EVALUATION OF SORGHUM *(Sorghum bicolor)* AS A SUBSTITUTE FOR MAIZE IN THE DIET OF GROWING RABBITS (*Oryctolagus cuniculus*)

By

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A thesis submitted to the graduate school in partial fulfillment for the award of a degree of Master of Science in Animal Production (Animal Nutrition option)

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DECLARATION

I declare that this thesis is my original work and has not been previously presented in this or any other University for any degree.

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DEDICATION

This work is dedicated to my parents, wife and children, the rabbit industry and all people who may find this information useful.

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LIST OF ABBREVIATIONS

ADFI......... Average daily feed intake

ADG............ Average daily gain

ANOVA...... Analysis of variance

AOAC......... Association of Official Analytical Chemists

AshD......... Ash digestibility

CAB............ Commonwealth Agricultural Bureaux

CBS............ Central Bureau of Statistics

CE............... Catechin Equivalents

CF............... Crude fiber

CFD............ Crude fiber digestibility

CIMMYT...... Centro Internacional De Mejoramiento De Maiz y Trigo (International maize and wheat improvement center)

CP............ Crude protein

CPD............. Crude protein digestibility

DM.............. Dry matter

DMD......... Dry matter digestibility

DMI............. Dry matter intake

DMRT........ Duncan's Multiple Range Test

EDTA........... Ethylene diamine tetra acetic acid

EE............... Ether extract

EED........... Ether extract digestibility

Eryth..........	Erythrocytes
FAO..........	Food and Agriculture Organisation
FCE..........	Feed conversion efficiency
FCR..........	Feed conversion ratio
FI.............	Feed intake
GLM..........	General linear model
Hb............	Haemoglobin
IFPRI.........	International Food Policy Research Institute
Kcal..........	Kilocalories
KO %.........	Killing out percentage
Leuc..........	Leucocytes
MOA.........	Ministry of Agriculture
MOALD&M..	Ministry of Agriculture Livestock Development and Marketing
MOLD........	Ministry of Livestock Development
M&V.........	Mineral and vitamin
NFE..........	Nitrogen free extract
NFED.........	Nitrogen free extract digestibility
NRC..........	National Research Council
OM..........	Organic matter
OMD.........	Organic matter digestibility
PCV..........	Packed cell volume
R^2	Coefficient of determination

RCBD........ Randomised complete block design

SAS........... Statistical analysis systems

SBM.......... Soybean meal

SEM........... Standard error of the mean

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ABSTRACT

Two experiments were carried out at Tatton farm, Egerton University, between February and August 2000 to evaluate the suitability of sorghum as a substitute for maize in the diet of growing rabbits. In the first experiment, Thirty-six (36) young New Zealand white rabbits, aged five weeks, were used in a 3x2 factorial arrangement of treatments in a randomised complete block design (RCBD) experiment. Six different diets were formulated to contain one of the three grains (maize, white sorghum or brown sorghum) and one of the two levels of crude protein (16 or 18.5%). Weaning weight at 35 days of age was used as the blocking criterion. Results indicated that white sorghum was not significantly different ($P > 0.05$) from maize in any of the parameters considered (feed intake, weight gain, feed conversion efficiency, feed digestibility, as well as the blood parameters). Animals fed on diets containing brown sorghum had a lower average daily gain (ADG) and a poorer feed conversion efficiency (FCE) ($P < 0.01$) in comparison with those fed on diets containing maize or white sorghum. The 18.5% CP level gave a better FCE ($P < 0.05$) compared with the 16% CP level. However, increasing the level of CP did not improve the utilisation of any of the grains to any extent greater than it did for the other grains. In the second experiment, twenty five (25) New Zealand white rabbits of 35 days of age were used in a completely randomised design to evaluate the effect of substituting maize with varying levels of brown sorghum, in the diet, on the performance of growing rabbits. The control diet contained 40 g of maize per

100 g of diet. In the other four diets, this maize portion was substituted with brown sorghum at the rate of 25, 50, 75 and 100% respectively. Results indicated that the use of brown sorghum in these diets significantly ($P < 0.05$) depressed the average daily gain, feed conversion efficiency, crude protein digestibility, crude fiber digestibility, the level of packed cell volume, haemoglobin concentration, as well as the erythrocyte and leucocyte counts in the experimental animals. From the two experiments, it was concluded that white sorghum can effectively replace maize in the diet of growing rabbits. On the other hand, the use of brown sorghum in the diets of growing rabbits may depress their growth rate. This may be due to the high concentration of tannins in the brown sorghum.

CHAPTER 1

INTRODUCTION

1.1 The Background

High population growth in the sub-Saharan Africa has highlighted the urgent need for the development of agricultural production. A study by Winrock International Institute for Agricultural Development (1992) indicated that human population in sub-Saharan countries will grow 2.6 times reaching 1294 million by the year 2025. According to that study, this population growth will demand a 4% annual increase in the production of meat; a rate which is considered ambitious but feasible. Livestock production in sub-Saharan Africa, therefore, needs to be increased substantially if only to catch up with the growth in demand for meat by the increased population.

The Kenyan government has in the past formulated policy guidelines on food production [e.g. the Livestock Development Policy (MOLD, 1980) and the National Food Policy (Republic of Kenya, 1981)]. However, there is still need for the country to hold food security as a major priority since it is one of the countries with the highest population growth rates (CBS, 1994). The challenge, then, is how to continue increasing food production (animals and crops) in the face of an ever-decreasing per capita land size.

Rabbits are some of the overlooked animal resources. Yet, they have a very high potential for food production because of their high reproductive rate and their fast growth rate (Cheeke, 1987). The comparative efficiency with which rabbits turn feed material into protein-rich foods for human consumption (Sandford, 1986) is an added advantage. Although rabbit meat is not universally acceptable because of some taboos and religious beliefs, this meat is notable because of its high protein content, low cholesterol level and the ease of digestion which makes it particularly suitable for the young, old and the sick people. The initial investment required to start up a small-scale rabbit production enterprise, is quite low (Schiere, 1990) as their housing requirements are simple and feed requirements low as compared with e.g. ruminants (Cheeke, 1987). Consequently, even the poor families can afford to keep rabbits. They can also be kept by various groups of people in the society including children. For those with a desire for leaner meat with a lower cholesterol content, rabbit meat offers an attractive alternative to beef, chevon, mutton and pork.

One of the major factors limiting rabbit production in Kenya is the unavailability of feeds. The feeds that are normally fed to the rabbits in Kenya comprise mainly farm by-products and a variety of palatable weeds such as the black jack, gallant soldier, sow thistle etc (MOALD&M, 1992). Since there are no effective means of conservation that have been developed for these forages, there exists some periods of acute shortage every year (MOLD, 1983). In addition, the overall nutritional quality of forages, generally, fluctuates quite a lot in the course of the year (Church, 1991), such that the forages available during certain times of the year may be deficient nutritionally. These short falls, in quality and quantity, can be taken care of through the use of concentrates.

Livestock concentrates are based on maize and wheat (as well as their by-products), a condition that puts the livestock into direct competition with man for these cereals. In the past, Kenya has often been insufficient in the production of these two cereals and the scope of expansion for their production is limited (Republic of Kenya, 1997). This problem may be overcome through the use of alternative cereals such as sorghum.

1.2 objective

To investigate the suitability of sorghum (brown and white cultivars) as a substitute for maize in the diet of growing rabbits.

1.3 Justification

1) In Kenya, the traditional sources of animal protein (e.g. beef, pork, mutton, chevon and chicken) are fairly expensive and therefore, most people may not afford to eat meat as regularly as is required for good health. As a result, a cheaper source of protein such as the rabbit may be required.

2) The feeds that are normally utilized by rabbits have a seasonal distribution and cannot be relied upon during the dry seasons. At some stage of growth, also, their nutritional quality may not be adequate for any meaningful

animal production. In the above two situations, the use of concentrates may be recommended.

3) The production of maize and wheat in Kenya is not sufficient to cater for both human consumption and animal feed manufacturing and hence there is need to explore other alternatives. Kenya has a wide scope of expanding sorghum production and because most of the local people prefer maize to sorghum in their diets, sorghum may, consequently, be used as a substitute for maize in the manufacture of animal feeds (concentrates).

CHAPTER 2

LITERATURE REVIEW

2.1 The role of concentrates in rabbit feeding

Rabbits can utilise green crops and other vegetation (even more efficiently than other livestock) and produce meat of excellent quality (Sandford, 1986). However, as has already been noted in the previous section, the availability of these forages in tropical countries like Kenya can be a problem during the dry period. These forages also vary considerably; from very good nutrient sources such as lush young grasses and legumes, to very poor feeds such as straws, which may not be adequate to maintain an animal (Church, 1991).

It has been shown that the nutritional value of even the very poor roughages can be improved considerably by proper supplementation (Church, 1991). Supplementation has also been reported to be useful even for forages, which are apparently good feedstuffs for rabbits. In a study by Mutetikka (1987), rabbit pellets were used as supplements at three levels (low, medium, and high) on three forage diets (rhodes grass, sweet potato vines and dry maize leaves). The weekly weight gains increased as the level of supplementation increased.

Apart from the use of concentrates for supplementation purposes, they may also be used to bridge the gap during the dry period when forages are scarce. Concentrates are also advocated for large-scale producers where their use may be the only practicable option (Okerman, 1988). Thus, there are several situations where the concentrates are really essential.

2.2 Cereal production as a constraint to feed manufacturing in Kenya.

The manufacture of livestock feeds in the country, has in the past, been based upon cereal components (mainly maize) to provide the energy content of the ration (MOA, 1982). But the production of these cereals is occasionally not enough to cater even for human consumption alone. Maize is Kenya's most important staple crop, but its cultivation has stagnated around 1.4 million hectares, with limited scope for further expansion (Republic of Kenya, 1997). A survey conducted by Ottichito and Sinange (1991) revealed that the national average maize production was only 33 million bags. At a per capita maize consumption of 124 kg/year (CIMMYT, 1991), this amount of maize is only adequate for about 24 million people. As the Kenyan population is projected to reach 28 million by the year 2001 (Republic of Kenya, 1997), it implies that the amount of maize to feed the additional people will most likely have to be imported.

The production of wheat in Kenya is likewise inadequate. The country produces only about 3 million bags out of the 6 million bags required for local consumption (Republic of Kenya, 1997). Since the availability of high potential land in Kenya is already a constraint (Republic of Kenya, 1997), it seems unlikely that the output of maize and wheat can be increased fast enough to cater for both human consumption and the livestock feed industry.

2.3 Sorghum as an alternative livestock feed in Kenya

Lack of adequate cereal production has been cited as one of the problems hampering pig and poultry production in Kenya (Republic of Kenya, 1997). Whenever there is a shortage of either maize or wheat, whatever little that may be available, is reserved for human use so that little or none is available for the animals (MOA, 1982). In such situations, it is the upcoming industries such as that of rabbit production, which are likely to suffer the most.

In the past, the requirements for the livestock feed industry have been met when needed, by importation of maize. Importation licences for this purpose have been granted readily (MOA, 1982). To increase maize availability by importation is undesirable because of the cost, uncertainty of supply and political implications of relying on other countries. In addition, the desirability of allowing maize importation even when there could be some alternative feed resources such as sorghum, for which the farmers cannot find a competitive market, is indeed questionable.

2.3.1 Sorghum production in Kenya

Sorghum is well adapted for growing in semi-arid conditions (Dogget, 1988). The arid and semi-arid areas make up 80 percent of Kenya's total land surface (Republic of Kenya, 1997). By virtue of the very vast nature of these regions, Kenya has a tremendous scope of expanding sorghum production.

In an attempt to alleviate the ever recurring animal feed shortages, the Ministry of livestock development through the livestock development policy, has in the past, sought to work closely with the Ministry of agriculture, to develop sorghum (and other crops such as millet) specifically for use as animal feeds (MOLD, 1980). A sorghum and millet project was established in this country for this purpose. However, available statistics show a slow rate of growth in sorghum production. For instance, according to the FAO (1999), the area under sorghum in 1989 was 127,000 hectares and this increased to only 140,000 hectares in 1998. An earlier report (MOA, 1982) had cited lack of market as one of the problems hampering sorghum production in Kenya. According to that report, the production of sorghum in the country can be increased very quickly if an economic price and efficient marketing system for the crop is established. The report further added that such a marketing system would depend on the development of some suitable end uses for the sorghum. The report, therefore, recommended that plans be made to channel sorghum into commercial livestock feed as soon as sufficient quantities are available, in the hope that the increased use of sorghum in the manufacture of animal feeds might itself serve as a stimulus for more sorghum production in the country.

2.3.2 Composition of the sorghum grain

The composition of sorghum is close to that of maize, but is richer in cellulose, less rich in fats (CAB international, 1987) and very low in carotenes (Pond *et al.*, 1995). Lebas *et al.* (1986) have given the composition of sorghum grain relative to that of maize and wheat (Table 1).

Like in other cereals, carbohydrates, with the exception of hulls, are primarily starch with small amounts of sugars (Pond *et al.*, 1995). The starch granules of sorghum are similar to those of maize, and glucose appears to be the principle free sugar in sorghum.

Sorghum protein is deficient in lysine, and needs to be supplemented by a high protein feed containing a good level of lysine. Soybean meal, fishmeal, and meat and bone meal are possible supplements (Dogget, 1988). Protein content of sorghum grain (12%) is higher than that of maize (9.4%) (Table 1). It should, however, be assumed to be no more than 8% if grown in areas of the non-affluent world where fertilisers are not used on the sorghum grain crops (Dogget, 1988). Apart from lysine, threonine, is the other limiting amino acid in sorghum (Pond *et al.*, 1995).

Table 1: Composition of some cereal grains

	Dry matter (%)	Crude protein (%)	Ether extract (%)	Crude fibre (%)	Energy (Kcal/Kg)
Maize	87	9.4	4.3	2.1	3300
Sorghum	87	12.0	3.2	2.5	3200
Wheat	88	12.5	2.2	2.5	3100

Source: Lebas *et al.* (1986).

Phosphorus level has been found to be low in sorghum (Dogget, 1988). In addition, some of this phosphorus is in form of phytic acid that, therefore, renders some minerals (such as calcium, iron, and zinc) insoluble (Pond *et al.*, 1995). The highest concentration of phytic acid is in the germ (Hulse *et al.*, 1980).

In the diets of animals such as poultry and pigs, sorghum has also been observed to be deficient in some vitamins such as A, D, riboflavin, pantothenic acid, niacin, choline, and B_{12} (Dogget, 1988). Rabbits may be able to obtain vitamin-B complex from a combination of caecal digestion and caecotrophy, but the low levels of the other vitamins above, might affect the performance of the growing rabbits on sorghum diets if supplementation is not done.

Sorghum may also contain some tannins, the content of which varies considerably depending on the cultivar (CAB international, 1987). Okoh *et al.* (1982), analysed 16 improved varieties of sorghum in Nigeria, and found considerable variations in tannin levels. According to CAB international (1987), the tannin content varies between 0.2 – 3.0%. However, Chubb (1983) has reported tannin contents as high as 5% in certain strains of sorghum, while Mukuru *et al.* (1992) found sorghum with tannin content as high as 7.35% catechin equivalents.

2.3.2.1 The effect of tannins on palatability and feed intake

High tannin levels are thought to affect the palatability of feed rations (Wall and Ross, 1970). The binding of food tannins to the salivary proteins and the epithelium of the mouth, makes the food unpalatable and depresses the voluntary intake (Makkar, 1993). According to Pond *et al.* (1995), some bird-resistant varieties whose seed coats are high in tannins are actually not well liked by most animals. Monogastric animals acclimatise to tannin-rich diets by increasing the size of their salivary glands and producing more salivary protein which in addition is especially rich in proline and consequently has a high affinity for tannins (Makkar, 1993).

Some experimental results tend to suggest that palatability of feeds, which contain condensed tannins, is actually not a major problem. According to one such experiments (Price and Butler, 1980), chicks and rats consumed more of the high-tannin grain than the low-tannin controls.

2.3.2.2 The effect of tannins on digestibility of feeds

Digestibility has been singled out as the principal problem with sorghum grains (Dogget, 1988). Sorghum tannins have a depressing effect on the digestibility of feeds (CAB international, 1987; Ravindran and Doraisamy, 1993). Kumar (1992) reported that tannins may form a less digestible complex (involving both hydrogen bonding as well as hydrophobic interactions) with dietary proteins and may also bind and inhibit endogenous proteins including the digestive enzymes. Several studies have, however, questioned this inhibitory theory, because of the apparent lack of free tannin available to bind digestive enzymes in the small intestines or caecum-colon (Foley and McArthur, 1994).

Precipitation of protein-tannin complexes generally depends upon the pH, ionic strength and the molecular size of the tannins. Protein precipitation and likewise the incorporation of tannin phenolics in the precipitate, increases with the increase in molecular size up to a molecular size of 5000 daltons (and above), when the tannins become insoluble and loose their protein precipitating capacity (Kumar, 1992). Price and Butler (1980) suggested other factors upon which the extent of inhibition of the digestive enzymes by the tannins would likely depend on. These include: 1) the amount of dietary protein (which can get bound in the place of the enzymes), 2) opportunity prior to ingestion for the tannin dietary complexes to form, 3) relative amounts of the various enzymes and the order in which they are encountered, and 4) the differing affinities between the tannin components and the various enzymes.

Sorghum grain with a high tannin content is less readily fermented by rumen micro-organisms and has a lower net energy and apparent CP digestibility for steers than the normal sorghum (Singh and Mehra, 1987). In caecotomized cocks, Elkin *et al.* (1996) found an overall inverse relationship between catechin equivalents and individual digestibilities of lysine, methionine, isoleucine, phenylalanine, histidine and arginine. For the rabbits, the digestibility of sorghum does not seem to be a major problem. Aitken and Wilson (1962) have given the digestible nutrients in sorghum and some other rabbit feeds (Table 2). From the table, it can be seen that sorghum compares well with maize in terms of energy, crude protein and crude fibre. However, it is not clear which cultivar of sorghum was used or even how the various cultivars compare to each other in terms of the digestible nutrients. It is also not clear as to what size or breed of the rabbits were used, or even their physiological condition. The question of sorghum cultivars is important because as mentioned earlier, different cultivars vary in their tannin content.

2.3.2.3 Effects of tannins on animal performance

There exists some considerable species differences in their sensitivity to antinutritive factors (Kumar, 1992). According to Price and Butler (1980), the extent of inhibition of digestive enzymes by tannins varies with species and as a result, there are considerable differences in the ability of different species to handle tannins. Animals such as the mule, deer, rats and mice, have been shown to secrete proline-rich proteins in saliva, which constitute the first line of defence against ingested tannins (Kumar, 1992). In ruminants, dietary condensed tannins (2 – 3%) have been shown to impart some beneficial effects because they reduce the wasteful protein degradation in the rumen by formation of a protein – tannin

Table 2: The digestible nutrients in some cereal grains for rabbits.

	CP (%)	Fat (%)	CF (%)	NFE (%)	Energy of digestible feed (Kcal/Kg
Maize	8.4	3.4	2.1	63.3	3660
Sorghum	8.7	2.7	1.9	68.0	3500
Wheat	7.5	1.3	0.6	68.5	3520

Source: Aitken and Wilson (1962)

complex which appears to dissociate post-ruminally at a low pH where presumably, the protein becomes available for digestion (Kumar, 1992).

In a certain experiment (Ford *et al.*, 1980), protein digestibility of a high tannin sorghum cultivar was found to be lower by 5% (chicken) or 3% (rat) than that of a low tannin cultivar. Elkin *et al.* (1990) showed that high-tannin sorghums decreased growth and feed efficiency in rats and chicken compared to low tannin diets but in contrast, ducks fed high-tannin sorghum-based diets had greater weight gain although the feed efficiency values were poorer than for those fed low tannin sorghums.

The extent of inhibition of digestive enzymes by tannins can also vary with the age of the animal (Price and Butler, 1980). Douglas and Sullivan (1993) reported that increasing tannin levels linearly decreased weight gain and increased FCR in 1 day – 4 week and 4 – 8 weeks old turkeys, but did not affect weight gain or FCR of turkeys 8 – 12 weeks old. It was suggested that the presumably more fully developed digestive processes of 8 week old turkeys were able to overcome the antinutritive effects of tannins.

Sorghum appears to be a viable source of animal feed (Ahmed, 1993). Feeding trials indicate that sorghum grains are worth somewhat less than corn (Pond *et al.*, 1995) but due to the varying levels of tannins between the various cultivars of sorghum, the performance obtained with sorghum based rations is also varied (CAB International, 1987). Jacob *et al.* (1996a) evaluated the feeding value of Kenyan sorghum for layers and found out that egg production and feed efficiency on sorghum based diets were lower compared to those of maize based diets (64.7% versus 70.9%). But in another study where Serena sorghum was substituted for maize in broiler starter diets (Jacob *et al.*, 1996b), the results obtained suggested that high tannin sorghum can be substituted for white maize in broiler starter diets with no significant adverse effects on growth or feed efficiency. According to Dogget (1988), high tannin grains have been found to be less efficient for poultry and pigs.

2.3.2.4 Utilisation of tannin-containing feed by rabbits

Condensed tannins in the black locust tree (*Robinia pseudoacacia*) reduce feed intake and growth rate of rabbits (Kumar, 1992). Digestibility of protein, fibre and energy were lower when the leaf meal of the same tree was fed to weanling rabbits compared to that of alfalfa meal (Cheeke, 1987). Sunflower leaf meal similarly gave poor results when used at a level of 40% in the diet of weanling rabbits as a replacement for alfalfa meal. Pronounced hair chewing was also noted in the animals fed the sunflower leaf meal diet, and this probably resulted from the induction of a protein deficiency by the tannins in sunflower leaves (Cheeke, 1987).

On the other hand, *Calliandra calothyrsus* (which also contains tannins) has, reportedly, been used as a rabbit feed in Australia with some apparently good results (Paterson *et al.*, 1996). It is, therefore, possible that the tannins could have a deleterious effect in one situation and not in another depending on circumstances that are not clear from the above examples. Feed factors such as the level of inclusion, level of crude protein, and other nutrients in the diet and animal factors such as age, previous exposure, weaning weight, level of development etc., could be the cause these differences. These factors deserve some investigation.

2.4 Sorghum as a rabbit feed

According to Seymour (1977) any kind of ground grain can be used in the diet of rabbits. Although sorghum has not been used extensively in rabbit feeds, it should presumably give adequate results (Cheeke, 1987). Church (1991) also supports the use of sorghum in the diets of rabbits. Giammatei (1976) has reported that among the grains liked most by rabbits, sorghum ranks the third after oats and the soft types of wheat. The Ministry of Livestock Development also recommends the use of sorghum meal (MOLD ,1986) and sorghum grain (MOALD&M, 1992) for rabbits.

It is however noted that in all the above cases, no specific recommendations have been made regarding the level of inclusion of sorghum in rabbit diets. Considering that sorghums vary considerably in their tannin as well as protein contents (Okoh *et al.*, 1982), it can be expected that animal performance on the various sorghum cultivars might likewise differ. No such studies have been reported on rabbits.

2.5 Conclusions

1) There is need to promote rabbit production in Kenya because it can provide a cheap source of high quality protein and can also add to the family's income.

2) The feedstuffs currently used for feeding rabbits in the country are not sufficient because of recurrent shortages in the dry season, and fluctuation in nutritional quality. These therefore require supplementation with concentrates. There is also need for forage conservation.

3) In commercial rabbit production, the scale of production necessitates the use of cheaper concentrates.

4) Maize and wheat production in the country are not sufficient to cater for human consumption and leave a surplus for animal feed manufacture. Where surpluses are available, priority is likely to be given to the more established enterprises such as poultry and pigs. There is therefore a need to try the less competitive feed resources such as sorghum in the rations of rabbits.

5) Where feed trials have been done on species such as poultry and pigs, various inconsistencies have been reported. Furthermore, the rabbit has a peculiar digestive system viz. caecal fermentation and caecotrophy, and therefore the results from the other monogastric animals (pigs and poultry) may not apply for the rabbits. There is therefore need for rabbit feeding trials.

CHAPTER 3

MATERIALS AND METHODS

This study was carried out on Tatton farm in Egerton University. The farm is in Nakuru district located in the Great Rift Valley region of Kenya. The altitude of the farm is approximately 2,250 m above sea level. The area falls within the sub-humid tropical climate (Larkin, 1972) with a moisture index of 10-30, and a temperature range 10^0C (minimum) to 25^0C (maximum) (Republic of Kenya, 1994). The farm has an annual rainfall ranging from 658.9 to 1434.6 mm (mean = 1011.1 mm).

3.1 Experiment 1: The effect of protein level, grain type and weaning weight on the performance of growing rabbits.

3.1.1 Experimental diets

Six experimental diets were formulated to contain either 1) maize, 2) white sorghum, or 3) brown sorghum and one of two crude protein levels (16% or 18.5%). The brown sorghum was purchased from Ahero market (Kisumu district) while the white sorghum was bought from the Nakuru municipal market. The tannin contents of the grains were 0.05, 0.52 and 5.6 % Catechin Equivalents (CE) for maize, white sorghum and brown sorghum respectively, as determined by the Vannilin-Catechin method (Gupta *et al.*,1992).

The experimental diets were balanced for minerals, crude fibre and vitamins using the ingredients shown in Table 3. The proximate composition of the diets (Table 4) was determined using standard AOAC (1995) methods.

3.1.2 Animals and experimental design

Twelve (12) does were mated on the same day. After parturition the kindlings were left to suckle for 5 weeks after which they were given identification numbers (ear notching) and then sorted out into six groups (blocks) of six animals each, based on liveweight. The thirty-six (36) New Zealand White rabbits were used in a randomised complete block design experiment with a 3x2 factorial arrangement. Each of the six rabbits from each of the six groups was then randomly allocated to one of the six treatments. The identification numbers were used to ensure that kindlings from the same doe did not all end up in the same treatment. The layout of this experiment as well as the respective live weights (in grammes) of the experimental animals is presented in Table 5.

3.1.3 Experimental period

The experiment was conducted between March and May of year 2000. The experimental period comprised a one-week preliminary period followed by six weeks of data collection.

Table 3: The ingredient (% of diet) composition of the experimental diets.

Ingredient	Diet					
	1	2	3	4	5	6
Maize	35.70	35.28	-	-	-	-
White sorghum	-	-	34.51	35.91	-	-
Brown sorghum	-	-	-	-	35.29	35.28
SBM[1]	8.72	8.59	8.43	8.78	8.59	8.59
Fish meal	11.05	14.61	10.14	14.93	10.31	14.61
Lucerne	10.49	12.55	10.14	12.83	10.31	12.55
Maize cobs	30.45	26.51	33.31	25.01	32.01	26.51
Corn oil	1.06	-	1.02	-	1.03	-
Molasses	2.11	2.06	2.04	2.12	2.06	2.06
M&V premix[2]	0.12	0.12	0.11	0.12	0.12	0.12
Salt (NaCl)	0.29	0.28	0.28	0.29	0.29	0.29
Total	100.00	100.00	100.00	100.00	100.00	100.00

[1]SBM = Soy bean meal
[2]M&V premix = Mineral and vitamin premix

Table 4: The proximate composition (%) of the experimental diets.

Nutrient	Diet					
	1	2	3	4	5	6
DM	91.67	91.81	91.90	91.89	92.01	91.85
CP*	16.02	18.51	16.05	18.53	15.99	18.50
EE*	3.81	3.74	3.86	3.65	4.03	3.71
CF*	12.32	12.78	12.85	12.59	12.79	12.40
Ash*	7.04	8.53	7.06	8.35	7.42	8.46
NFE*	60.81	56.44	60.18	56.88	59.77	56.93
Calculated tannin content (% CE)	0.018	0.018	0.179	0.179	1.976	1.976

* Values expressed as percentage of the dry matter.

Table 5: The layout of experiment 1.

Grain type		Maize		White sorghum		Brown sorghum		
Dietary protein		16%	18.5%	16%	18.5%	16%	18.5%	
Diet		1	2	3	4	5	6	Block average (g)
	1	550[1]	525	550	550	550	575	550.00
	2	525	525	525	500	500	500	512.50
Block	3	500	475	450	450	500	450	470.83
	4	425	450	400	425	450	425	429.17
	5	375	375	375	375	375	375	375.00
	6	250	325	250	350	300	275	291.67
Treatment average (g)		437.5	445.8	425.0	441.7	445.8	433.3	

[1]These numbers refer to the initial weights (g) of the individual rabbits.

3.1.4 Management

The experimental animals were housed individually in hanging wire cages (75X30X45 cm) providing a floor area of 2,250 cm^2 per rabbit. The cages were suspended 1m above the concrete floor.

Food and drinking water were provided *ad libitum* to each rabbit. These were put into separate metallic containers that were fastened to the cages to minimise wastage. Water was changed every other day.

3.1.5 Measurements and chemical analysis

The measurement of the various variables was carried out as follows:

1) Animals were weighed individually at the start of the experiment and thereafter on a weekly basis during the experimental period. Weighing was done using a pan-scale of a 5-kg capacity and graduations of 25 g. The total weight gain was computed as the difference between the final and the initial weight, while the average daily gain (ADG) was calculated as the total weight gain divided by the number of experimental days

2) The amount of feed offered as well as the amount of feed leftovers were weighed and recorded for each animal on a weekly basis. The average feed intake was calculated as the total amount of feed consumed divided by the number of days in the experimental period.

3) Faeces were collected from individual animals on a daily basis for five consecutive days during the last week of the experiment, dried in an oven at 60^0C

and stored in sealed polythene bags. Later on, these were analysed for the different nutrients using the same method used for the diets (AOAC, 1995).

4) Blood was collected from the ear veins into individually marked vials using 3 drops of EDTA (in each vial) as an anticoagulant. The total volume of blood collected from each rabbit was 2 ml. Analysis for the various variables (erythrocytes, leucocytes, haemoglobin and packed cell volume) were done within the next 24 hours following the collection of the blood. The counting of the red and white blood cells was done under a light microscope and magnification of 40. The packed cell volume was measured by first centrifuging the blood for five minutes at 12,000 revolutions per minute in a micro-haematocrit centrifuge, and then a Hawksley micro-haematocrit reader was used to measure the percentage of the packed cells. The concentration of haemoglobin was measured using a haemometer.

5) The weather changes (temperature, relative humidity and rainfall) were taken on a daily basis as recorded at the University weather recording station, which is located about 100 M from the experimental house.

6) Feed conversion efficiency was computed as the amount of feed consumed divided by the amount of weight gained during the experimental period.

7) The calculated tannin content of the diet was obtained by multiplying the quantity of the grain used in a particular diet with the respective percent concentration of tannins in the grain (e.g. 35.7 x 0.05% for diet 1)

3.1.6 Statistical analysis

The data obtained above was subjected to analysis of variance using the GLM procedure of the SAS programme (SAS, 1996). Whenever the F-test was significant at $\alpha = 0.05$, means were separated using the Duncan's multiple range test.

The model of analysis was: $Y_{ijk} = \mu+\alpha_i+\beta_j+\lambda_k+\beta\lambda_{jk}+\varepsilon_{ijk}$

Where Y = observation, μ = Population mean, α= block (weaning weight), β = grain type, λ = protein level, $\beta\lambda$ –grain type x protein level interaction, and ε =the residual error.

3.2 Experiment 2: The effect of substituting maize with varying levels of high-tannin sorghum, in the diet, on the performance of growing rabbits.

3.2.1 Experimental diets

Five experimental diets were compounded to contain 16% CP. The energy part in diet 1 was supplied by maize (40g/100g of diet) while in diet 2, 3, 4, and 5, maize was replaced by 25, 50, 75 and 100% high-tannin sorghum respectively. The ingredients used for experiment two diets are shown in Table 6 while the proximate composition of the diets is shown in Table 7. The crude protein

Table 6: The proportions of the ingredients used in the diets in experiment 2.

	Diet				
Ingredient (% of diet)	1	2	3	4	5
Maize	40	30	20	10	0
Brown sorghum	0	10	20	30	40
Fishmeal	20	20	20	20	20
Lucerne	28	28	28	28	28
Maize cobs	8	8	8	8	8
Molasses	2.7	2.7	2.7	2.7	2.7
M&V premix[1]	0.1	0.1	0.1	0.1	0.1
Salt (NaCl)	0.2	0.2	0.2	0.2	0.2
Corn oil	1.0	1.0	1.0	1.0	1.0
Total	100.0	100.0	100.0	100.0	100.0

[1]M&V premix = Mineral and vitamin premix

Table 7: The proximate composition of diets used in experiment 2.

	Diet				
	1	2	3	4	5
Proximate composition (%) (analysed values)					
DM	86.81	87.01	87.62	87.71	86.61
CP*	16.11	16.01	16.16	16.17	16.09
EE*	8.92	6.93	6.82	6.58	5.43
CF*	12.75	12.95	13.02	12.67	12.56
Ash*	10.95	8.96	9.59	8.93	9.52
NFE*	51.27	55.15	54.41	55.65	56.40
Calculated tannin content (% CE)	0.02	0.496	0.972	1.448	1.924

* Values expressed as a percentage of the dry matter.

content of the sorghum used in this experiment was similar to that of maize. The five diets were therefore similar in their proximate composition but differed in the proportions of brown sorghum, which ranged between 0 and 40% of the total diet, replacing 0 to 100% of the maize in the diet. The tannin contents of maize and brown sorghum were 0.05 and 4.81% CE, respectively.

3.2.2 Animals and experimental design

New Zealand white rabbits were generated as in experiment 1 and weaned at the age of five weeks. Twenty-five of these rabbits were selected at random and put into a completely randomised design experiment. The layout of the experiment as well as the respective live weights of the experimental animals is presented in Table 8.

3.2.3 Experimental period

The experiment was conducted between July and August 2000. The experimental period comprised a one-week preliminary period followed by 5 weeks of data collection.

3.2.4 Management

The animals were housed as in experiment 1. Water and feed were similarly provided *ad libitum*.

Table 8: The layout of experiment 2

		Treatment				
		1	2	3	4	5
	1	450[1]	500	675	550	625
	2	650	575	550	725	600
Replicate	3	675	700	650	550	500
	4	625	550	550	450	600
	5	550	625	500	650	650
Treatment average(g)		590	590	585	585	595

[1]The numbers refer to the initial weights (g) of individual rabbits.

3.2.5 Measurements and computations

The measurements for the weather changes, feed intake and weight gain, analysis of feeds and faeces, and the computation of the feed conversion efficiency were carried out as in experiment 1. Similarly, blood collection and analysis was as in experiment 1 except that Potassium cyanide was used as the anticoagulant instead of EDTA.

At the end of the feeding trial, all animals were starved for 12 hours after which three animals were randomly selected from each treatment, weighed and then killed for the purpose of determining the dressing percentage and the relative weights of the internal organs. The head, legs, skin as well as the internal organs were removed. The internal organs as well as the remaining carcass were weighed separately and their weights expressed as a percentage of the liveweight of the particular animal.

3.2.6 Statistical analysis

The results obtained above were analysed in a similar manner to those of experiment 1. Separation of the means was similarly done as in experiment 1.The model of analysis in this case was as follows: $Y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$

Where Y = the observation, μ = population mean, α = effect of diet and ε = the residual error.

The data obtained in this experiment were also subjected to regression analysis (SAS, 1996). The model of analysis was as follows: $Y = \alpha + \beta X$, where α is the intercept and β is the coefficient of the regression.

The weather pattern during the second experiment was compared with that of the first experiment, using a two-sample t-test (Steel and Torrie, 1980).

CHAPTER 4

RESULTS

4.1 Experiment 1: The effect of protein level, grain type and weaning weight on the performance of growing rabbits.

4.1.1 Environmental conditions.

The results of the environmental conditions (temperature, rainfall and relative humidity) are presented in appendices 1 and 2. During the period when animals for experiment 1 were being reared, the area experienced only 2.8 mm of rainfall and an average relative humidity of 45.1%. The averages for the maximum and minimum temperatures were 26.5 and 10.0^{0}C respectively. During the experimental period, the area received a total of 65.8 mm of rainfall. The average relative humidity was 67.8% while the averages for the maximum and minimum temperatures were 25.3 and 10.4^{0}C respectively.

4.1.2 The effect of diet on the performance and blood parameters of rabbits and the digestibility of the diets.

The results of average daily feed intake (ADFI), ADG and FCE are given in Table 9. The ADFI of the rabbits was not significantly different ($P > 0.05$) between the different treatment groups. There were significant differences ($P < 0.05$) in ADG that were observed between animals receiving diets 2 (maize,

Table 9: The effect of diet on feed intake, weight gain and feed conversion efficiency.

	Diet						
	1	2	3	4	5	6	
Grain	maize		White sorghum		Brown sorghum		
Dietary CP (%)	16	18.5	16	18.5	16	18.5	SEM
Parameter							
ADFI (g)	81.6	79.7	79.6	87.2	81.2	74.0	4.67
ADG (g)	20.7^{abc}	21.5^{ab}	20.6^{abc}	23.4^{a}	16.7^{c}	17.4^{bc}	1.42
FCE	3.97^{bc}	3.73^{c}	3.86^{bc}	3.78^{bc}	4.89^{a}	4.40^{ab}	0.21

n =6 rabbits per treatment.

^{abc} means within a row with different superscripts are significantly different ($P < 0.05$).

18.5% CP) and 5 (brown sorghum, 16% CP), 4 (white sorghum, 18.5% CP) and 5, and also between 4 and 6 (brown sorghum, 18.5% CP). Feed conversion efficiency was found to be best in the animals taking diet 2 and poorest in the animals receiving diet 5. The animals taking diets based on brown sorghum had the poorest FCE. Significant differences in FCE ($P < 0.05$) were observed between animals taking diet 1 (maize, 16% CP) and 5, 2 and 5, 2 and 6, 3 (white sorghum, 16% CP) and 5, and 4 and 5.

Table 10 shows the results of the effect of the diet on nutrient digestibility. Significant differences ($P < 0.01$), in the digestibility of CP were observed between animals receiving diets 1 and 2, 2 and 3, 2 and 5, 3 and 4, 4 and 5 and 5 and 6. Diets 1, 3 and 5 that had a 16% level of crude protein had a significantly lower ($P < 0.01$) CP digestibility compared to diet 2 (maize, 18.5% crude protein). The digestibility of CP of the diets based on any of the grains (maize, white sorghum, brown sorghum) was significantly ($P < 0.05$) improved by raising the level of CP from 16 to 18.5%. No significant differences ($P > 0.05$), in the digestibility of the other nutrients, were observed between the animals.

The effect of diet on the various blood variables is presented in Table 11. Based on the Duncan's multiple range test, it was observed that the number of leucocytes in animals taking diet 2 was significantly higher ($P < 0.05$) compared with those taking diet 5. On ranking it emerged that animals receiving diets with a higher crude protein content (diets 2, 4 and 6), tended to have the highest

Table 10: The effect of diet on nutrient digestibility.

Digestibility (%)	Diet 1	2	3	4	5	6	SEM
DM	65.5	64.6	65.1	64.6	64.9	65.8	0.44
OM	66.5	66.1	66.4	66.1	66.2	67.1	0.47
CP	76.9^{bdc}	80.4^{a}	76.2^{dc}	79.4^{ab}	74.6^{d}	77.8^{abc}	0.98
EE	80.6	78.3	79.2	78.1	80.8	80.1	1.95
CF	26.4	24.8	26.9	25.4	25.4	25.6	2.15
Ash	53.5	49.7	49.7	49.8	51.3	52.3	2.31
NFE	71.8	71.1	72.3	70.9	72.6	72.8	0.77

n =6 measurements per treatment.

^{abcd} means within a row with different superscripts are significantly different ($P < 0.05$).

Table 11: Physiological parameters of the growing rabbits.

	Diet						
Parameter	1	2	3	4	5	6	SEM
Leucocytes (10^3/ml)	3.2^{ab}	4.6^{a}	3.3^{ab}	3.5^{ab}	2.5^{b}	3.3^{ab}	0.56
Erythrocytes (10^6/ml)	3.6	3.7	3.2	3.9	2.8	3.3	0.44
Haemoglobin concentration (g%)	9.3	10.7	10.2	10.3	8.6	9.4	1.1
PCV (%)	23.5	32.2	26.3	27.5	22.5	25.7	3.6

^{abc} means within a row with different superscripts are significantly different ($P < 0.05$).

leucocyte count although no statistical differences ($P > 0.05$) were observed. The other blood parameters (erythrocytes, PCV and haemoglobin level) followed a similar trend.

The results of the analysis of variance for the data in experiment 1 are summarised in Appendix 3 (P values given). The analysis of variance did not reveal any significant ($P > 0.05$) interaction between grain type and protein level. Based on weaning weight, grain type and protein level as sources of variation, there emerged some significant differences ($P < 0.05$) in some of the variables such as the ADG, FCE as well as the haemoglobin concentration. The digestibility of crude protein was significantly different ($P < 0.05$) between animals that were fed on different grains and also between animals that were on different protein levels. Since the analysis of variance did not reveal any significant interaction between grain type and protein level, the results that are shown in the sections that follow are those relating to the blocks (weaning weight) and then protein and grain type as independent factors.

4.1.3 The effect of varying the dietary crude protein level on the performance of growing rabbits

The effect of dietary crude protein level on feed intake, weight gain and feed conversion efficiency is shown in Table 12. Increasing the protein level from 16 to 18.5% did not affect the ADFI and ADG. However, rabbits receiving the higher crude protein level tended ($P < 0.05$) to have higher average daily gain

Table 12: The effect of protein level on feed intake, weight gain, feed conversion efficiency and the digestibility of feed components.

	Crude protein level		
Parameter	16%	18.5%	SEM
ADFI (g)	80.7	80.3	2.78
ADG (g)	19.4	20.8	0.72
FCE	4.2[a]	4.0[b]	0.08
DM intake*	647.8	638.5	26.53
Digestibility (%)			
DM	65.2	65.0	0.25
OM	66.4	66.4	0.26
CP	75.6[a]	78.9[b]	0.61
EE	80.2	78.8	1.15
CF	26.2	25.3	1.26
Ash	51.5	50.6	1.45
NFE	72.2	71.6	0.45

n = 18 observations per treatment.

[ab] means within a row with different superscripts are significantly different ($P < 0.05$).

* Dry matter intake during the digestibility trial (7days).

compared to those taking diets with lower protein concentration. Increasing the protein level improved the feed conversion efficiency significantly ($P < 0.05$) from 4.23 to 3.97.

Dry matter consumption during the digestibility trial as well as the digestibilities of the various feed components are also shown in Table 12. There was no statistical difference ($P > 0.05$) in dry matter intake at the two protein levels during the digestibility period. The digestibility of crude protein was higher ($P < 0.001$) for the animals receiving the higher (18.5%) protein level as compared to those on the lower (16%) CP level. All other parameters were not affected.

The effects of dietary protein level on some blood variables are shown in Appendix 4. Increasing the dietary protein level from 16 to 18.5% resulted into a relative but insignificant ($P > 0.05$) increase in the number of erythrocytes and leucocytes, haemoglobin concentration and the PCV of the blood. These increments were in the magnitude of 8.2, 14.0, 17.96 and 26.0% for the haemoglobin concentration, erythrocytes, PCV and the leucocytes respectively.

4.1.4 The effect of varying the grain types on the performance of growing rabbits

Table 13 presents the effect of grain type on the feed intake, weight gain, feed conversion efficiency and digestibility of the various feed components. Feed intake was similar ($P > 0.05$) for all the groups of animals regardless of the type of grain used in making the diet. However, results show that the white sorghum

Table 13: The effect of grain type on feed intake, weight gain, feed conversion efficiency and the digestibility of various feed components.

Parameter	Grain type			
	Maize	White sorghum	Brown sorghum	SEM
ADFI (g)	80.7	83.4	77.5	3.41
ADG (g)	21.1[a]	22.0[a]	17.0[b]	0.88
FCE	3.9[a]	3.8[a]	4.6[b]	0.10
DM intake* (g)	630.4	676.8	622.1	32.50
Digestibility (%)				
DM	65.0	64.9	65.4	0.31
OM	66.3	66.3	66.7	0.32
CP	78.6[a]	77.8[a]	75.2[b]	0.75
EE	79.4	78.7	80.4	1.41
CF	25.6	26.2	25.5	1.55
Ash	51.6	49.8	51.8	1.77
NFE	71.5	71.6	72.7	0.56

n = 12 observations per treatment.

* Dry matter intake during the digestibility trial (7 days).

[ab] means within a row with different superscripts are significantly different ($P < 0.05$).

was relatively more preferred to maize which was in turn more preferred to brown sorghum. Rabbits fed on brown sorghum diets added less weight ($P < 0.01$) compared with those on maize-based diets. Rabbits fed on the diets based on white sorghum were similar ($P > 0.05$) to those fed on maize-based diets. However, the diets based on white sorghum tended to give better weight gains than those based on maize. Feed conversion efficiency followed the same trend as that of weight gain with maize and white sorghum diets giving better ($P < 0.001$) feed conversion efficiency values than the brown sorghum diets.

Dry matter intake of the experimental animals during the digestibility period (Table 13) was similar ($P > 0.05$) for all regardless of the main source of energy. The digestibility values for the dry matter, organic matter, ether extract, crude fibre, nitrogen free extract and ash were also similar ($P > 0.05$) for the animals on the different grains. Regarding the digestibility of CP, diets based on brown sorghum were significantly inferior ($P < 0.01$) to the other types of grains. Maize and white sorghum diets gave similar values for crude protein digestibility. The effect of grain type on some blood variables (erythrocytes, leucocytes, haemoglobin concentration and the PCV) is presented in Appendix 4. Rabbits fed on brown sorghum diets tended to have some relatively lower values for all the blood variables considered although there were no significant differences ($P > 0.05$) observed between animals taking different grains. On the other hand, animals taking the maize-based diets had some relatively higher values than those taking diets based on white sorghum except for haemoglobin concentration.

4.1.5 The effect of weaning weight on the performance of growing rabbits

Table 14 shows the effects of weaning weight on feed intake, weight gain, feed conversion efficiency as well as feed digestibility. Weaning weight did not have any significant effect on post-weaning feed intake ($P > 0.05$) but affected both the feed conversion efficiency and the post-weaning weight gains ($P < 0.05$). The results indicate an inverse relationship between weaning weight and post-weaning weight gain, although significant differences were only observed between animals in blocks 1 and 5, and also between those in blocks 1 and 6. Animals of smaller weaning weights showed better weight gains than the animals that were heavier at weaning. At the end of the experiment, the lighter animals had almost caught up with the heavier ones. The relationship between weaning weight and the feed conversion efficiency was also an inverse one. As concerns the FCE, significant differences ($P < 0.05$) were observed between the animals in blocks 1, 2, 3, and 4 on one hand versus those in blocks 5 and 6 on the other.

The dry matter consumption during the digestibility period was not different ($P > 0.05$) between the animals with various weaning weights. Similarly, weaning weight did not have any significant influence ($P > 0.05$) on the digestibility of any of the feed components.

Data on the effect of weaning weight on various blood variables is presented in Appendix 4. Animals that had intermediate weights at weaning had a tendency of having lower values for the erythrocytes, leucocytes, haemoglobin concentration as well as the PCV.

Table 14: The effect of weaning weight on feed intake, post-weaning weight gain, feed conversion efficiency and digestibility of feed components.

Block	Weaning weight	ADFI	ADG	FCE	DMI	DMD	OMD	CPD	EED	CFD	AshD	NFED
1	550	77.9	17.8[a]	4.4[a]	641.4	64.3	65.6	77.1	78.6	25.5	50.3	70.7
2	512	79.9	18.2[ab]	4.5[a]	600.0	65.3	66.7	77.0	76.8	27.8	50.0	72.4
3	471	78.7	18.7[ab]	4.2[a]	603.9	65.5	66.9	76.8	80.0	28.1	51.0	72.2
4	429	87.7	21.5[ab]	4.2[a]	700.1	65.5	67.0	77.8	81.8	26.0	51.7	72.5
5	375	81.5	22.1[b]	3.7[b]	676.7	64.9	66.0	77.4	80.2	24.1	51.9	71.6
6	292	77.4	22.1[b]	3.5[b]	636.0	65.0	66.2	77.3	79.7	23.2	51.5	72.2
SEM		4.82	1.29	0.14	45.96	0.44	0.45	1.06	2.00	2.17	2.51	0.79

[ab] means within a column with different superscripts are significantly different ($P < 0.05$).

4.2 Experiment 2: The effect of substituting maize with varying levels of high-tannin sorghum, in the diet, on the performance of growing rabbits.

4.2.1 Environmental conditions.

The results of the environmental conditions (temperature, humidity and rainfall) are presented in appendices 1 and 2. During the rearing period for experiment-2 animals, the area received 103.7 mm of rainfall while the average relative humidity was 81.6%. The averages for the maximum and minimum temperatures were 22.0 and 10.3^{0}C respectively. During the experimental period, the area received a total of 104.3 mm of rainfall while the average relative humidity was 83.5%. The averages for the maximum and minimum temperatures were 21.3 and 10.2^{0}C respectively.

A comparison between the rearing period for this group (experiment 2) and that of experiment 1, revealed some significant ($P < 0.01$) differences in the maximum temperatures and relative humidity values of the two periods. On the other hand, there was no significant difference ($P > 0.05$) in the minimum temperatures during the two periods.

4.2.2 Analysis of variance

The probability values obtained from the ANOVA are presented in Appendices 5 and 6. The results did not show any differences ($P > 0.05$) in feed intake. There were no differences ($P > 0.05$) in the digestion of DM, NFE, EE and ash, but there were some significant differences ($P < 0.05$) between the diets in the digestibility of OM, CP and the CF. As is shown in the later sections, there were also some differences ($P < 0.05$) in the erythrocyte and leucocyte counts as well as the PCV but the haemoglobin concentration was not significantly different ($P > 0.05$). The ADG, FCE and the killing out percentage of rabbits as well as the relative weights of their internal organs were similar ($P > 0.05$) for all the experimental groups.

4.2.2.1 Feed intake, weight gain and feed conversion efficiency.

The results on feed intake, weight gain and feed conversion efficiency are presented in Table 15. Although there was no statistical difference ($P > 0.05$) in the consumption of the experimental diets, the consumption of diet 1 by rabbits tended to be higher as compared with the other diets. The consumption of diet 2 was about 10% less than that of diet 1. The consumption of the sorghum-containing diets (diets 2, 3, 4 and 5) varied only slightly (0.25 to 4.0%). No definite trend emerged and some diets with high sorghum content were consumed more than those with less sorghum (diets 3 versus 4), while the reverse was also true (diets 4 versus 5).

Table 15: The effect of substitution of maize with brown sorghum on the feed intake, weight gain and feed conversion efficiency.

Parameter	Diet 1	2	3	4	5	SEM
ADFI (g)	94.68	85.74	82.40	82.98	82.79	5.20
ADG (g)	26.86	21.71	21.29	20.43	20.71	1.74
FCE	3.54	3.99	3.87	4.14	4.07	0.17

n = 5 observations per treatment.

means within a row are similar (P > 0.05).

The trends in the average daily weight gain of rabbits and feed conversion efficiency are also presented in Table 15. Although there were no significant differences between the diets, the ADG resulting from diet 1 was relatively higher compared to the other diets. The ADG values for the other (diets 2, 3, 4 and 5) were fairly close. Similarly, feed conversion efficiency was relatively poorer for the sorghum-containing diets as compared to the control although there were no statistical differences ($P > 0.05$).

4.2.2.2 Digestibility

From the data collected during the digestibility trial (Table 16), dry matter consumption by rabbits was the same ($P > 0.05$) for all the diets, but the digestibility of some feed components differed significantly ($P < 0.05$). The digestibility of the DM, EE, ash and NFE were similar ($P > 0.05$). The digestibility of organic matter in diets 2, 3 and 5 were comparable to those of the control diet ($P > 0.05$), but diet 4 was considerably inferior ($P < 0.05$). The digestibility of crude protein decreased systematically with the increase in amount of brown sorghum in the diet. However only diets 4 and 5 were significantly poorer ($P < 0.01$) as compared with the control diet.

Table 16: The effect of substituting maize with varying levels of sorghum, on diet digestibility.

	Diet					
Parameter	1	2	3	4	5	SEM
DM intake*(g)	655.8	563.9	540.3	531.9	584.2	47.11
Digestibility (%)						
DM	61.5	62.3	60.6	57.3	60.2	1.16
OM	65.0^{a}	64.7^{a}	63.2^{ab}	59.7^{b}	62.3^{ab}	1.11
CP	78.2^{a}	76.9^{a}	74.7^{ab}	71.6^{b}	71.3^{b}	1.27
EE	87.9	87.1	86.3	84.4	84.3	1.30
CF	29.9^{a}	21.5^{b}	20.5^{b}	16.8^{b}	20.7^{b}	2.09
Ash	37.4	42.1	39.6	36.1	39.1	2.98
NFE	65.7	69.6	68.2	64.0	68.4	1.90

* DM intake (5 days) during the week digestibility was carried out.

n = 5 observations per treatment.

^{ab} means within a row with different superscripts are significantly different ($P < 0.05$).

4.2.2.3 Blood, carcass characteristics and the relative weights of internal organs.

The effect of diet on the number of erythrocytes and leucocytes, haemoglobin concentration and the PCV are presented in Table 17. Inclusion of sorghum even at the lowest level of substitution (diet 2), significantly depressed ($P < 0.05$) the level of packed cell volume and the number of erythrocytes and leucocytes in the experimental animals, but variations amongst the sorghum-containing diets (diets 2, 3, 4 and 5) were insignificant. The haemoglobin concentration in the blood of the experimental animals decreased linearly as the level of sorghum in the diet increased although there were no statistical differences ($P > 0.05$) between any of the diets.

The dressing percentage and the relative weights of some internal organs are also shown in Table 17. These did not show any statistical differences ($P > 0.05$) among rabbits receiving the different diets. Similarly no specific trends became evident from these results.

4.2.3 Regression analysis

The results of regression analysis are tabulated in Appendices 7 to 10. These results indicate that there were significant ($P < 0.05$) linear relationships between tannin content on the one hand and the ADG, FCE and the digestibility of the OM, CP, EE and CF on the other. Likewise, there was a significant ($P < 0.05$) linear relationship between dietary tannins and the erythrocyte count, leucocyte count, PCV as well as the haemoglobin concentration. The coefficient

Table 17: The effect of substitution on some blood variables, carcass characteristics and the relative weights of internal organs .

Parameter	n[1]	Diet 1	2	3	4	5	SEM
Erythrocytes (10^6/ml)	5	5.57^a	4.42^b	4.30^b	4.31^b	4.34^b	0.289
Leucocytes (10^3/ml)	5	5.42^a	3.96^b	3.58^b	3.60^b	3.24^b	0.343
Haemoglobin concentration (g%)	5	11.80	10.56	10.04	9.72	9.08	0.625
Packed cell volume (%)	5	39.85^a	31.03^b	30.18^b	27.30^{bc}	22.21^c	2.222
Dressing percentage	3	51.69	50.97	50.44	51.14	51.61	1.391
Lungs*	3	0.60	0.77	0.64	0.64	0.72	0.080
Heart*	3	0.27	0.24	0.30	0.25	0.29	0.024
Liver*	3	3.86	3.81	3.91	3.78	3.36	0.222
Kidneys*	3	0.78	0.82	0.86	0.82	0.83	0.055
Stomach*	3	5.38	5.20	5.26	5.65	4.76	0.559
Caecum*	3	6.74	6.96	6.46	6.02	7.06	0.748

[abc] means within a row with different superscripts are significantly different ($P < 0.05$).

* Values expressed as a percentage of the liveweight.

n[1] = number of observations per treatment.

of determination values (R^2) for the above regressions are, however, relatively low (0.18 to 0.57). If x represents the tannin content of the diet, the equations describing the above relationships are as follows:

		R^2
1.	ADG = 26.27 – 1.36x	0.209
2.	FCE = 3.56 +0.12x	0.178
3.	% OM digestibility =66.05 –1.03x	0.247
4.	% CP digestibility = 66.05 – 1.03x	0.247
5.	% EE digestibility =89.02 –1.01x	0.227
6.	% CF digestibility = 28.82 –2.31x	0.295
7.	Erythrocyte count = 527820 –23740x	0.210
8.	Leucocyte count = 5376 –472x	0.422
9.	Haemoglobin concentration (%) = 12.18 –0.64x	0.356
10.	PCV (%) =41.82 – 3.90x	0.575

The linear relationship between dietary tannins and all the other variables under consideration (killing out percentage, the relative weights of internal organs as well as the digestibility of the dry matter, nitrogen free extract and ash), was not significant ($P > 0.05$).

CHAPTER 5

DISCUSSION

5.1: The experimental animals

At weaning (five weeks of age), the New Zealand white rabbits used in experiment 1 had an average weight of 438 g with a range of 250 – 550 g. Mtenga and Laswai (1994) reported similar weaning weights (434 –440 g) for crosses between New Zealand white, Californian and Chinchilla. However, most studies in which New Zealand white rabbits have been involved, have reported higher weaning weights than those obtained in the current study. Cheeke (1987) indicated that it is possible for New Zealand white rabbits to achieve a liveweight of 500 g at the age of 4 weeks.

The low weaning weights in this experiment are attributed to two factors. First, the environmental temperatures and secondly the type of feed. The rearing period was characterised by high ambient temperatures. According to Poole (1987) the desired range of temperature for rabbits is 15 to 20°C. In this experiment the average value for the maximum temperatures (26.5 °C) were rather high, a factor that could have negatively affected the feed consumption and hence the suckling ability of the does. Lebas *et al.* (1986) indicated that the number of solid meals eaten in 24 hours, declines systematically as the temperature rises between 5 and 30°C.

The type of feed used by the does during the rearing period was of a lower quality. The feed (chicken growers mash) had a crude protein content of 13.5%

while suckling does require a minimum crude protein content of 16% (NRC, 1977). Lebas (1987) reported that reducing the dietary level of crude protein from 16 to 13% can substantially reduce weaning weight in rabbits. The feed used in this study could, therefore, have led to the low weaning weights observed in experiment 1.

In experiment 1, the average weight (438 g) of the different treatment groups was similar ($P > 0.05$) and, therefore, weight did not affect the between-treatments comparisons (Table 5). The blocks however, were constituted such that each of them was significantly different from all the other blocks and this enabled the assessment of the effects of weaning weight upon the performance of the rabbits. The animals used in experiment 2 had a better average weaning weight (589 g at the age of five weeks) compared to those in experiment 1. This improvement was attributed to similar improvements on the weather pattern and also in the diets used on the suckling does. The maximum temperatures averaged at 22 °C which was significantly different ($P < 0.05$) from that experienced in experiment 1.

Findings from past research have shown that sex does not strongly influence the weaning weight (Alvarez *et al.*, 1974), the dry matter intake (De Blas *et al.*, 1981) and the blood composition (Jain, 1986) of rabbits. Similarly, unlike in most domestic livestock species, the sex effect does not strongly influence the weaning-to-market growth (De Blas *et al.*, 1981; McNitt and Lukefahr, 1993) as well as the carcass characteristics (Garcia *et al.*, 1993; McNitt and Lukefahr, 1993) in rabbits. Since the allocation of individual animals to the various treatments was done randomly (without regard to sex), it is assumed that the sex ratio was fairly similar in all the treatments. However, in some experiments, contrary findings have been obtained. In one such case, Pla and Cervera (1997), observed some significant sex differences between rabbits on the slaughter weight and dressing percentage. Because of the age at weaning and size of the rabbits at the beginning of the current study and also due to the precision required in the exercise, the animals used in both experiments were not sorted out according to sex.

Blood parameters reflect the internal environment of an animal. The parameters were taken in order to ascertain the health status of the experimental animals and influence of tannins. Jain (1986), compiled literature on the normal ranges of the various blood variables of rabbit blood. According to that literature the normal ranges are; $3.0X10^6 - 8.0X10^6$, $3.2X10^3 - 23.5X10^3$, 8.4 –15.5%, and 33.56 – 48.0% for the red blood cells, white blood cells, haemoglobin concentration and packed cell volume, respectively. The values obtained in the present study for the red blood cells and haemoglobin concentration are low but still within the normal ranges. On the other hand, the values for white blood cells and the packed cell volume were below the documented range. The method of blood collection and in particular the concentration of the anticoagulant could have contributed to these deviations. The blood exhibited a very high clotting tendency, prompting the use of a higher-than normal quantity of the anticoagulant. The clotting is likely to have affected the erythrocyte and leucocyte counts while the extra dilution could have slightly lowered the packed cell volume and the haemoglobin percentage.

5.2: Experimental diets.

The various ingredients used in both experiments, are recognised as feedstuffs for rabbits. However, where the use of sorghum has been alluded, no clear distinction has been made between the low and high tannin sorghums.

The proximate composition of the diets in both experiments compare favourably with the recommendations of NRC (1977). Experiment 1 was designed to study the effects of varying the type of grain (maize, white sorghum or brown sorghum), and the dietary protein level (16 or 18.5%), on the performance of growing rabbits. The levels of tannins and crude protein were assumed to be the only important differences between the various diets. Experiment 2 was designed to evaluate the effect of substituting maize with brown sorghum and the level of tannins was assumed to be the major cause of variation observed between the treatments.

Pelleting is known to improve the nutritive value of rabbit diets by 5 – 7% (Lebas, 1987). For some technical reasons diets used in the present study could not be pelleted and were, therefore, provided in a mash form. Although this might have affected the consumption of these diets, the effect was the same across the diets and this factor was not expected to have affected the between-treatment comparisons.

5.3 The effect of weaning weight on the performance of the growing rabbits.

5.3.1 Feed intake, weight gain and feed conversion efficiency

Weight gain and feed conversion efficiency improved linearly in rabbits with low weaning weights. This is contrary to the findings of De Blas *et al.* (1981) who found that animals of higher weaning weights also portrayed higher post-weaning average daily gains as well as higher liveweights at the age of 11 weeks.

The heritability for weaning weight in rabbits is estimated to be 0.45 (Alvarez *et al.*, 1974) implying that genetic and environmental factors have almost equal roles in the expression of this trait. In the present study it is apparent that the low differences in the weaning weights were more of an environmental effect (e.g. poor mothering ability of the dams, and differences in litter size) than a genetic one. The better feed conversion efficiencies and higher weight gains that were observed with the smaller animals could be a compensatory mechanism that is typical of other animals under similar circumstances.

Stomach capacity and the energy value of a feed are the factors most recognised in the determination of feed intake in animals. Rabbits continue to feed until either the maximum gut fill is reached, or their energy requirements are met, whichever comes first (Cheeke, 1987). Feed intake was not affected by weaning weight probably due to the fact that animals that had lower weights at weaning may have consumed almost the same amount of feed as the heavier ones to provide conditions for compensatory growth.

5.3.2 Nutrient digestibility

Like in other animals, digestibility of feed can be influenced by feed factors as well as some animal factors (Cheeke, 1987) particularly the age and health status of the animal (Lebas *et al.*, 1986; Cheeke, 1987). In the present study, weaning weight did not have any significant effect on the digestibility of any of the feed components and this could be so because all the animals were of the same age regardless of their weaning weights.

5.3.3 Blood composition

Since haemoglobin is a constituent part of the red blood cells, the trends of these two variables can be expected to be the same. Similarly, the trend seen in the packed cell volume is dependent on the red and white blood cells. The trends observed in this study are in full agreement with these facts.

Animals of the intermediate weaning weights tended to have the lowest levels for all the blood variables. This trend was consistently so for all the blood variables. However the trend cannot be explained from current set of data.

5.4 The effect of protein level on the performance of growing rabbits

5.4.1 Feed intake, weight gain and feed conversion efficiency

In this study, the level of protein in the diet did not affect feed intake and weight gain. This is in agreement with the findings of Taie and Zanaty (1993) but contrary to those of Reddy (1981), Ayyat (1994) and Jacob *et al.* (1992a). It is documented that rabbits can readily accept one batch of feed and still reject another batch of the same feed. This has been attributed to the presence of some yet unidentified factors that interfere with the palatability of rabbit feeds (Cheeke, 1987). In line with this, rabbits have been seen to have a preference for plant proteins over meat and fish meal (NRC, 1977). The change from a low protein to a high protein diet particularly if different sources of protein are used can, therefore, give misleading results about the feed intake. However, like in other non-ruminants, regulation of feed intake in rabbits is thought to be primarily controlled by the level of glucose in the blood (Cheeke, 1987). Within the scope of the current study, protein does not appear to be involved in the control of feed intake. These findings are, therefore, in agreement with the theory of glucose being the primary regulator of feed intake. Regarding the weight increase reported in other experiments, this could have resulted from increased intakes.

Increasing the dietary protein level resulted into a significant improvement in the feed conversion efficiency. Similar observations have been made on growing New Zealand white rabbits of 6 –12 weeks of age (Taie and Zanaty, 1993). As there was no significant interaction between grain type (tannin content) and protein level in this experiment, the observed improvement in FCE cannot be explained from the binding of tannins to the excess protein in the diet. One probable reason for this improvement could be that protein might be acting as the limiting nutrient when the dietary level of crude protein is set at 16%. From their work, Jacob *et al.* (1992a) concluded that the protein requirements for maximum growth of rabbits is greater than the 16% recommended by NRC (1977). Cheeke (1987) has also suggested that a crude protein level of 18% could be the ideal one for growing rabbits under the tropical conditions. The results from the current study also suggest that a 16% level of crude protein is not adequate for growing New Zealand rabbits.

5.4.2 Nutrient digestibility

Increasing the protein level from 16 to 18.5% significantly improved the digestibility of dietary crude protein. Similar findings have been reported by Jacob *et al.* (1992b) in an experiment where New Zealand white rabbits were fed on diets containing 12, 14, 16 or 18% crude protein. In that experiment, the digestibility of crude protein increased linearly with increasing dietary crude protein. However, in a similar experiment, De Blas *et al.* (1981) observed that this trend was dependent on the source of protein. After putting into account the fact that forages generally have a lower crude protein digestibility than animal sources, they failed to see any difference in digestibility of crude protein between the high and low protein diets. The major sources of protein in the diets of the current experiment were fishmeal, soybean meal and lucerne, but the high protein diets were proportionately richer in animal proteins compared to the low protein diets. This may partly account for the increase in digestibility when the dietary crude protein level increased from 16 to 18.5%.

According to De Blas *et al.* (1981), digestibility of crude protein for concentrate feeds can be as high as 78.6%. The crude protein digestibility values obtained in the current study (75.6 – 78.9%), are in agreement with this. This range is also close to the range (70.71 –75.88%) observed by Jacob *et al.* (1992b) with diets containing 12 – 18% crude proteins.

The digestibility of the other dietary components (DM, OM, EE, CF, ash and NFE) was not significantly different between the two protein levels. This is in accordance with the findings of Jacob *et al.* (1992b). In their experiment, Jacob *et al.* (1992b) obtained the digestibility values of 66.75, 68.97, 86.68 and 20.15 for the DM, OM, EE and CF, respectively. These values are comparable to those obtained in the present study.

5.4.3 Blood composition

All the blood variables considered in this experiment were consistently higher for the high protein diets compared with the low protein diets. This is consistent with the fact that protein is a requirement in the formation of blood as a major component of cells and also as a constituent of the haem portion of the haemoglobin molecule.

5.5 Effect of grain type on the performance of growing rabbits

5.5.1 Feed intake, weight gain and feed conversion efficiency

In experiment 1, the effect of grain type on feed consumption was not significant. This is in agreement with the findings obtained with other animals such as rats (Schaffert *et al.*, 1974; Price and Buttler, 1980) and chicken (Price and Buttler, 1980). However there were some minor differences between the grains, with the rabbits showing a relatively higher preference for the low-tannin grains (maize and white sorghum). Likewise, increasing the level of brown sorghum in the diets of experiment 2 did not have a marked effect on feed intake but the general trend was for the intake to decrease as the level of brown sorghum increased. This trend was only disrupted by diet 5, which appeared to be slightly better than diets 3 and 4, but perhaps this anomaly could not have arisen if the number of animals used in the experiment was large enough. The trend in experiment 2 can therefore be considered to be in agreement with that observed in experiment 1. This trend where the intake tends to decrease as the tannin content increases is consistent with the fact that tannins have an astringent taste (Nyachoti *et al.*, 1997), which could lower the consumption of feed.

The average daily feed intake values for experiments 1 and 2 are considerably low compared to the range of feed intake (110 – 130g) described by Lebas *et al.* (1986), but compares favourably with the 76.87g observed by Igwebuike *et al.*(1995), for a maize-based diet. The findings of the current experiment are also in agreement with the value (81.99g) obtained by Sundaram *et al.* (1997) under some tropical conditions. The large deviation of the values of this study compared to those of Lebas *et al.* (1986), could therefore be a reflection of the diversity of the conditions under which the two sets of values were obtained (temperate versus tropical).

In the first experiment, the average daily gain and feed conversion values for rabbits offered brown sorghum were shown to be considerably inferior to those of maize and white sorghum. In experiment 2, the inclusion of sorghum in the diet, also resulted into some relative drop in average daily gain. The better weight gains associated with maize and white sorghum can be attributed to their slightly better feed intakes and feed conversion efficiencies. The poor performance of the rabbits fed on brown sorghum could be as a result of the tannins present in sorghum grains. Douglas *et al.* (1993) reported that increasing the tannin level in the diets, linearly depressed the weight gains of turkeys and lowered their feed conversion efficiencies. Mukuru *et al.* (1992) demonstrated that treating high-tannin sorghum with wood ash slurry, reduced the assayable tannin content of high-tannin sorghum, and overcame the growth depression of dietary tannins in rats. Experiments conducted with other animal species such as rats (Schaffert *et al.*, 1974), pigs (Wahome *et al.*, 1992) and broilers (Mbugua *et al.*, 1995), have all highlighted the inferiority of brown sorghum on weight gain and feed conversion efficiencies of the respective animals.

The values for average daily gains achieved in both experiments 1 and 2, fairly conform to the range of 20 –25 g described by Cheeke (1987) as the typical range for tropical regions. These values are also considerably higher than the 10.15 g achieved by Bamgbose *et al.* (1997) or 14.36 reported by Olumeyan *et al.* (1996) for maize-based diets. How ever, the figures obtained in the present study are quite low as compared to the maximum recorded values (35 –40 g) although these may only be achievable under temperate conditions (Cheeke, 1987).

On feed conversion efficiency, Olumeyan *et al.* (1996), recorded a value of 3.45 for a maize-based diet, while Igwebuike *et al.* (1995), obtained a value of 7.8 on rabbit diet based on sorghum waste. The feed conversion values reported in the current experiment are therefore reasonable.

5.5.2 Nutrient digestibility

The digestibility of crude protein in both experiments 1 and 2 decreased linearly with increasing tannins in the diet. Similar trends have been observed in studies where rabbits were fed on feedstuffs such as black locust leaves (Ayers *et al.*, 1996) and grape pomace (Ferreira *et al.*, 1996), that also contain condensed tannins. Studies with other non-ruminant animal species such as chicken (Longstaff and McNab, 1991; Elkin *et al.*, 1996) and pigs (Jansman *et al.*, 1993 and Lizardo *et al.*, 1995) have also shown similar trends. It has been suggested that tannins are responsible for reducing the protein digestibility in the high-tannin sorghum cultivars (El Maki *et al.*, 1999)

The brown sorghum used in experiment 2, resulted in a significant decrease in the digestibility of CP and OM, as well as a general decrease in the digestibility of EE and NFE. This is similar to what was observed in pigs by Jansman *et al.* (1993). Studies involving various animal species have demonstrated that sorghum tannins are capable of interfering with the activities of enzymes such as trypsin (Jansman *et al.*, 1993, Lizardo *et al.*, 1995and Nguz *et al.*, 1998), gamma-glutamyl transferase (Lizardo *et al.*, 1995), chymotrypsin (Jansman *et al.*, 1993), lipase (Chubb, 1983) and alpha-amylase (Longstaff and McNab, 1991; Nguz *et al.*, 1998). In an experiment with young chicks, Longstaff and McNab (1991) observed that tannins inactivated trypsin the most, alpha-amylase to a lesser extent and lipase the least and, consequently, lowered the digestion of amino acids the most, starch to a lesser extent and lipid the least. In the current study, the different feed components were also affected to different levels perhaps because the enzymes were also affected to different extents.

Unlike the sorghum used in experiment 2 (tannin content of 4.81% CE), the brown sorghum that was used in experiment 1 did not affect the digestibility of any of the other feed components (apart from protein) despite having a higher level of tannins (5.6% CE). Such an anomaly has also been reported by Elkin *et al* (1996) in a study that involved feeding cockerels on a variety of sorghum cultivars. They found that some cultivars of similar tannin contents produced nutrient digestibilities that were markedly different, a finding that led them to conclude that the condensed tannins may only be partially responsible for the variations in nutrient digestibilities of sorghum.

5.5.3 Blood composition.

In the first experiment of the current study, all the blood variables tended to be lower for the diets containing brown sorghum as compared to those of maize or white sorghum. In agreement with this, the blood variables in the second experiment also decreased progressively as the level of brown sorghum in the diet increased. Nutrition is an important factor in blood formation. Nutritional anaemias are mainly as a result of low dietary levels of protein, vitamins and minerals (Jain, 1986). According to Makkar (1993), there is sufficient evidence that tannins decrease the utilisation of proteins, carbohydrates, amino acids, minerals and vitamins. This impaired metabolism could partly account for the lower levels of the various blood parameters when the brown sorghum was used in these experiments. Nyachoti *et al.* (1997) also reported that tannins have an influence on the bioavailability of iron leading to poor iron absorption in humans and other species. The tannins in the brown sorghum may, therefore, have adversely affected the blood formation in one way or another.

5.5.4 The dressing percentage and relative weights of some internal organs.

Diet is one of the factors known to influence the dressing percentage in rabbits (Fielding, 1991). In the current study, the dressing percentages ranged from 50.44 to 51.69 and were not significantly different between the various diets, implying that brown sorghum is as good as maize in that context. The dressing percentage of rabbits normally ranges from 50 to 56% (Fielding, 1991), and this is in full agreement with the current study.

The weights of various organs are of great importance in biological research (Rao *et al.*, 1977). To counteract different conditions, some organs may respond by becoming either hypo- or hyper-active (Nyachoti *et al*, 1997). According to Makkar (1993), some serious damage on the liver and kidneys, and degeneration of other organs can result from feeding animals on tannins.

The relative weights of all the liver, lungs, heart and kidneys that were observed in this study, are comparable to the 3.06, 0.72, 0.25 and 0.86% for the liver, lungs, heart and kidneys, respectively, obtained by Igwebuike *et al.* (1995) under a tropical environment. These results do not reveal any evidence of damage, or any differences between the diets. The level of tannins in the diets may not have been sufficient to provoke such changes. In addition, such a comparison of organs based on relative weight alone may not be sufficient to bring out all the differences that might be in existence.

5.6 Regression analysis.

Regression analysis is important in estimating the relationship between factors. In the current study, regression analysis revealed some negative linear relationships between dietary tannin content as the independent variable and the digestibility of CP, OM, EE and CF as the dependent variables. This is expected because as discussed earlier, tannins are capable of binding the various digestive enzymes and therefore lowering the digestibility of various nutrients.

Regression analysis also revealed some significant and negative linear relationships between tannin content and weight gain, erythrocyte and leucocyte count, haemoglobin concentration and packed cell volume. This can partly be explained by the digestibility reducing property of the tannins. As discussed earlier, tannins are also thought to interfere with the metabolism of various nutrients and this may, therefore, lead to the reduced growth as well as the reduction in the blood variables under consideration.

The coefficient of determination (R^2) value indicates the proportion of the total variation of the dependent variable that can be explained by its linear relationship with the independent variable. In the current study, the coefficient of determination values were rather low indicating a lack of good fit of the data on the respective regression lines.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1) Low-tannin sorghums can be used as a substitute for maize in the diets of growing rabbits. High-tannin sorghums on the other hand, cannot be used in the diets of growing rabbits without compromising their performance.

2) Within the range of crude protein used in this study, the use of a higher protein level does not counteract the effect of the tannins.

3) Increasing the protein level can improve body weight gain and the feed conversion efficiency of growing rabbits.

RECOMMENDATIONS

1) A thorough economic analysis may be required in order to establish whether it is worth using a protein level higher than the standard (16%).

2) There is need to establish the tolerance levels of the rabbits to tannins.

3) Future studies should include some more detailed analysis of blood as well as other tissues and organs.

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APPENDICES.

Appendix 1: Environmental conditions during the study period (Experiments 1 and 2).

Month	Temperature (°C)			Humidity	Rainfall
	Minimum	Maximum	Mean	(%)	(mm)
January	8.5	25.1	16.8	45	1.2
February	9.5	26.3	17.9	38	0.8
March	9.9	26.4	18.2	54	2.0
April	11.5	25.0	18.3	66	56.8
May	10.9	24.8	17.9	71	30.6
June	10.2	23.1	16.7	74	115.9
July	10.3	21.6	16.0	83	88.8
August	10.2	21.1	15.7	84	105.9

Appendix 2: Environmental conditions during the rearing period of experimental animals (experiments 1 and 2).

	Experiment1				Experiment 2			
	Temperature (^{0} c)			Humidity	Temperature (^{0} c)			Humidity
Day	Max.	Min.	Mean	(%)	Max.	Min.	Mean	(%)
1	26.1	11.5	18.8	50	23.1	12.0	17.6	69
2	26.0	10.0	18.0	18	22.4	9.7	16.1	78
3	26.5	11.2	18.9	59	22.5	11.5	17.0	78
4	26.2	10.0	18.1	18	22.0	8.7	15.4	79
5	26.3	11.2	18.8	36	22.5	8.8	15.7	74
6	25.0	10.0	17.5	45	22.5	8.7	15.6	53
7	26.5	12.5	19.5	30	22.5	8.6	15.6	69
8	25.5	6.0	15.8	28	24.2	10.8	17.5	84
9	26.0	8.0	17.0	27	22.8	11.0	16.9	84
10	26.5	9.0	17.8	29	21.5	12.1	16.8	80
11	27.0	8.5	17.8	32	22.1	14.0	18.1	89
12	27.1	8.9	18.0	32	21.0	12.4	16.7	94
13	26.3	9.0	17.7	38	19.8	11.5	15.7	78
14	27.0	10.0	18.5	47	21.9	10.2	16.1	84
15	27.8	11.0	19.4	42	21.5	9.4	15.5	89
16	27.7	10.0	18.9	48	22.1	11.1	16.6	89
17	26.0	10.3	18.2	48	21.5	8.7	15.1	83
18	25.5	11.0	18.3	65	21.2	9.7	15.5	84
19	24.4	7.8	16.1	46	21.0	8.2	14.6	83
20	27.1	10.0	18.6	54	21.8	9.8	15.8	84
21	25.0	10.0	17.5	62	21.7	11.0	16.4	89
22	26.0	10.0	18.0	48	22.0	10.4	16.2	83
23	27.7	10.2	19.0	48	20.5	11.5	16.0	89
24	27.7	10.0	18.9	54	21.9	9.4	15.7	79
25	26.6	10.4	18.5	54	23.5	10.5	17.0	79
26	26.8	10.4	18.6	50	20.5	10.3	15.4	84
27	27.0	10.9	19.0	54	22.3	12.2	17.3	89
28	27.0	11.0	19.0	50	20.8	10.2	15.5	88
29	27.0	9.5	18.3	52	19.6	8.8	14.2	88
30	28.0	10.0	19.0	49	21.2	10.5	15.9	79
31	27.2	10.2	18.7	52	23.2	10.4	16.8	84
32	27.0	11.5	19.3	56	23.2	9.9	16.6	78
33	27.0	10.1	18.6	52	23.2	11.5	17.4	84
34	25.5	9.3	17.4	52	22.3	9.3	15.8	79
35	26.7	9.4	18.1	54	23.0	9.3	16.2	78
Mean	26.5	10.0	18.3	45.1	22.0	10.3	16.2	81.6
SE	0.14	0.20	0.14	2.00	0.18	0.22	0.14	1.27

Appendix 3: The probability values of effects in the model (Experiment1).

Source of variation	DF	Pr > F													
		ADFI	ADG	FCE	DMD	OMD	CPD	EED	CFD	AshD	NFED	Leuc.	Eryth.	Hb.	PCV
Block	5	0.675	0.040	0.000	0.313	0.251	0.989	0.631	0.560	0.991	0.613	0.811	0.051	0.001	0.644
Grain type	2	0.476	0.001	0.000	0.547	0.624	0.009	0.678	0.940	0.673	0.256	0.276	0.282	0.253	0.585
Protein level	1	0.920	0.175	0.026	0.574	0.842	0.007	0.407	0.607	0.668	0.337	0.110	0.171	0.240	0.168
Grain X Protein interaction	2	0.321	0.647	0.353	0.124	0.265	0.984	0.912	0.894	0.591	0.577	0.600	0.665	0.726	0.589
Error	25														
Corrected total	35														

Appendix 4: The effect of protein level, grain type and weaning weight on some blood variables.

		Erythrocytes (10^6/ml)	Leucocytes (10^3/ml)	Haemoglobin concentration (g%)	Packed cell volume (%)
Protein level	16	3.21	2.99	9.36	24.11
	18.5	3.66	3.78	10.13	28.44
	SEM	0.22	0.34	0.45	2.16
Grain type	Maize	3.67	3.88	9.98	27.83
	White sorghum	3.56	3.38	10.27	26.92
	Brown sorghum	3.07	2.91	8.99	24.08
	SEM	0.27	0.42	0.57	2.64
Weaning weight	550	4.20	3.37	11.38	27.33
	512	3.49	3.05	9.53	27.50
	471	2.98	3.98	9.18	24.83
	429	2.46	2.88	6.48	21.67
	375	3.81	3.60	11.63	25.50
	292	3.68	3.43	10.27	30.83
	SEM	0.39	0.59	0.79	3.73

Appendix 5: The results indicating the p- values for experiment 2 - ADFI, ADG, FCE and nutrient digestibility.

Variable	ADFI	ADG	FCE	DMD	OMD	CPD	EED	CFD	AshD	NFED
F value	0.99	2.33	1.87	2.79	3.69	6.00	1.58	5.36	0.580	1.39
Pr > F	0.434	0.091	0.155	0.054	0.021	0.002	0.218	0.004	0.681	0.272
Significance	ns	ns	ns	ns	*	**	ns	**	ns	ns

* = significant P < 0.05

** = significant P < 0.01

ns = not significant

Appendix 6: ANOVA results - Blood composition, killing out percentage and relative weights of internal organs.

Variable	Eryth.	Leuc.	PCV	Hb.	KO%	Lungs	Heart	Liver	Kidneys	Stomach	Caecum
F value	3.07	6.22	8.40	2.68	0.13	0.75	1.32	1.02	0.32	0.34	0.31
Pr > F	0.040	0.002	0.000	0.061	0.966	0.579	0.328	0.442	0.860	0.845	0.864
Significance	*	**	***	ns	ns	ns	ns	ns	ns	ns	ns

*** = significant $P < 0.001$

Appendix 7: Regression analysis results - Weight gain, feed intake and feed conversion efficiency.

Variable	ADG		Feed intake		FCE	
Parameter	α	β	α	β	α	β
Parameter estimate	26.271	-1.357	3278.88	- 92.928	3.5585	0.1203
Standard error	1.829	0.551	184.034	55.488	0.1788	0.0539
Pr > F	0.0001	0.0218	0.0001	0.1075	0.0001	0.0356
R^2	0.2085		0.1087		0.1781	

Appendix 8: Regression analysis results - Digestibility of nutrients.

Variable	CPD		DMD		OMD		EED		CFD		AshD		NFED	
Parameter	α	β	α	β	α	β	α	β	α	β	α	β	α	β
Parameter estimate	66.0	- 1.0	62.8	- 0.8	66.1	- 1.0	89.0	- 1.0	28.8	- 2.3	39.6	- 0.3	67.3	- 0.03
Standard error	1.24	0.37	1.30	0.39	1.24	0.37	1.29	0.39	2.47	0.75	3.07	0.93	2.11	0.635
Pr > F	0.00	0.01	0.00	0.05	0.00	0.01	0.00	0.02	0.00	0.01	0.00	0.78	0.00	0.968
R^2	0.247		0.152		0.247		0.227		0.295		0.003		0.000	

Appendix 9: Regression analysis results - Killing out percentage and the relative weights of internal organs.

Variable	KO%		Lungs		Liver		Heart		Kidneys		Caecum	
Parameter	α	β	α	β	α	β	α	β	α	β	α	β
Parameter estimate	51.17	0.002	0.6377	0.017	4.061	- 0.105	0.2523	0.006	0.791	0.0103	6.7393	- 0.031
Standard error	1.313	0.3960	0.0833	0.0251	0.222	0.0670	0.0270	0.008	0.0525	0.0158	0.7295	0.220
Pr > F	0.000	0.9960	0.0001	0.6498	0.0001	0.1410	0.0001	0.499	0.0001	0.5251	0.0001	0.891
R^2	0.00000		0.0163		0.159		0.0358		0.0318		0.0015	

Appendix 10: Regression analysis results - Blood composition.

Variable	Erythrocytes		Leucocytes		Hb. concentration		PCV	
Parameter	α	β	α	β	α	β	α	β
Parameter estimate	527820	- 23740	5376.00	- 472.0	12.184	- 0.64	41.8184	- 3.9016
Standard error	31893.72	9616.32	381.813	115.121	0.5963	0.1798	2.3210	0.6998
Pr > F	0.0001	0.0214	0.0001	0.0004	0.0001	0.0017	0.0001	0.0001
R^2	0.2095		0.4223		0.3552		0.5747	