58.4[a]	(±0.9)	20.3[a]	(±0.6)	10.0	(±0.6)	0.4	(±0.01)
WA	92.1	(±0.6)	57.2[b]	(±1.5)	19.9[b]	(±0.5)	10.0	(±0.6)	0.4	(±0.01)

[ab] Means within columns and parameters within MOCM levels and calcium sources with different superscripts are significantly different (P<0.05)

L – Lime, W – Wood ash

The elemental composition of the tibia bones as affected by the main treatments, MOCM level and Ca sources are presented in Table 3.22. The effects of MOCM levels and Ca sources were statistically analysed and interpreted separately. The tibia bones of the birds in the 50% MOCM treatment was lower (P < 0.05) in ash, Ca and P concentrations than those in the other MOCM treatments. In addition, when using WA as Ca source in the diet, it resulted in a lower Ca and ash content in the tibia bones compared to the use of limestone.

Table 3.23 The effect of dietary level of macadamia oil cake meal (MOCM) and calcium source on feed intake (FI), egg weight (EW), egg production (EP), feed conversion ratio (FCR) and eggshell strength (ESS) mean of hens during the 4-week layer experiment

	Parameters									
	FI (g/day)		**EW (g/day)**		**EP (%)**		**FCR (g feed/g egg)**		**ESS (N)**	
	Mean	**(±SEM)**	**Mean**	**(±SEM)**	**Mean**	**(±SEM)**	**Mean**	**(±SEM)**	**Mean**	**(SEM)**
Treatments										
0% MOCM (L)	90.2[b]	(±8.99)	42.1	(±1.28)	10.7	(±1.76)	5.4	(±1.15)	-32.4	(±5.80)
0% MOCM (W)	84.6[b]	(±8.64)	39.2	(±0.86)	11.0	(±4.63)	5.7	(±2.02)	-34.5	(±3.88)
10% MOCM (L)	88.7[b]	(±8.73)	41.2	(±2.11)	13.8	(±7.65)	5.3	(±2.37)	-34.5	(±3.37)
10% MOCM (W)	81.9[b]	(±8.42)	39.0	(±1.16)	14.4	(±1.34)	3.8	(±0.34)	-27.1	(±4.26)
50% MOCM (L)	115.4[a]	(±4.03)	37.2	(±7.91)	8.4	(±7.18)	5.1	(±0.32)	-26.3	(±7.01)
50% MOCM (W)	88.5[b]	(±15.96)	40.6	(±10.02)	4.0	(±4.10)	6.2	(±2.03)	-25.9	(±7.17)

[ab]Means within columns within parameter with different superscript differed significantly ($P<0.05$)

L – Lime, W – Wood ash, N – Newton, EP (%) – number of eggs produced over a 4 week period per hen

3.7 The results of parameters measured during the layer study

The results of daily feed intake, egg weight, egg production, feed conversion ratio and eggshell breaking strength per chicken over a four week period for the layer experiment are presented in Table 3.23. The FI ranged from 81.9 g/day in the 10% MOCM plus WA treatment to 115.4 g/day in diet of 50% MOCM plus lime. The diet of 50% MOCM plus lime had a higher ($P < 0.05$) FI than the other treatment diets. There was no ($P > 0.05$) difference in FI between the other treatment diets. The egg weight (EW) ranged from 37.3 g/day in diet of 50% MOCM plus lime to 42.1 in diet of 0% MOCM plus lime. There was no ($P > 0.05$) difference in EW between any of the treatment diets. The egg production (EP) ranged from 4.0% in diet of 50% MOCM plus WA to 14.4% in diet of 10% MOCM plus WA. There was no ($P > 0.05$) difference in EP between any of the treatment diets. The diet of 10% MOCM plus WA had a high EP, but without any significant difference compared to the other treatment diets.

The FCR ranged from 3.8 in diet of 10% MOCM plus WA to 6.2 in diet of 50% MOCM plus WA. There was no ($P > 0.05$) difference in FCR between any of the treatment diets. The eggshell strength (ESS) ranged from –34.6 N in diet of 10% MOCM plus lime to –25.9 N in diet of 50% MOCM plus WA. However, there was no ($P > 0.05$) difference in ESS between the treatment diets.

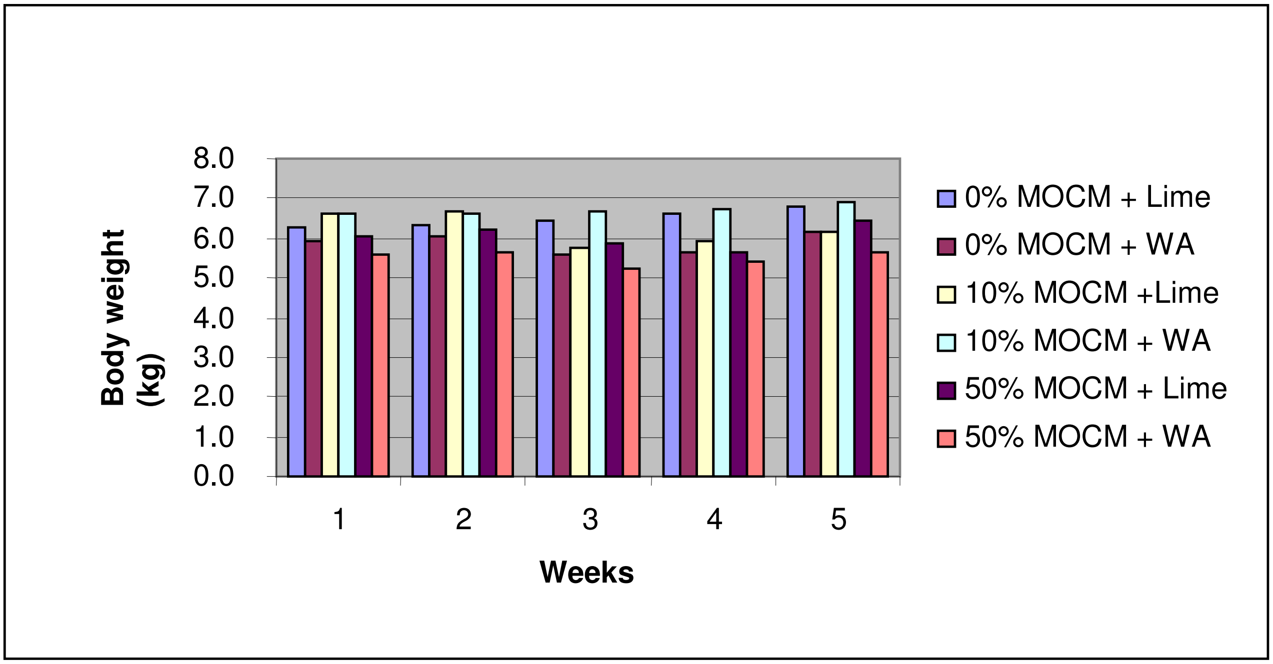

Figure 3.3. The effect of macadamia oil cake meal and wood ash on body weight of laying hens

The BW and BWG for the layer trial are presented in Figure 3.3 and 3.4, respectively. The weight is presented in (kg) as it represents the total nine hens per treatment in the layer trial. Graphically, the results in Fig. 3.3 show a fluctuation or drop in BW for treatment diets of 0% MOCM + WA, 10% MOCM + lime in week 3, and also the same for the diet of 50% MOCM in the same week. Results in Fig.3.4 concur with the observation found in Fig. 3.3 as it clearly indicates loss in weight by hens in diets of 0% MOCM + WA, 10% MOCM + lime and 50% MOCM, especially in the third week.

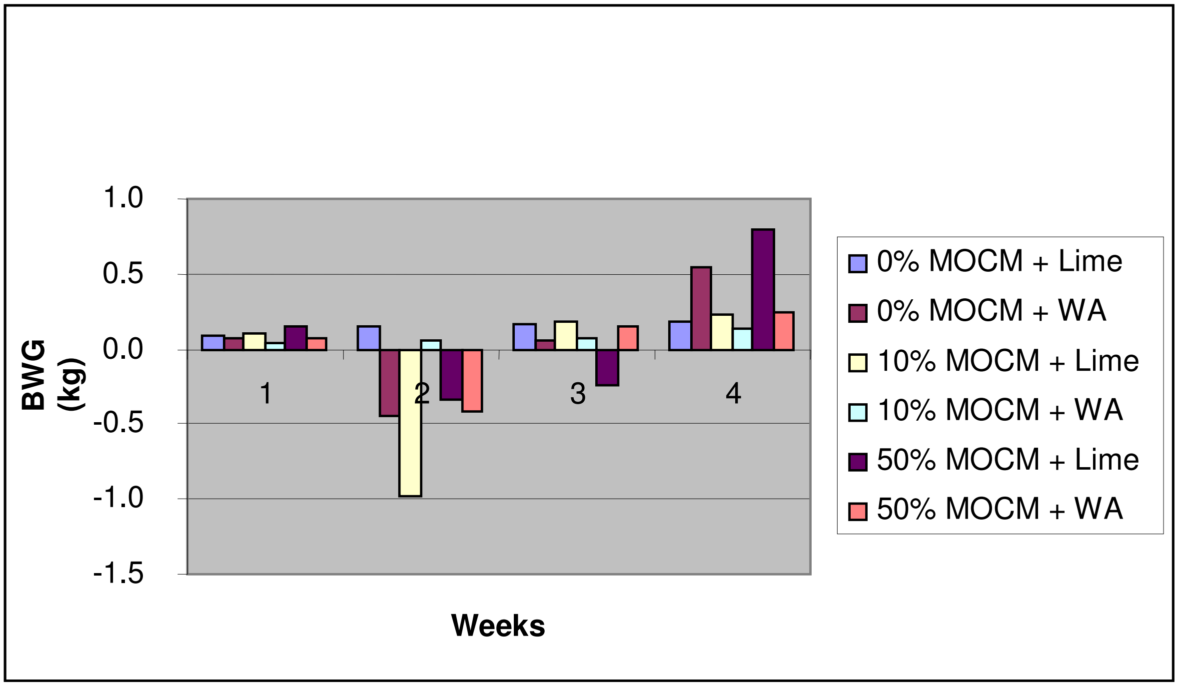

Figure 3.4. The effect of macadamia oil cake meal and wood ash on body weight gain of laying hens

CHAPTER 4 – DISCUSSION

There is dearth of knowledge on the suitability and the appropriate levels of inclusion, or substitution value, of MOCM as an ingredient in poultry diets. The efficient utilization of agro-industrial by-products among others, MOCM, is of importance in rural small-scale poultry production. Many authors and researchers have applauded the need for research on the use of cheap by- and waste products as poultry feed. In an effort to reduce the cost of poultry production, nutritionists have to utilize by- and waste products that are not directly utilizable by humans (Ani and Okorie, 2005).

There are many potential oil crops in addition to soybean, each with strengths and weaknesses that can be used as protein sources in animal nutrition. Local adaptation to growing conditions and local availability provide distinct advantages for feed production in many developing countries. A continuous supply of protein meal of known quality can be made available, as is the case with palm kernel cake, the by-products of oil palm production, e.g. in Malaysia and Indonesia (FAO, 2002).

A major consideration associated with the feeding of by-products is the variation in quality after processing of the "parent" product. This inherent variation is considered to resemble the nutrient composition of the "parent" product due to processing methods employed to convert the product to a usable commercial product (Parsons *et al*., 1997).

In the present study MOCM effectively replaced conventional feed ingredients in the diets of chickens, though it had a poor nutrient composition, especially a low protein and energy and high crude fibre content. However, this by-product has been found to have suitable concentrations of nutrients, as reported by Skenjana *et al*. (2002); and this can make the by-product to be a pivotal ingredient in diets for poultry.

The chickens used for the present study were the New Hampshire, a breed mostly kept in rural areas and is therefore suitable for scavenging environments, and they are characterised by relatively slow growth. Minh (2005) reported that the indigenous poultry breeds have low productivity and are not suitable for intensive systems.

However, these breeds are very suitable for low-input scavenging and semi-scavenging system. In contrast, the commercial breeds generally have superior characteristics compared to indigenous breeds, such as higher body weight gains and productivity (Vang, 2003).

4.1 Chemical composition

Little has been reported in the literature on the chemical composition and potential nutritive value of MOCM, except a report by Skenjana *et al.* (2002). However, like many by-products, variability of nutrient content is of concern for those who contemplate using this product. Because MOCM has shown to vary considerably in nutrient content, samples should be assayed continuously to ensure that high quality MOCM is used in diets for animal feeding. The CP content of MOCM used in this study was 140 g/kg DM, which is low compared to the mean value of 254 g/kg DM reported by Skenjana *et al.* (2002). The MOCM contained a high level of CF (385 g/kg DM) and a relatively low available energy level which allows the by-product to be classified as an "intermediate product" in poultry feeding (Van der Merwe & Smith, 1977). The resulting fibre content was elevated in the by-product, while the recommended is from 3-5% of crude fibre in complete diets of growing chickens (NRC, 1994). However, the NDF concentration of the product used in the present study is similar with that reported by Skenjana *et al*. (2002). The NDF content of MOCM was 419 g/kg DM, indicating a fibrous product. Skenjana *et al*. (2002) could classify the MOCM they analysed as a protein source because it contained more than 20% protein. The by-product in the present study cannot be classified as a protein source due to its low CP (140 g/kg DM) and had relatively high fibre content (385 g/kg DM). Although the by-product (MOCM) contains high levels of fibre and fat and a low level of protein, one can classify the product as a possible energy source or filler. It is evident from the computer formulated experimental diets (Tables 2.3 to 2.5) that wheat bran, which can also be classified as an intermediate product, was largely replaced by MOCM.

Although it is difficult to explain the reason for the differences between the samples of MOCM, the oil cake used in the present study could have been derived from poor quality macadamia nuts or was of inferior quality due to the processing technique applied. However, a more likely reason could be that the macadamia seeds or the by-product might have been subjected to conditions such as exposure to rain and poor weather conditions that resulted in the leaching of nutrients from the product. Skenjana *et al*. (2002) also evaluated a macadamia product that contained a mixture of nuts and hulls and the product had a low nutritive value, though the batch tested in the present study did not contain visible hull particles.

Feed ingredients should, therefore, be selected on the basis of availability, price and the quality of the nutrients they contain. Certain ingredients invariably constitute the greatest part of diets, in terms of amount and cost (NRC, 1994).

Arosemena *et al*. (1995) reported on the use of selected by-product feedstuffs (BFP) where variability in chemical composition of the BFP influenced the composition of the total diet. However, the impact was small compared with the contribution of the other concentrates in the total mixture. They concluded that the magnitude of the effect will depend on the contribution of the by-products to the total ration and the nutrients of interest.

Irrespective of the low CP and high fibre content of the present product, this product could become cheaply available to farmers in rural areas. Depending on the processing technique applied, the MOCM by-product can be classified as protein, energy source or intermediate product.

The mean Ca and P concentrations of the MOCM analysed by the Skenjana *et al*. (2002) were 3.44 and 3.88 g/kg DM, respectively. This is higher than the 1.60 and 2.30 g/kg DM, respectively, found in MOCM of the present study. Furthermore, it is likely that part of the P could be in the form of phytate. It is well known that the majority of P in foodstuffs of plant origin such as maize and soyabean meal is in the form of phytate, which has a low availability to monogastric animals, such as poultry and pigs (Simons *et al*. 1990; NRC, 1994; Summers, 1997; Bedford, 2000; Lesson and Summers, 2001). Therefore, phytate is referred to as an anti-nutrient (Spring, 2008). Phytic acid does not only reduce P availability in poultry, but also the availability of other nutrients in poultry diets (Ravindra *et al*. 1999a,b; Ravindra *et al*., 2001; Sebastian *et al*., 1996a,b; Punna *et al*. 2001; Lan *et al*. 2002; Shirley and Edwards, 2003). Phytic acid acts as a chelator of Ca, Mg, Fe, and Zn and may inhibit the absorption of these minerals. In a rural feeding situation it would not be feasible to test a feed for anti-nutrients. However, poor animal performance would indicate the presence of such factors.

A major problem in the use of MOCM as an animal feed in the rural situation is its high and variable oil content. The product and feed mixtures containing MOCM would be susceptibility to oxidation and the consequent rancidity. This would create problems for rural farmers especially in hot weather conditions since they probably do not have proper storage facilities.

The MOCM might contain other anti-nutritional factors (ANF) and/or non-starch polysaccharides (NSP) causing a general inhibition of digestion and absorption in monogastric animals as they don't have the necessary enzymes to digest these components. Anti-nutritional factors are substances which either by themselves or through their metabolic products, interfere with the utilisation of dietary nutrients, and cause depressions in growth and feed efficiency and affect animal health (Huisman & Tolman, 1992).

The non-fibre carbohydrates (NFC) or non-starch polysaccharides (NSP) include any of the carbohydrates not found in neutral detergent fibre (NDF). Therefore, NFC is the water soluble and non-fibrous carbohydrates (starch, pectin and sugars). The carbohydrates soluble in the neutral detergent comprise a very heterogeneous group, both compositionally and nutritionally. Therefore, because it is calculated by difference, errors from each of the component analyses accumulate in NFC. Rumen microbes and animals utilizes the different fractions of protein, non-fibre carbohydrates and structural (fibre) carbohydrate fractions differently and their estimation in the feedstuffs elucidates more information about their availability (Sniffen *et al*., 1992).

The presence of NSP in MOCM might have lead to the poor performance observed in the birds that were fed 100% MOCM, which resulted in retarded growth and weight gain. The NFC concentration of MOCM was in the range of 167.9 g/kg. However,

one can conclude that there were probably not high concentrations of NSP because the birds fed 50% MOCM diet performed fairly well.
Non-starch polysaccharides cause an increase in viscosity of digesta and in intestinal tension, which impair diffusion of nutrients for digestion and absorption due to sticky droppings and, consequently, result in decreased energy value of feedstuffs and worsened feed conversion (van Barneveld *et al*., 1995; Grieshop *et al*., 2001)

Nitrogen-free extract (NFE) is a group of substance consisting of starches, sugars, dextroses, pentosans, organic acid, phytin, lignin and other substances. The percentage of NFE is found by difference and not by actual analysis. According to Ewing (1951), the cereal grains are particularly high in NFE, for example, maize, wheat, grain sorghum etc. have about 700 g/kg. The NFE content of MOCM was in the range of 201.9 g/kg DM, and this result is in agreement with the report by Janssen and Carré (1985) who stated that the correlation between crude fibre and starch with increasing fibre content resulted in reduced percentage of starch in NFE. In addition, Janssen and Carré (1985) also stated that, the positive contribution of crude fibre (in wheat by-products) to the feeding value is small since its digestibility is generally very low. However, the negative influence is substantial as there is a strong negative relationship with the digestibility of protein, fat and NFE. The last relationship is probably due to the high negative correlation between crude fibre and starch as with increasing fibre content, the percentage of starch in NFE diminishes.

4.1.1 Limiting order and amino acid profile

The amino acid concentration of the MOCM analysed in the present study was compared with the standard of nutrient requirement for chickens and the concentration was not high enough to meet the amino acid needs of poultry. The data shown in Table 4.1 indicate the percentage of individual amino acid in comparison with the requirements of broilers and layers, obtained from NRC (1994).

The results of the limiting order of amino acids are presented in Table 3.9. For the grower diets, 0% MOCM had leucine as the first limiting amino acids with threonine and arginine as being second and third limiting, respectively. The 10% MOCM diet had threonine as the first limiting and with lysine being the second limiting, arginine and isoleucine were third limiting as they had the same values (co-limiting). The diet with 50% MOCM included, had threonine as the first limiting and isoleucine, lysine and leucine as being second, third and fourth limiting amino acid, respectively.

For the layer diets, 0% MOCM had methionine as the first limiting amino acid, threonine, lysine and arginine being second, third and fourth limiting, respectively. The diet of 10% MOCM had methionine as the first limiting amino acid, threonine, lysine and arginine being second, third and fourth limiting, respectively. The diet of 50% MOCM had methionine as the first limiting amino acid, threonine, isoleucine and lysine being second, third and fourth limiting, respectively.

The sequence in which the amino acids of a protein become limiting for growth and production can be calculated from knowledge of the amino acid requirements of the animal and the amino acid composition of the dietary protein (Harper, 1959). By comparing requirements and the actual amino acids present in feed, the order of "limiting amino acids" can be estimated (Toride, 2000).

For chicks the 'first limiting' amino acid is most commonly methionine, although lysine and perhaps arginine may also be deficient (McDonald *et al*. 2002). Therefore, amino acid supplementation should focus on lysine and methionine concentration, especially in low protein diets. However, scavenging birds can also get amino acids from the environment, and these vary according to season and were significantly higher for the rainy season compared to the dry season (Minh, 2005).

The findings of the current study on different treatment diets were relatively in agreement with the findings by McDonald *et al*. (2002) as they reported relatively the same limiting order of AA in poultry diets. The treatment diets within which the grower experiment had threonine as the 'first limiting', arginine and lysine being the second; isoleucine and leucine were also deficient. For the treatment diets in the layer experiment, methionine was mostly the 'first limiting' with threonine being the second limiting. On the other hand, lysine, arginine and isoleucine were less deficient than the other amino acids.

The diet of 100% MOCM would definitely not be sufficient to meet the requirements of AA by chickens, unless supplementation is provided (NRC, 1994). Baker and Han (1994) reported that the amino acid requirements could not apply to all birds under all dietary, gender and body compositional circumstances. These researchers supported an idea of expressing the amino acid requirements as ideal ratios to lysine and similar expression was done for MOCM as it is indicated in Table 3.2. The amino acid profile needed for maintenance has been shown to be different from the profile needed to produce optimum weight gains (Baker *et al*., 1996; Coon *et al*., 1998). The balance of a mixture of AA in the diet is very unlikely to exactly meet the requirements of each of the animal tissues. A deficiency of an AA is likely to cause a reduction in performance and excesses of AA can also be deleterious (Buttery and D́′ Mello, 1994). It has therefore been suggested that the most important single factor affecting the efficiency of protein utilization for meat production is the dietary balance of AA (Cole and Van Lumen, 1994).

Table 4.1 Amino acid profile of MOCM (as fed, full-fat basis) as compared to the nutrient requirement of poultry (NRC, 1994)

Amino Acid profile	Broilers* (%)	Layers* (%)	MOCM (%)	10% MOCM (%)
Arginine	1.25	0.88	1.24	0.91
Glycine+Serine	1.25	-	0.74	2.75
Histidine	0.35	0.21	0.27	0.28
Isoleucine	0.80	0.81	0.44	0.54
Leucine	1.20	1.03	0.82	1.08
Lysine	1.10	0.86	0.64	0.61
Methionine	0.50	0.38	0.20	0.20
Methionine+Cystine	0.90	0.73	-	-
Phenylalanine	0.72	0.59	0.48	0.58
Phenylalanine+Tyrosine	1.34	1.04	-	1.06
Proline	0.60	-	0.69	0.83
Threonine	0.80	0.59	0.52	0.45
Tryptophan	0.20	0.20	-	-
Valine	0.90	0.88	0.56	0.62

* NRC, 1994, MOCM – Macadamia oil cake meal

Many researchers have also stressed the supplementation of amino acids to most of the by-product that are used as poultry feeds. From the evaluation of the AA in MOCM in the present study, it can be concluded that supplementation of AA would be necessary. The low concentration of a particular amino acid suggests that any diet formulation that is MOCM based must be supplemented with the deficient amino acids.

Knowledge of the availability of amino acids in feedstuffs is important for consistent formulation of diets that meet the bird's amino acid requirement. The amounts of amino acids available to animals, are often much lower than the quantity contained in feedstuffs (NRC, 1994).

4.1.2 Wood ash

The present study evaluated the possibility of using WA as an alternative for limestone (source of Ca) in chicken diets. From the findings regarding the chemical properties of WA, it was found that $CaCO_3$, a form of Ca also in limestone is available in high concentration; therefore this may suggest that the bioavailability of Ca in both limestone and WA is the same. The Ca content in WA and limestone is 25 and 35%, respectively, which suggest that the replacement of limestone by WA will require a higher inclusion percentage of WA as would with limestone.

From a nutritional point of view, little or no information is available for wood ash as alternative source of Ca for poultry feeding. Data published on the properties of wood ash are not as detailed as for ashes from coal. As a result, available data on the properties of WA are very variable (Etiegni & Campell, 1991; Ulery *et al.*, 1993; Someshwar, 1996). The XRD analysis results indicated that Ca was mainly in the form of calcite $CaCO_3$, viz. 58.8%, and in the same form as in feed lime. This is in agreement with results reported by Demeyer *et al.* (2001) and Van Ryssen & Ndlovu (2003).

4.2 Growth experiment

The experimental diets were formulated to contain different levels of MOCM and to simulate a possible practical situation for the feeding of poultry, and the different treatment diets consisted of MOCM, conventional feed ingredients and WA and feed lime as Ca sources. Birds in the control diet had a good performance, except for the observed separation of WA from the feed ingredients. The separation may be due to the fine particle sizes of WA and also less fat content in the control diet which may help bind the WA. Alternative methods of mixing the feeds that contain WA as an ingredient needs to be used to prevent the separation of fine particles, and one of the methods can be through pelleting. It is believed that smaller particle size leads to improved pellet quality (hardness) and efficiencies of pelleting process. Particle size encompasses both the size of various feed ingredients used in poultry diets as well as the consistency of the particle size. Many common issues such as mixing difficulties, wrong particle size and ingredient separation can be overcome by relatively fine milling of raw materials and exposing them to pelleting (Kleyn, 2006). However, once the pellet is exposed to feed gastro intestinal tract digestion of the bird (the crop in particular), the feed dissolves and we are in effect feeding a finely grounded mash diet (Kleyn, 2006). Uniformity of the diet has long been assumed to be important for optimum performance and it should be remembered that in young birds the beak dimension mitigate against prehension of large particles and that the gizzard is less well developed than in older birds (McCracken, 2002).

With the other treatment diets, it was observed that the inclusion of WA in diets were MOCM was present, did not have any separation incidences and this may be due to the fat content of MOCM as it resembled an adherence force to WA not to separate. The fat content may be a solution to fine particle separation; however, the diet may suffer the disadvantage of being susceptible to rancidity in store (McDonald, *et al*., 1995).

The treatment of 100% MOCM was terminated at eight weeks since the chickens had retarded growth and low body weight gains, demonstrating that the 100% MOCM diet both with and without Ca were not feasible. However, the inclusion level of up to 50% MOCM had no (P>0.05) differences in (muscle and fat), except for FI, BWG and FCE between treatment diets. The findings of the study are relative to the study conducted by Dong (2005) on the effect of replacement of concentrate with agro-industrial by-products (e.g. brewery waste, soya waste etc.) on duck performance and carcass composition traits, they reported that, concentrate supplied was reduced by more than 50%, and resulted in significantly lowered daily gain and as the ducks were unable to fully compensate for lower ME and digestible CP in the diets.

It is evident from low feed intake and body weight (birds in 100% MOCM diet) that they had from an early stage of growth; they had retarded growth which indicated their inefficient utilization of feed due to high fibre and low protein in the diet.

However, the incidence of mortalities among the birds in the 100 % MOCM diet was low, suggesting that MOCM may not contain toxic substances. A poor performance could be expected on a diet containing such a low concentration of CP of 140 g/kg for growing birds. However, considering the high CP concentration of 254 g/kg reported by Skenjana *et al*. (2002) indicates that MOCM could be fed at relatively high levels to poultry under rural farming conditions.

The effect of including MOCM as an alternative feed ingredient in diets for chickens, on feed intake showed differences between treatments. Because the inclusion rates of MOCM were predetermined in these diets, the major difference between the diets containing 0, 10 and 50% MOCM was their fibre content. Gear *et al*. (1981) observed that dietary fibre prevents effective utilization of dietary nutrients because of rapid transit times of the diets through the digestive tract.

Differences in FI between the different treatment groups fluctuated during the early stage of the growth study, but did not show a specific pattern. However, from week 10 onwards the feed intake of the 50% MOCM + WA group was significantly higher than that of the other groups, with the 50% MOCM + lime having higher intakes from week 12 compared to the 0% and 10% treatment diets. These findings are in line with that of other researchers.

Mc Donald *et al*. (1995) pointed out that within limits, the dilution of the energy content of the diets of monogastric animals could result in increased DM intakes in an attempt to maintain the level of available energy intake. Smith (2001) also stated that feed intake of poultry is determined mainly by their energy requirements and the major dietary factor that affects feed intake is the concentration of energy in the diets.

Sonaiya (1995) reported that most of the materials available for scavenging have a relatively low concentration of ME, since they contain high levels of crude fibre. Therefore, feeding poultry diets that are low in ME and high fibre would result in higher feed intake, as the chickens will eat more to satisfy or meet their energy requirements. The findings of Savory and Gentle (1976a, b) on agro-industrial by-products, suggested that a greater weight and volume of food is necessary to meet the requirements for energy and other nutrients at higher concentrations of fibrous ingredients in the diet. Also, Shim *et al*. (1989) and Onifade and Babatunde (1998) reported higher feed intake of broilers given diets based on high levels of fibrous brewer dried grains. Leeson *et al*. (1996a, b) reported that the increased feed consumption is definitively a response to energy dilution of the diets and the attempt by the birds to consume adequate amounts for maintenance as well as growth.

It could be speculated that the high fibre content in the 50% + WA treatment resulted in a higher rate of passage of the ingesta. However, the 50% MOCM + lime treatment contained similarly high fibre content, though did not show the same response in feed intake.

Although there was a linear decrease in performance with high level of MOCM, optimum growth rates were obtained when 10% MOCM was included in diets for chickens, especially the grower diet. The birds on the 10% MOCM diet had the same performance as those on the control diet, which clearly indicates that MOCM can be included in diet for chickens up to a level of 10% without adversely affecting performance of the bird. Akinola and Abiola (1999) and Abiola and Adekunle (2002), reported that, the use of melon husk (MH) in which it could replace 10% of maize in cockerel diets, the by-product has low level of protein content 9.5% and high crude fibre content 29%.

The chickens receiving the 50% MOCM treatment diet had lower body weights during most of the growing period. The low body weight of chickens in this diet does not correlate with the high feed intake, mentioned earlier. McDonald *et al.* (1995) stated that, the digestibility of a food is closely related to its chemical composition and the fibre fraction of a feed has the greatest influence on the digestibility, both the amount and chemical composition of the fibre are important. Various authors reported the implications of a fibrous diet on nutrient utilisation. Though the chickens had a high feed intake in the diet of 50% MOCM, the BW was lower compared to the other treatment diets. This may be due to the presence of anti-nutritional factors contained in MOCM, which if present, would make nutrients unavailable to the birds. In addition the, chickens does not have the necessary enzymes to digest high fibre content feeds.

Due to the high fibre content of the MOCM, chickens in 50% MOCM diet had a lower BWG at an early stage and recover as they grew older. The results on the BWG correlate with the body weight mentioned above, and again the fibre content of the feed contributed to the less BWG of the chickens in 50% MOCM diet. Abiola *et al*., (2002) reported that, the best result obtained with regard to body weight gain was 19.1 g/bird/day where alkali-treated melon husk (ATMH) replaced 10% maize, suggesting poor efficiency of feed utilisation by the birds due to the fibrous nature of the diets. The same results were found in the current study about the BWG, as the chickens in treatment diet of 50% MOCM compared to 10% MOCM, had lower BWG possibly due to the high fibre content of the diet as a result of high inclusion of MOCM.

The increase in BW by chick of 50% MOCM at an older stage, may suggest that a high level of inclusion of MOCM may be suitable for chickens at a later stage of growth as they seem to tolerate the high fibre and able to digest the diets as compared to young birds, because the gizzard is not well developed in young chicks than in older birds (McCracken, 2002). Birds on fibrous diets are known to exhibit greater mechanical grinding, and this usually stimulates the muscular walls of the gizzard and increases the intestinal length (Abiola, *et al*., 2002)

Feed conversion efficiency (FCE) is a key measure of performance and in poultry terms it means the return of one unit of bodyweight for x units of feed (King, 2006). Feed conversion efficiency was decreased with increased level of inclusion of MOCM (esp. for 50% MOCM) up to 11th week, and there after an increase was realized and the cause of poor FCE was due to the decreased BWG with increasing level of MOCM in the diet. Considering the performance of chickens in treatment diet of 10% MOCM alone, it could be observed that the diet had a good FCE as compared to the diet of 50% MOCM. Ali, *et al*., (2001) reported that a poorer FCE obtained may possibly be attributed to poorer utilization of ingested energy and possibly high fibre. In addition, they found that FCE were increased with increased level of soybean oil up to 6% but with higher level, the FCE were decreased on finisher period of broilers.

The incidence of poor FCE in the diet of 50% MOCM may have resulted due to the high fibre content and possibly anti-nutritional factors in the diet. Although there were improvements in gains and feed efficiency at 50% MOCM level of inclusion, the differences were not statistically significant.

4.2.1 Carcass composition

The result from the growth experiment clearly indicate similar carcass compositions in terms of carcass mass and bone percentage between the control and the diets in which 10% and 50% MOCM were included. The exception was with the 10% MOCM plus lime treatment, in that the carcasses in this treatment contained more fat compared to those in the other treatments. These results suggest that the inclusion level of MOCM and also the use of WA as an alternative to feed lime did not have an effect on the carcass mass and bone percentage of the chickens. Muscle as a percent carcass mass of 50% MOCM with feed lime diet was significantly higher ($P<0.05$) than the other treatment diets.

4.2.2 Analysis of the tibia bones

The physical measurements of both the right and left tibia bones did not yield any differences for all the treatment diets, including the comparison between the Ca sources. The BBS as a factor of Ca availability and deposition from the source provided to the chickens was the same for both limestone and WA. These results suggest that WA can be used as an alternative for limestone, with the same effect on bone strength for the chickens. Bone strength depends in part on the relative amounts and properties of the mineral content and organic matrix (Boskey *et al.*, 1999). In contrast, the results obtained by Williams *et al.* (2000) showed that the breaking strength of the tibia of chickens at 2 weeks of age was unaffected by dietary Ca and available P content, despite variation in occurring between diets.

The mineral content i.e. Ca and P of the tibia bone showed some difference in the diet of 50% MOCM compared to the other treatment diets. But the low Ca and P content of the bones did not have any influence on the BBS as there were no significant differences between the treatment diets. The ash to calcium ratio of the tibia bone for the study was in a range of 34-36%. Eastoe (1961) listed Ca and P in bone ash of mammals to be 35.6 to 36.3% and 15.5 to 16.4%, respectively. According to Field *et al*. (1974) bovine bone ash contains approximately 37% calcium and the percentage is constant over a wide age range. The result of Ca and P as percent ash for the present study was in the range of 33.4 to 35.5% and 16.0 to 18.0%, respectively.

4.3 Layer experiment

The results of the layer trial clearly indicated less significant differences between treatments with regard to the performance parameters measured. The hens used in the current study were of a dual purpose breed (New Hampshire). They are slow growing, which in turn results in hens reaching point-of-lay at an older age compared to commercial breeds. In addition, the New Hampshire breed is comparable with indigenous chickens that make them suitable as scavenging hens, and this is the production system mostly practised in rural and peri-urban areas. Minh (2005) stated that the major limitations of scavenging are generally the low productivity, especially under smallholder conditions and remote areas, and mainly as a result of low intake of nutrients and un-balanced nutrient diets. However, supplementation of energy, protein and amino acid improved performance and reduced production costs.

Minh (2005) reported that replacing soya bean meal (SBM) with 20% cassava leaf meal (CLM) in scavenging chickens did not affect the production performance of pullets and laying hens, although feed intake increased by about 10% compared to the control diet, possibly caused by high fibre in the CLM diets. The findings are in line with the result of the current study, as the diet of 50% MOCM with lime had a significantly higher ($P<0.05$) FI compared with the other diets (especially the control diet), which did not differ significantly between treatments. In addition, McNaughton and Deaton (1981) reported that sunflower seed meal (SFM) could be included in layer diets up to 30% without adversely affecting body weight, egg production or egg weight. In addition, they found that using high fibre SFM (24 % fibre) up to 30% in a layer diet significantly decreased feed efficiency while egg production, egg weight, eggshell strength and mortality were not affected.

The findings of the current study with regard to body weight as one of the parameters measured during the trial period, showed a reduced BWG in the diets of 0% MOCM +

WA, 10% MOCM + lime and 50% MOCM. The cause of loss in weight is not clear. These may be due to the change in production system i.e. cages vs. floor systems, as they were exposed to the floor system before reaching point-of-lay. In addition, the low body weight gain especially in diets contain MOCM might be associated with the ANF's that the MOCM might contain, which would reduce nutrient digestibility.

Though the inclusion level of MOCM in the current study seems to be high in comparison with the level reported on CLM, the fact remain that, the CLM is a by-product high in fibre and the difference is with regard to plant species. The level of CLM in practical poultry diets will also depend on the type of ingredients that are being replaced, and CLM was included in layer diets up to 25%, without adversely effecting egg production, egg quality and feed efficiency Minh (2005). Feed to gain ratio may not reveal much about the expected economic performance of a diet, yet it is a good indicator of biological efficiency (Sabamiwa and Akinwale, 1999). Odunsi (2002) reported that an increase in the dietary level of cashew kernel meal (CKM) did not significantly affect the hen day egg production. However, hens in confinement fed a balanced diet will convert food weight to egg weight at an efficiency of about 2.8 kg of feed per kilogram of egg weight (Sonaiya & Swan, 2004).

Diets based on SFM or SFM and groundnut (50:50) produced better responses in terms of egg production, FI, feed efficiency and egg weight than diets with only groundnut meal as a protein source Singh and Prasad (1981). The significant reduction in cost of production was due to the inclusion of bio-degraded agro by-products in the diets. Each of them replaced 50% of the maize allowing for the reduction of the maize from 400 g/kg to 200 g/kg in the tested diets. Bio-degrading of the agro by-products enhanced their feeding values by increasing their protein and energy levels and ensuring adequate egg production, Iyayi and Aderolu (2004).

Eggshell strength did not differ significantly between the diets as indicated in Table 3.26. The results support the findings of the BBS as mentioned earlier, where it was found that WA can be used as an alternative for limestone with regard to Ca supplementation to chickens. Therefore, the availability and efficient utilisation Ca in WA for both bone and egg shell strength is of the same value to the use of limestone as a Ca source. However, Odunsi *et al*. (2002) reported that shells of eggs produced by layers fed agro-industrial by-products (such as palm kernel cake) were thinner than from hens fed conventional diets. The authors noted that dietary sources high in non-starch polysaccharides probably through the carboxyl groups of the uronic acids can bind divalent cations such as Ca, Fe, Cu and Zn. Consequently, such diet may require additional supplementation.

In general, the results show the beneficial effects of MOCM and wood ash that can be obtained by feeding non-conventional feed ingredients to chickens. The results also demonstrated how efficient MOCM and WA could be utilized in comparison with conventional feed ingredients. This would be of the financial advantage to small-scale farmers, because the MOCM by-product is cheap to buy as it is regarded as a waste from the oil producing industry. On the other hand, WA as source of Ca can be produced by the "burning of wood" which is a norm that is commonly practiced in rural areas.

Even though wood ash had lower calcium content than feed lime, the results were the same as indicated by the breaking of the egg shell and tibia bones results, as there were no significant differences found between treatments. The inclusion of wood ash in feed, in comparison with feed lime was high in order to increase the calcium content and availability in wood ash. The calcium content in wood ash is in the form of calcium carbonate, (Table 3) similar to that in feed lime calcium. Therefore, the assumption made was that, the availability of calcium in wood ash for chickens would be the same as that of feed lime and this assumption was proven to be correct, suggesting that the Ca in wood ash has a bio-availability similar to the Ca in feed lime.

CHAPTER 5- GENERAL CONCLUSION

5.1 CRITICAL EVALUATION

As mentioned earlier that MOCM might be of high or low quality, it was unfortunate that the batch received for the present study was of bad or low quality. Therefore, the sample or batch was low in protein and it demonstrates the risk of using any batch of the by-product. It would be necessary for analysis to be done on the by-product before it can be fed to chickens. This might be difficult for rural situation as they don't have the necessary technology to do the analysis of feed ingredients that they feed to chickens. Apart from the downside mentioned about MOCM, the by-product if of high quality can be beneficial to a rural situation as it can be fed to chickens at a particular level and reduce the cost incurred during feeding of the chickens.

The feeding of MOCM as a sole feed ration proved to be an unfeasible practice as evident from the poor performance of chickens that received MOCM alone. It can be given provided the birds scavenge, as a way to supplement the required nutrients. A balanced diet, whereby different feed ingredients are mixed as a feed ration for chickens, would be a solution for the well being of chickens, but in rural conditions it would be difficult for farmers to provide a balanced diet unless it is bought as a complete feed.

The high fibre content in MOCM may interfere with the digestibility of the by-product if used as feed ingredient for high producing chickens, i.e. commercial layers or broilers. Most of the chickens raised in rural areas are of types with a slower growth potential that do not need feed of very high nutrient densities.

The period of the layer trial was too short (and hens were still early in the production cycle) for any conclusion to be made regarding the value of WA as Ca source for layer hens. The research should have been continued throughout the production cycle to see the effect of wood ash during the laying period. Financial, time and housing forced a premature termination of the trial.

The feeding of laying hens with wood ash as a calcium supplement was problematic when feed ingredients did not have enough fat that could bind the wood ash. The problem was evident from the diet where MOCM was not included in the ration, then WA tended to separate from other ingredients and the intake of WA was lowered due to its fine particle size. Therefore, care should be taken when formulating feeds for layers.

Some of the egg quality indices were not monitored in this research, for example, blood and meat spot, Haugh unit measure of internal egg quality and specific gravity. They are also parameters to be included in an egg trial as they affect egg quality, especially the internal quality. Other analyses that could have been included are phytate and non starch polysaccharides (NSP) determination in the MOCM.

Wood ash is an important by-product of the burning of wood and has potential as a valuable Ca source for chickens, especially in rural areas. The use of WA as an alternative for limestone seems to be a valuable option when considering the economic conditions of low-input subsistence farming systems found in rural areas. Further investigations are needed in order to evaluate its feasibility and effectiveness in the local livestock production systems, particularly in relation to labour availability, and to determine levels of land-use pressure to ensure the sustainability of the resource.

Due to the varying nutrient composition of MOCM as a result of the processing, analysis of the by-product is highly recommended before it can be fed to chickens and also farmers must be informed about the processing method applied.

5.2 RECOMMENDATIONS FOR FURTHER RESEARCH

The results of the study have shown that MOCM and wood ash are acceptable to chickens as feed ingredients. These non-conventional feed ingredients competed well with the more commonly used conventional feed ingredients included in poultry feeds.

As the MOCM is cheap and highly available in areas in close proximity of macadamia oil plants, this by-product has definite potential to reduce feed cost. More research is necessary to ensure the optimum utilisation of MOCM.

The results of the study have shown that wood ash can be an effective Ca supplement. However, these results need to be validated in subsequent trials using longer laying periods and the availability of the Ca in WA needs to be determined.

The importance of unconventional feed resources for family or rural poultry production depends on their availability in sufficient quantities for farm use, simple preparation and processing methods, knowledge of the potential nutritive value and (for comparison) the price and availability of conventional commercial feeds.

CHAPTER 6- REFERENCES

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