STUDIES ON THE NUTRITIVE EVALUATION OF PIGEON PEAS (*Cajanus Cajan*) AS A PROTEIN SUPPLEMENT IN BROILER STARTER FEEDS

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DECLARATION

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

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ABSTRACT

Studies were conducted to evaluate the nutritional quality and acceptability of pigeon peas (*Cajanus cajan*) as a protein supplement in chick feeds.

Raw pigeon peas were included in starter diets at levels of 0, 10, 15 and 20 percent of the diet. Feeding diets containing 10 or 15 percent raw pigeon peas to chicks from hatching up to five weeks produced no adverse effects on growth and feed efficiency. However, the inclusion of 20 percent pigeon peas reduced growth and feed efficiency by 8.50 and 8.25 percent respectively, thus indicating the presence of some nutritional limitations in the pigeon peas. There was a notable increase in the pancreas weight as the level of raw pigeon peas in the diets was increased, suggesting the presence of protease inhibitors in the pigeon peas.

In an attempt to overcome the effect of the protease inhibitors, the pigeon peas were subjected to wet thermal processing. The peas were autoclaved at 121°C, and 1.05 kg/cm^2 pressure for 15 or 30 minutes, or were steamed for 30 minutes. Feeding the raw or the variously heat-treated pigeon peas at the 20 percent level in chick diets produced no significant differences in growth rates, feed efficiency or pancreas size. This showed that the

protease inhibitors in pigeon peas were rather resistant to prolonged heat treatment and probably the inhibitor levels were not very high. However, the diet containing pigeon peas autoclaved for 15 minutes produced 5.45 and 7.62 percent improvements in growth rate and feed efficiency respectively, suggesting that moderate heat treatment of pigeon peas had some effect in improving their utilization.

In further efforts to improve the feeding value of pigeon peas, the 20 percent raw pigeon peas, and those autoclaved at 121°C, 1.05 kg/cm^2 pressure for 15 minutes were supplemented with 0.2% DL methionine or 0.2% DL methionine and 0.1% L tryptophan. Supplementing the diet containing raw pigeon peas with 0.2% DL methionine or 0.2% DL methionine and 0.1% L tryptophan did not result in any significant improvement in the performance of chicks. Therefore, the addition of the limiting amino acids to diets containing raw pigeon peas had no effect. Feeding diets containing autoclaved pigeon peas unsupplemented or supplemented with 0.2% DL methionine produced results similar to the diets containing raw pigeon peas supplemented with 0.2% DL methionine or 0.2% DL methionine and 0.1% L tryptohan. Addition of methionine alone to diets containing autoclaved pigeon peas showed no effect. Finally, the diets containing autoclaved pigeon peas and supplemented with 0.2% DL methionine and 0.1% L tryptophan resulted in 16.95 percent better growth rates than the diet containing raw pigeon peas unsupplemented, showing clearly that the amino acid supplementation was very effective after subjecting the pigeon peas to heat treatment.

From the results obtained, it appears that raw pigeon peas may not be included in starter rations at levels higher than 15 percent. Wet thermal processing alone was not able to significantly improve the feeding value of pigeon peas. Finally it was shown that both autoclaving the pigeon peas at $121^{o}C$, 1.05 kg/cm^2 pressure for 15 minutes and supplementing the diets with methionine and tryptophan were essential if levels of pigeon peas above 15 percent were to be included in chick feeds.

1. INTRODUCTION

There is a growing awareness that the protein deficiency problem is one of the most critical and difficult aspects of food and feed problems in both the human and animal sectors. If animal protein of adequate quality is to be provided in sufficient amounts to meet the needs of the world's expanding human population, animal nutritionists have to ensure that the nutrient requirements of the animals are met. Proteins of animal origin such as poultry meat and eggs provide a concentrated source of readily assimilable amino acids in suitable proportions for human needs. Poultry meat is one of the richest sources of proteins per unit of energy, and eggs in addition, furnish liberal amounts of vitamin A, riboflavin and iron. Therefore any contribution to increased poultry production would support endeavours to overcome the protein deficits.

The conventional protein feedstuffs are becoming increasingly in short supply for animal feed production. In the search for alternative protein sources, the food and grain legumes are offering many advantages in the form of a wide range of germ plasm of wide environmental adaptability with which to meet the protein needs of both the human and animal population. Food legumes can be described as potentially the most valuable and yet probably the least exploited of the naturally occurring sources of food protein. Of the 600 genera, with more than 13,000 species that comprise the family *Leguminosae*, only some 20 of the seed producing species are utilized popularly in appreciable quantities (Aykroyd and Doughty, 1964).

The easily cultivated and drought resistant pigeon pea (*Cajanus cajan*) is grown in both the tropics and sub-tropics and could go a long way in supplementing vegetable and animal protein in poultry rations. Among grain legumes, pigeon peas rank fifth in total world production. India is the leading world producer of pigeon peas. In Africa, Uganda and Malawi are the leading producers (FAO, 1972; Kay, 1979).

The potential of pigeon peas as a protein supplement has drawn much attention because its protein content is more than twice that of most cereal grains and its protein contains a much higher percentage of lysine than cereal protein. Although with the exception of soybeans and groundnuts, the average amount of protein in other grain legumes varies from 18 to 32 percent, there is considerable variation within each species. The amount of total protein in the pigeon peas normally ranges from 18 to 28 percent. However, there are reports of the protein content increasing up to 32 percent (Van Schaik, 1971).

As for the amino acid profile of pigeon peas, though adequate in lysine, they are deficient in tryptophan and the sulfur amino acids. Sulfur amino acid deficiencies are common to most grain legumes, but can be overcome by amino acid supplementation or by complementary compounding with feedstuffs having higher sulfur amino acid levels (Scott et al., 1969).

Pigeon peas, like other legumes, contain trypsin inhibitors which have been reported to affect their nutritive value when fed in raw form, and thus necessitation for some heat processing. However, the trypsin inhibitor levels in Cajanus cajan are not as high as in most other pulses (Liener, 1973).

While information regarding the chemical composition of pigeon peas are available in the literature, there appear to be a notable lack of research on the nutritive quality of these peas for poultry. Studies reported herein were conducted to assess and to improve the nutritional value of the pigeon pea meal as a supplementary protein source for chick starter diets. Varying levels of raw pigeon peas were included in broiler starter diets as a replacement for part of the soybean meal, in order to establish the optimum levels of inclusion which will not have any adverse effects on the performance of young birds. In an attempt to overcome the problems of trypsin inhibitors and amino acid deficiencies, which affect their nutritive value, the higher level of pigeon peas to be included in broiler starter diets were subjected to various methods of heat processing, and subsequently to both heat processing and supplementation with methionine and tryptophan.

2. LITERATURE REVIEW

2.1 Pigeon pea Production in the Tropics

Among the grain legumes, pigeon pea ranks fifth in total world production, after dry beans, dry peas, chick peas, and broad beans (FAO, 1972). However, Rachie, (1972) expressed the view that pigeon pea production is grossly underestimated because the crop is seldom grown in pure stands on a field scale and there is a fair amount of production at the subsistence level.

The geographical origin of the pigeon pea has been a subject of much discussion. Some authorities consider that it is of Indian origin. There is evidence, however, that it was cultivated in Egypt before 2000 B.C. and many authorities consider that it may have originated in the region between Egypt and East Africa and to have spread in Africa and in the South East Asian sub-continent in Prehistoric times. It is now widely grown between 30^{O}N and 30^{O}S (Sinha, 1977; Kay, 1979). Thus it has several local names such as Congo pea, Angola pea, Noeye pea, Red gram, Tur, Arhar, Gandul, and many others.

The reported principal world production occurs in India and Burma in South Asia, Uganda and Malawi in Africa and the Dominican Republic, Venezuela and Puerto Rico in Latin America, with India alone producing nearly 92 percent of the total world production (Litzernberger, 1974; Oracca-Tetteh, 1976; Kay, 1979).

Although world yields are low, averaging only about 600 kg/ha, yield records from experimental plantings indicate that the yield potential of pigeon peas is high. Yields in excess of 4000 kg/ha and 5000 kg/ha have been reported in Puerto-rico and India respectively. In Eastern Africa, yields averaging between 450-670 kg/ha have been reported, with the short duration types yielding up to 2000 kg/ha (Regional Pulse Improvement Project, 1968).

Cajanus is a monotypic genus of the tribe Phaseoleae, Order Leguminoseae, and suborder Papilionaceae (Pathak, 1970). Two varieties are recognized namely, Cajanus cajan variety flavus and Cajanus cajan variety bicolor. The former is early maturing, semi-dwarf in habit and has yellow flowers and green pods, usually with 2 or 3 seeds. The Tur cultivars of India are typical of the variety flavus. The latter, includes most of the truly perennial types; the plants are late maturing and tend to be larger, more bushy, with purple speckled yellow flowers and green pods, often blotched with dark red and containing 4 or 5 distinctly speckled seeds. The perennial types are more widely grown, but are often harvested as annual crops because yields decline steadily after the first crop (Smartt, 1976). However, the shorter duration cultivars appear to have a greater yield potential (Rachie and

Wurster, 1970). Innumerable hybrids have arisen by cross-pollination of the original varieties with the result that every possible gradation now exists (Kay, 1979). Numerous improved cultivars of pigeon peas have been developed, many of which have been selected to suit local environmental and climatic conditions.

Pigeon peas are grown over a wide range of conditions. They are grown on a wide range of soil types, from light red soils to heavy clay soils. They perform well on the alkaline and saline soils up to pH 8, while they also seem to be adapted to soil pH as low as 5.0. Pigeon peas are susceptible to frost damage. The most favourable temperature range is 18-29^{o}C. The average annual rainfall between 50-100 cm is most suitable. Early maturing varieties take 120 days to mature, while the late varieties require over 200 days (Sharma and Green, 1975; Kay, 1979).

2.2 Chemical composition of Pigeon peas

The chemical composition of pigeon peas, like other pulses, tends to vary with variety, growing location and time of sowing. In this section, a review of the pigeon peas chemical composition, and in particular protein content, is given as reported by different researchers.

2.2.1 Protein Content and Amino Acid Profile

Pigeon peas are moderate in both protein quantity and quality. According to Khan and Rachie (1972), pigeon peas contain between 20 and 28 percent protein. Ahmad and Shah (1975), reported a protein content of 25 percent. Akbar *et al*., (1973) reported 21.4 percent; while Singh (1973) reported 22.3 percent. Ramiah (1938) made a chemical study of five different varieties of Indian pigeon peas and reported protein contents varying from 21.44 to 23.64 percent. Mtenga and Sugiyama (1974) analysed pigeon peas grown in Tanzania and reported a protein content of 21.7 percent. Dahiya *et al*., (1976) studied the relationship between seed size and protein content in pigeon peas and found no significant correlation between seed weight and protein content. Oracca-Tetteh (1976) analysed pigeon peas grown in Ghana and reported protein contents ranging from 20-to 25 percent. On the average, the total protein in the seed varies from 18 to 24 percent (Sharma *et al*., 1975).

The chief protein of the pigeon pea is the globulin, Cajanin, which accounts for 58 percent of the total protein. Another globulin concajanin accounts for a further 8 percent (Johnson *et al*., 1964). Krishna *et al*.,(1977) reported 61 percent globulins in pigeon peas, and separated this percentage into three fractions; the alpha fraction, which was insoluble at pH 4.7; and the beta and gamma fractions which were soluble at pH 4.7. Further analysis of the amino acid composition of the different golublin fractions showed that the gamma fraction was comparatively rich in sulfur containing amino acids.

The amino acid content of legume grains depends on species, varieties, localities and management practices (Bressani, 1972). According to FAO (1970), pigeon peas have the following average amino acid composition (mg/100 g): lysine 1607; histidine 775; arginine 1015; threonine 608; serine 259; glycine 203; alanine 882; cystine 204; methionine 107; valine 751; iso-leucine 648; leucine 1316; tyrosine 421; phenylalanine 1727.

Like other grain legumes, the pigeon pea is deficient in the sulfur amino acids, cystine and methionine, and in tryptophan. According to Orr and Watt (1957), and Mtenga and Sugiyama (1974), tryptophan is more limiting than methionine. However, Bressani (1972), and Dako, (1966) reported that both methionine and tryptophan were equally limiting. More recent work by Ahmad and Shah (1975) also indicates that the sulfur containing amino acids and tryptophan are the most limiting in the pigeon pea. Methionine and tryptophan levels have been found to differ significantly among varieties (Singh et al., 1973), with the wider range occuring in the case of methionine. The analyses of fourteen genotypes of pigeon peas grown during two seasons indicated the following composition: Protein 19.76-23.63 percent; methionine 1.2-1.88 percent, and tryptophan 0.43-0.62 percent of protein.

2.2.2 Other Nutrient Components

Pigeon peas are reported to be fairly rich in carbohydrates. Ramiah and Satyanarayan (1938) reported carbohydrate contents ranging from 61.86 to 65.81 percent for five different varieties of Indian pigeon peas. According to Hulse (1975) pigeon pea carbohydrate content which consists mainly of starch is variously reported between 50 and 65 percent. Johnson and Raymond (1964) examined the sugars in pulses by circular paper chromatography and reported the following for the pigeon pea: 1.6 percent sucrose, 1.1 percent raffinose, 2.7 percent stachyose, and 4.1 percent verbascose.

The fat content in pigeon peas is very low. It appears to lie between 1 and 2 percent (Hulse, 1975; Ahmad and Shah, 1975). The fibre content in pigeon peas is more variable and lies between 2 and 9 percent (Oracca-Tetteh, 1976).

Pigeon peas contain modest amounts of vitamin A, approximately 150 I.U./100 g. The thiamine and riboflavin contents are approximately 0.5 mg/100 g and 0.15 mg/100 g respectively. The niacin content is reported between 1.5 and 2.5 mg/100 g (Hulse, 1975).

The ash content of pigeon peas is approximately 3 percent (Ahmad and Shah, 1975). Pigeon peas are a good source of iron (6-9 mg/100 g) and their calcium levels are comparatively high and usually five to ten times the levels in major cereal grains (Hulse, 1975). The calcium content is reported between 154-194 mg/100 g, while phosphorus content ranges between 238-372 mg/100 g (Kay, 1979).

2.3 The Feeding Value of Pigeon peas

The pigeon pea is used as a human food, livestock feed, and as a green manure crop (Aykroyd and Doughty, 1964). The pod, seed and leaves of pigeon peas form an excellent fodder for cattle. The pigeon pea is an important protein food in many tropical areas. In India, it is consumed locally in the form of a dhal or dehulled split pea. In Africa and Indonesia, the mature seeds are usually soaked for several hours before being pounded and fried, or steamed and eaten in the form of a puree. The fresh green seeds are a very popular vegetable particularly in the Caribbean area, where considerable quantities are processed. Srikantia (1973) describes experiments in which groups of children received 50% of their total protein from pigeon pea while another group received the same amount from milk. The growth of the children in the two groups was identical suggesting that the legume protein was a satisfactory replacement for milk.

Ground seeds can be incorporated as a source of protein in poultry rations (Gohl, 1975). Springhall et al., (1974) fed pigeon pea seed meal to chickens from hatching to six weeks, at levels between 5 and 40 percent of the total diet, as a replacement for part of the soybean meal in the control diet. Diets containing 5 to 30 percent pigeon peas resulted in body weights as good as those of control birds fed a starter diet based on maize and soy bean meal. Levels above 30 percent resulted in significant depressions in growth. They attributed the reduced weight gains to deficiency of one of three amino acids, cystine, tryptophan or phenylalanine.

Most of the research work regarding the nutritional evaluation of pigeon peas has been carried out using rats. Dako (1966) reported that cooking of pigeon peas improved their nutritional value by destroying the substances inhibiting trypsin activity; raw peas caused hyperactivity of the pancreas, diarrhoea and apathy. Addition of tryptophan or methionine, each alone, to raw or cooked peas had no effect on the protein efficiency ratio (PER), but the combination of the two amino acids improved the PER by about 100 percent.

Mtenga and Sugiyama, (1974) compared the protein quality of cow peas, groundnuts, kidney beans, pigeon peas and soybeans grown in Tanzania and they reported that soybeans showed the highest protein score followed by pigeon peas, kidney beans, cow peas and lastly groundnuts.

2.4 Antinutritional Factors in Pigeon peas and Other Pulses

A wide variety of antinutritional substances are found among the pulses. These include protease inhibitors, phytohemagglutinins, goitrogens, cyanogens, antivitamin factors, metal binding constituents, estrogenic factors, toxic amino acids, lathyrogens, favogens and unidentified growth inhibitors (Liener, 1973). Despite this rather extensive list, pulses have been used for food for thousands of years. Fortunately, cooking inactivates some of the antinutritional factors, while others being present mostly at small concentrations are not as deleterious in a varied diet. In this section, evidence will be provided covering mainly the occurence, and the nutritional and physiological significance of protease inhibitors, and in particular trypsin inhibitors which are the most widely distributed antinutritional factors in pulses. Other antinutritional factors which occur in pigeon peas are also reviewed briefly.

2.4.1 Protease Inhibitors

Substances which have the ability to inhibit the proteolytic activity of certain enzymes are found throughout the plant kingdom, particularly among the legumes (Liener, 1969). Read and Haas (1938) appear to have been the first to recognize the presence of an inhibitor of trypsin in plant material. A trypsin inhibitor from soybean protein was isolated in crystalline form by Kunitz (1945, 1946). The presence of an inhibitor of trypsin in soybeans which could be inactivated by heat seemed to offer, at the time a reasonable explanation for the observation made many years before by Osborne and Mendel (1917) that heat treatment improved the nutritive value of soybean proteins. Trypsin inhibitors have also been found in a large number of other legumes including the peanut, navy bean, lima bean, chick pea, pigeon pea etc., in fact all legumes which have been examined to date have been found to contain trypsin inhibitors to varying degrees (Liener and Kakade, 1969). Most of the protease inhibitors have been found in the seeds of various plants, but are not necessarily restricted to this part of the plant.

The presence of a trypsin inhibitor in pigeon peas was first reported by Sohonie and Bhandarkar (1955) and subsequently purified by Tawde (1961). The minimum molecular weight of this inhibitor is about 15,660 which places it intermediate in size between the trypsin inhibitors of Lima beans (8000-10,000) and the Kunitz soybean inhibitor (21,500). Tawde (1961) showed that 1 ug of the pigeon pea trypsin inhibitor inhibited 1 ug of the trypsin enzyme. The trypsin inhibitor content of Cajanus cajan is much lower than that of Phaseolus vulgaris. Pigeon peas were reported to contain 418 TIU/ml, while black beans and kidney beans contained 2050 TIU/ml and 1,552 TIU/ml respectively (Liener, 1973).

Studies of Kunitz (1947) and Green (1957) had shown that the combination of the Kunitz soybean inhibitor with trypsin was accompanied by a decrease in the sum of the free amino acids, thus suggesting that the interaction had occurred through ionic groups.

Effects of trypsin inhibitors are difficult to explain due to interference of other effects such as toxic factors - hemagglutinins and goitrogens, and additionally by animal factors, experimental procedures and their evaluation as presented by different workers. However, there seems to be little doubt that hypertrophy of the pancreas represents one of the physiological effects produced by feeding raw soybeans or the isolated inhibitor to rats and chicks (Chernick et al., 1948; Booth et al., 1960; Alumot and Nitsan, 1961; Nesheim et al., 1962; Rackis, 1974). Booth et al., (1960) were of the opinion that pancreatic hypertrophy leads to an excessive loss of endogenous protein secreted by the pancreas. Since this protein, consisting largely of pancreatic enzymes, is quite rich in cystine, the resulting effect is a net loss of sulfur containing amino acids from the body. This would explain the need for methionine, which is inherently limiting in soybean protein, is rendered even more acute in diets containing raw soybeans. Evidence has recently been presented to indicate that trypsin or chymotrypsin in the intestine suppresses pancreatic enzyme secretion by feedback inhibition, and that trypsin inhibitors evoke increased enzyme secretion by counteracting the suppression produced by trypsin (Green and Lyman 1972; Neiss *et al.*, 1972). *In vitro* studies have shown that the trypsin inhibitor does not specifically retard the enzymatic release of methionine but appears to affect all the amino acids to approximately the same extent (Riesen *et al.*, 1947; Ingram *et al.*, 1949; Hou *et al.*, 1949). Goldberg and Guggenheim (1962) observed that several amino acids, including lysine, tryptophan, as well as methionine, were more slowly absorbed from the gut in the case of rats receiving raw soybeans versus those fed the heated product. Lyman and Lepkovsky (1957) suggested that the growth depression caused by the trypsin inhibitor may be the result of the endogenous loss of essential amino acids derived from a hyperactive pancreas which is responding in a compensatory fashion to the effects of the trypsin inhibitor. In the chick much of this endogenous nitrogen and sulfur probably ends up in the faeces as evidenced by the faeces from chicks fed raw soybeans is almost entirely of pancreatic origin (Lepkovsky *et al.*, 1959). In the young chicken, the hypertrophic response of the pancreas is delayed (Nitsan and Alumot, 1964) so that the amount of trypsin produced by the pancreas is not sufficient to counteract the trypsin inhibitor (trypsin inhibitor levels higher than trypsin) and an inhibition of the intestinal proteolysis results. Pancreatic hypertrophy has not only been observed on feeding raw soybeans but also other legumes such as kidney beans (Wagh *et al.*, 1965), navy beans (Kakade *et al.*, 1967), as well as pigeon peas (Dako, 1966).

Histological and biochemical examination of the enlarged pancreas reveals true hyperplasia, which is characterized by an increase in the number of cells in the pancreatic tissue (Applegarth et al., 1964; Kakade et al., 1967), but which at the same time provides evidence that the zymogen granules have been depleted (Applegarth et al., 1964). Konijn and Guggenheim (1967), however, believe that pancreatic enlargement is the result of an increase in cell size rather than the number of cells.

2.4.2 Other Antinutritional Factors in Pigeon peas

Apart from having trypsin inhibitors, pigeon peas contain significant levels of phytin and polyphenols (often described as tannins). Sundarajan (1937), using a colorimetric method, found 200.3 mg/100 g of phytin-phosphorus present in pigeon peas, of which 75.89 percent was phytin. There is no available literature as regards the effect of pigeon pea phytates in animals. However, Hulse, (1975) pointed out that the phytin levels in pigeon pea may be sufficiently high to interfere with iron, magnesium and zinc absorption. Phytic acid premixed with casein decreased the availability of zinc for the growth of chicks compared to untreated casein (O'Dell and Savage, 1960; O'Dell, et al., 1964). The soybean protein from which phytic acid had been removed was no longer capable of binding zinc in vitro (Allred et al., 1964). It would appear that the specific metal binding constituent of soybean protein is phytic acid of which isolated soybean protein contains about 0.5 percent (O'Dell and Savage, 1960).

The polyphenols are known to be widely distributed among the Leguminosae. The biochemical mechanism whereby polyphenols interfere with protein metabolism in humans and animals has yet to be determined, but there is evidence to suggest that polyphenols or tannins can be correctly described as antinutrients (Hulse, 1975). Price et al., (1980) determined tannin contents of cow peas, chick peas, pigeon peas and mung beans. Tannin concentrations ranged from 0 to 0.7 percent for cow peas, and 0 to 0.2 percent for pigeon peas, and none in the chick peas and mung beans. They concluded that, of the plants surveyed cow pea was the only one likely to contain amounts of tannin that may be nutritionally harmful.

2.5 Methods of Improving the Nutritive Value of Legumes

Legumes can contribute a valuable source of high lysine protein for complementing the deficiency of lysine in cereal proteins, provided the other amino acid deficiencies and the anti-nutritional factors in legumes are overcome. Over the years, man has devised ways and means of eliminating anti-nutritional factors through various methods of processing legumes.

Cooking, germination, fermentation, soaking, supplementing with the limiting amino acids, or a combination of two or more of these preparative measures have proved to be effective in improving the nutritive value of legumes. Soybeans have received the most attention with respect to the effect of heat treatment on its trypsin inhibiting activity. However, there is adequate evidence showing that beans and peas are also improved by heat treatment. The extent to which the trypsin inhibitor in legumes is destroyed by heat is a function of the temperature, pressure, duration of heating, particle size, and moisture conditions. These variables have to be controlled closely in order to obtain a legume meal with improved nutritive value. In general, autoclaving in an atmosphere of steam at 1.05 kg/cm^2 for 10 to 15 minutes serves to inactivate the trypsin inhibitor of soybeans almost completely (Liener, 1972).

At present, available information indicates that moderate heat treatment improves the nutritive value of most legumes by inactivation of deleterious heat labile compounds (Pushpamma, 1975). Studies by Kienholz et al., (1962) showed that autoclaving peas at 0.7 kg/cm^2 steam pressure for two hours improved their nutritional value for chicks and poults. Marquardt et al. (1974) reported similar observations with faba beans. However, not all legumes seeds have been found to be improved by autoclaving . Those reported not to be so include the peanut, chick pea, sweet pea, mung bean, and the common bean (Borchers, 1950). No correlation was observed between the effect of autoclaving on nutritive value and the presence or absence of the trypsin inhibitor in the raw legume seeds. Autoclaving increased the digestibility of those legumes with higher initial trypsin inhibitor activity. The pigeon pea and lima bean inhibitors were noted to be resistant to heat denaturation (Tawde, 1961). However, Pusztai (1967) noted that the pigeon pea trypsin inhibitor could be precipitated by 5 percent trichloroacetic acid and destroyed by moist heat.

Although germination is known to result in an improvement in the nutritive value of soybeans and a number of legumes, this effect appears to be unrelated to any changes in trypsin inhibitor activity in the germinated seeds (Liener, and Kakade, 1969). The reason for the beneficial effect of germination on the growth promoting property of legumes is not clearly established.

In accordance with the classic concept that the nutritive value of a protein is determined by its amino acid composition, numerous studies have been undertaken to determine whether supplementation of the raw bean proteins with various amino acids would achieve the same effect as heating. Such experiments showed that the addition of methionine or cystine to unheated soybean meal improves utilization to essentially the same effect as proper heating (Hayward and Hafner, 1941; Evans and McGinnis, 1948; Barnes et al., 1962; Borchers, 1962). However, additional methionine will not raise the nutritive value of raw soybean to the level of heated soybean similarly supplemented with methionine (Liener et al., 1949). Devadas et al. (1967) observed an improvement of food intake, weight gain, protein efficiency ratio and Net Protein utilization caused by methionine and tryptophan supplementation to red gram which they fed to albino rats. Similar observations with Cajanus cajan were reported by Bressani, (1972). Maner, et al. (1971) observed that cooking and methionine supplementation of the germinated peas supported performance of rats not different from the soybean meal control.

3. MATERIALS AND METHODS

3.1 Experiment 1.

The feeding of raw pigeon peas (Cajanus cajan) at 0, 10, 15 and 20 percent of the diets and their effects on the performance of broiler chicks upto 5 weeks of age.

3.1.1 Objectives:

To investigate whether raw pigeon peas could be fed to broiler chicks as a protein supplement without causing adverse effects on the growth of chicks, and to establish the maximum levels at which raw pigeon peas could be incorporated into broiler starter diets.

3.1.2 Experimental Diets

The pigeon peas used in the experiment were of seed quality. They were obtained from the University of Nairobi pigeon pea project and had been grown in the Machakos and Kitui districts of Kenya. The raw dry pigeon peas were ground in a laboratory mill prior to mixing in the diets. They were then included in the experimental diets at levels of 0, 10, 15 and 20 percent of the total diet. Four nearly isonitrogenous diets were formulated. The composition of the four experimental diets is shown in Table 1.

Table 1: Composition of broiler starter diets used in Experiment 1.

Feedstuffs (%)	Level of raw pigeon peas in diets			
	0	10	15	20
Ground maize	60.00	55.00	52.50	50.00
Soybean meal	25.00	20.00	17.50	15.00
Pigeon peas	0.00	10.00	15.00	20.00
Fish meal	6.00	6.00	6.00	6.00
Meat and bone meal	6.00	6.00	6.00	6.00
Lard	2.00	2.00	2.00	2.00
Salt	0.50	0.50	0.50	0.50
Vit/min. Premix[1]	0.50	0.50	0.50	0.50
Total (%)	100.00	100.00	100.00	100.00
Calculated CP (%)	22.82	22.42	22.22	22.01
Calculated ME (Kcal/kg)	3085.00	3061.50	3049.75	3038.00

[1]Provided per kilogram of diet:- Vitamin A, 20,000 I.U.; Vitamin D, 4,000 I.U.; Vitamin E, 16 mg; Vitamin K, 4 mg; Vitamin B_2, 12 mg; Vitamin B_{12}, 0.02 mg; Choline Chloride, 300 mg; Folic acid 2 mg; Niacin, 60 mg; Pantothenic acid, 20 mg; Cobalt, 2 mg; Copper, 28 mg; Iodine, 4 mg; Iron, 48 mg; Manganese, 134 mg; Zinc, 134 mg; Selenium, 0.2 mg, BHT (Antioxidant), 240 mg.

3.1.3 Experimental Animals

Day old Shaver 'Star-Bro' broiler type chicks, obtained from Muguku Poultry Farm, were used.

3.1.4 Experimental Design

The day old chicks were individually weighed. The replicate groups were drawn from various body weight groups in an attempt to ensure approximately similar initial body weights. Three groups of ten chicks each were placed on each treatment. A total of 120 chicks were used in the experiment. The experiment was conducted in a completely randomized design by random allocation of the replicates to the twelve experimental pens in the brooder. The chicks were brooded in electrically heated, thermostatically controlled battery brooders with raised wire floors. Twenty four hour lighting was provided. Feed and water were offered *ad libitum*.

3.1.5 Quantitative Measurements

Weekly records of feed consumption and body weight gains were maintained up to five weeks of age. Body weight gain was obtained by weighing the replicate groups every week and determining the weekly difference in weight. Mean weekly body weight gain per treatment was calculated as a mean of the three replicates. Weekly feed consumption was obtained from the difference between feed offered and feed leftover at the end of every week. Mean feed consumption per treatment was calculated as a mean of the three replicates. Feed conversion efficiency (F.C.E.) was calculated as a ratio of feed consumption to body weight gain. Mortality was recorded and the dead chicks were subjected to post-mortem examination.

At the termination of the experiment at five weeks of age, three chicks were randomly selected from each treatment, were weighed individually and sacrificed. The pancreas from each of the chicks was removed and weighed. The pancreas weight was expressed as a ratio of the body weight.

3.1.6 Analytical Procedure

Proximate composition analyses for all the feedstuffs and experimental diets were carried out in the Nutrition Laboratory Kabete, according to the procedures of the Association of Official Analytical Chemists (A.O.A.C., 1975).

3.1.7 Statistical Analyses

Data were subjected to Analysis of Variance, and Duncan's Multiple range test was used to show significant differences between the treatment means (Steel and Torrie, 1960).

3.2 Experiment 2:

The effect of Thermal processing of pigeon peas on the performance of Broiler chicks from 0-5 weeks of age.

3.2.1. Objective:

To study the effects of various methods of thermal processing on the feeding value of pigeon peas.

3.2.2 Experimental Diets

The pigeon peas used in the experiment were obtained from the same source as in Experiment 1. The raw pigeon peas were ground through a 2 mm screen in a laboratory mill prior to heat processing. The ground seeds were divided into four portions. One portion was autoclaved at 121^{o}C 1.05 kg/cm^2 pressure for 15 minutes; Another portion was autoclaved at 121^{o}C, 1.05 kg/cm^2 pressure for 30 minutes; The third portion was steamed in a steam blancher for 30 minutes, while the fourth portion was left in the raw form. The heat treated pigeon peas were dried in an oven at 60^{o}C, cooled, and then reground through a 2 mm screen prior to mixing in the diets. Four isonitrogenous diets were formulated with 20 percent raw or with the variously heat treated pigeon peas. The composition of the experimental diets is given in Table 2.

Table 2: Composition of broiler starter diets used in Experiment 2.

Feedstuffs (%)	State of pigeon peas in diets			
	Raw	Autocl[1]	Autocl[2]	Steamed[3]
Ground maize	50.00	50.00	50.00	50.00
Soybean meal	15.00	15.00	15.00	15.00
Pigeon peas	20.00	20.00	20.00	20.00
Fish meal	6.00	6.00	6.00	6.00
Meat and bone meal	6.00	6.00	6.00	6.00
Lard	2.00	2.00	2.00	2.00
Salt	0.50	0.50	0.50	0.50
Vit./min. Premix[4]	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00
Calculated CP (%)	22.01	22.01	22.01	22.01
Calculated ME (Kcal/kg)	3038.00	3038.00	3038.00	3038.00

[1]Autoclaved at 1 atmospheric pressure (1.05 kg/cm^2), 121^{o}C for 15 minutes.

[2]Autoclaved at 1 atmospheric pressure (1.05 kg/cm^2), 121^{o}C for 30 minutes.

[3]Steamed in a steam blancher for 30 minutes.

[4]Vit/mineral Premix provided the same quantities of vitamins and minerals as outlined in experiment 1.

3.2.3 Experimental Animals

Day old Shaver 'Star Bro' broiler type chicks were obtained from the same source as in Experiment 1.

3.2.4 Experimental Design

A similar procedure as outlined in 3.1.4 was used to ensure that various replicate groups of chicks had approximately the same initial body weights. Three groups of eight chicks each were subjected to each treatment. A total of 96 chicks were used in the experiment. The experiment was set up in a completely randomized design by random allocation of the replicates to the twelve experimental pens. Similar brooders as described in experiment 1 were used. Feed and water were offered ad libitum.

3.2.5 Quantitative Measurements

Body weight gains, feed consumption, feed conversion efficiency and pancreas weight were recorded as indicated in experiment 1.

3.2.6 Histopathological Examinations of the Pancreas

After taking the weights of the pancreas obtained from each treatment, the pancreas were preserved in 10 percent neutral formalin solutions. After two weeks in formalin, sections of the pancreas were prepared for examination under an electron microscope.

3.2.7 Analytical Procedures and Statistical Analyses

These followed the procedures described in 3.1.6 and 3.1.7 respectively.

3.5 Experiment 3.

The supplementing of pigeon pea diets with methionine and tryptophan and the response to growth of broiler chicks up to 4 weeks of age.

3.3.1 Objective:

Diets containing 20 percent raw or autoclaved pigeon peas were supplemented with methionine, or methionine and tryptophan combined to improve the nutritional value of pigeon peas.

3.3.2 Experimental diets

Pigeon peas used in the experiment were obtained from the same source as in experiment 1. The raw pigeon peas were ground in a laboratory mill prior to mixing in the diets. Some of the raw ground peas were autoclaved at a temperature of 121^{o}C and a pressure of 1.05 kg/cm^2 for 15 minutes with the aim of inactivating protease inhibitors before supplementing with the limiting amino acids. Both raw and autoclaved pigeon peas were included in the diets at a level of 20 percent of the total diet. Six isonitrogenous diets were formulated containing raw pigeon peas; raw pigeon peas plus 0.2 percent DL methionine; raw pigeon peas plus 0.2 percent DL methionine plus 0.1 percent L tryptophan; autoclaved pigeon peas; autoclaved pigeon peas plus 0.2 percent DL methionine; autoclaved pigeon peas plus 0.2 percent DL methionine plus 0.1 percent L tryptophan. The above levels of amino acid supplementation were determined from the difference between the calculated level of amino acid in the diet and the level recommended by the National Research Council (1971). The composition of the experimental diets is presented in Table 3.

3.3.3 Experimental Animals

Day old Shaver 'Star Bro' broiler type chicks were obtained from the same source as in experiment 1.

3.3.4 Experimental Design

A similar procedure was used as in the previous experiments to ensure that various replicate groups of chicks had approximately the same initial body weights. Three groups of eight chicks each were placed on each experimental diet or treatment. A total of 144 chicks were used in the experiment. The experiment was again set up in a completely randomized design by random allocation of the treatment replicates to the eighteen experimental pens in the brooders used in the previous two experiments. Feed and water were offered *ad libitum*.

Table 3: Composition of broiler starter diets used in Experiment 3

Feedstuffs (%)	Raw pigeon peas plus			Autoclaved[1] pigeon peas plus		
	Unsupplemented	0.2% DL-met.	0.2% DL-meth. 0.1% L-try.	Unsupplemented	0.2% DL-met.	0.2% DL-met. 0.1% L-try.
Ground maize	50.00	50.00	50.00	50.00	50.00	50.00
Sunflower	12.00	12.00	12.00	12.00	12.00	12.00
Pigeon peas	20.00	20.00	20.00	20.00	20.00	20.00
Fish meal	7.00	7.00	7.00	7.00	7.00	7.00
Meat and bone meal	8.00	8.00	8.00	8.00	8.00	8.00
Lard	2.00	1.80	1.70	2.00	1.80	1.70
Vit/min. Premix[2]	0.50	0.50	0.50	0.50	0.50	0.50
Salt	0.50	0.50	0.50	0.50	0.50	0.50
Methionine	-	0.20	0.20	-	0.20	0.20
Tryptophan	-	-	0.10	-	-	0.10
Total (%)	100.00	100.00	100.00	100.00	100.00	100.00
Calculated CP (%)	21.81	21.81	21.81	21.81	21.81	21.81
Calculated ME (Kcal/kg)	2982.50	2965.50	2957.00	2982.50	2965.50	2957.00

[1] Autoclaved at 121°C, 1.05 kg/cm^2 for 15 minutes.

[2] The quantities of minerals and vitamins provided by the premix are the same as outlined in Table 1.

3.3.5 Quantitative Measurements

Weekly body weight gains, feed consumption and feed conversion efficiency were recorded as in the previous experiments.

3.3.6 Analytical Procedures and Statistical Analyses:

These followed the procedures described in 3.1.6 and 3.1.7 respectively.

4. RESULTS

4.1 Proximate composition of pigeon peas.

Whole and dehulled pigeon pea meals were analysed for proximate composition. The analytical values are presented in Table 4. Whole pigeon pea meal had an average protein content of 22.30 percent. The average protein and fat contents of the dehulled meal were 1.57 and 4.78 percentage units higher respectively than those of the whole pigeon pea meal. However, the ash and moisture contents of the dehulled pigeon pea meal were lower than those of the whole pigeon pea meal.

The pigeon pea hull was analysed for crude fibre content and was found to contain 52.56 percent crude fibre.

4.2 Experiment 1

4.2.1 Proximate composition of the diets used in Experiment 1.

The analytical proximate compositions of the diets used in Experiment 1 are presented in Table 5. The four experimental diets were approximately isonitrogenous with crude protein contents in the range of 22 percent. The four diets contained approximately 11% moisture, 5% ash, 6% fat, and 5% crude fibre. The crude fibre content appeared to increase slightly as the level of pigeon peas in the diets was increased.

Table 4: Proximate composition of the whole and dehulled pigeon peas.

	Chemical composition (%)	
	Whole pigeon peas	Dehulled pigeon peas
Crude protein	22.30	22.65
Ether extract	2.30	2.41
Crude fibre	8.16	2.55
Moisture	11.13	9.44
Ash	4.24	3.65
Nitrogen free extract	51.87	59.30
Carbohydrate	60.03	61.85

Table 5: Proximate composition of the diets used in Experiment 1

Experimental diet	Chemical composition (%)					
	Protein	Moisture	Ash	Fat	Fibre	NFE
0% Raw pigeon peas	22.00	11.25	5.19	6.52	5.08	49.96
+ 10% Raw pigeon peas	21.62	11.32	5.24	6.14	5.24	50.44
+ 15% Raw pigeon peas	21.60	11.40	5.12	6.42	5.38	50.08
+ 20% Raw pigeon peas	21.58	11.20	5.27	6.23	5.64	50.08

4.2.2 Body weight gains (g), Feed Intake (g), Feed Conversion Efficiency (F.C.E.) and Pancreas weights (mg/g).

Mean weekly body weight gains and the total body weight gains (g) per chick, fed broiler starter diets containing varying levels of raw pigeon peas for a period of five weeks are presented in Table 6. Chicks fed diets containing 0%, 10%, 15%, and 20% raw pigeon pea meal gained 882 g, 853 g, 857 g and 807 g, per chick respectively, over the five week period. There were no significant differences in body weight gains resulting from feeding the control diet or the diets containing 10 or 15 percent raw pigeon pea meal. The diet containing 20 percent raw pigeon pea meal resulted in lower ($P < 0.05$) body weight gains than the control diets.

Figure 1 shows the graphical representation of mean weekly body weight gains versus age for broiler chicks fed the starter diets with varying levels of raw pigeon pea meal. The lower weight gains resulting from feeding the chicks the diet containing 20 percent raw pigeon pea meal are clearly seen in Figure 1, especially after the second week. At five weeks of age, chicks fed the control diet were 75 g heavier than the chicks fed the diet containing 20 percent raw pigeon peas.

Table 6: Mean weekly body weight gains (g) per chick fed diets containing varying levels of raw pigeon peas from 0 to 5 weeks of age in Experiment 1.

Experimental diets	Mean body weight gains (g)					
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 1-5
+ 0% Raw pigeon peas	66	137	187	220	272	882[a]
+ 10% Raw pigeon peas	67	126	182	208	270	853[ab]
+ 15% Raw pigeon peas	65	128	177	215	272	857[ab]
+ 20% Raw pigeon peas	64	126	172	197	248	807[b]
SEM[1]	-	-	-	-	-	20

Means followed by different superscripts in the last column are different ($P< 0.05$).

[1]Standard error of means.

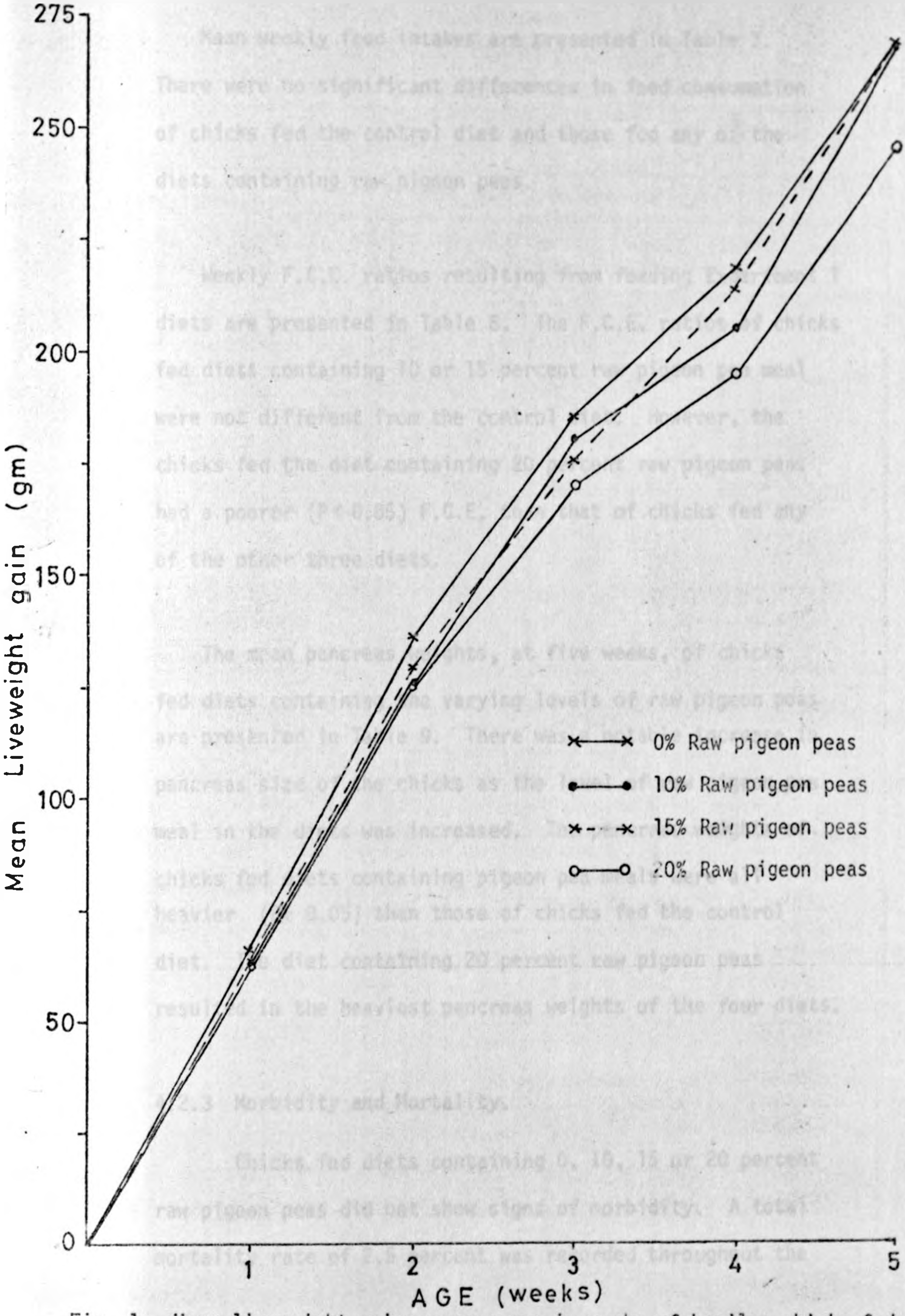

Fig. 1: Mean liveweight gains versus age in weeks of broiler chicks fed starter diets with varying levels of raw pigeon peas in Experiment 1.

Mean weekly feed intakes are presented in Table 7. There were no significant differences in feed consumption of chicks fed the control diet and those fed any of the diets containing raw pigeon peas.

Weekly F.C.E. ratios resulting from feeding Experiment 1 diets are presented in Table 8. The F.C.E. ratios of chicks fed diets containing 10 or 15 percent raw pigeon pea meal were not different from the control diet. However, the chicks fed the diet containing 20 percent raw pigeon peas had a poorer ($P < 0.05$) F.C.E. than that of chicks fed any of the other three diets.

The mean pancreas weights, at five weeks, of chicks fed diets containing the varying levels of raw pigeon peas are presented in Table 9. There was a notable increase in pancreas size of the chicks as the level of raw pigeon pea meal in the diets was increased. The pancreas weights of chicks fed diets containing pigeon pea meals were all heavier ($P < 0.05$) than those of chicks fed the control diet. The diet containing 20 percent raw pigeon peas resulted in the heaviest pancreas weights of the four diets.

4.2.3 Morbidity and Mortality.

Chicks fed diets containing 0, 10, 15 or 20 percent raw pigeon peas did not show signs of morbidity. A total mortality rate of 2.5 percent was recorded throughout the

Table 7: Mean weekly feed consumption (g) of broiler chicks fed starter diets containing varying levels of raw pigeon peas in Experiment 1.

Experimental diets	Mean feed consumption (g)					
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 1-5
+ 0% Raw pigeon peas	99	213	330	477	592	1711[a]
+ 10% Raw pigeon peas	104	205	309	450	607	1675[a]
+ 15% Raw pigeon peas	104	210	320	472	605	1711[a]
+ 20% Raw pigeon peas	99	218	315	465	600	1697[a]
SEM	-	-	-	-	-	51

Means followed by similar superscripts in last column are not different ($P > 0.05$).

Table 8: Mean weekly feed conversion efficiency (F.C.E.) ratios of broiler chicks fed starter diets containing varying levels of raw pigeon peas in Experiment 1.

Experimental diets	Mean feed conversion efficiency ratios					
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 1-5
+ 0% Raw pigeon peas	1.50	1.55	1.76	2.17	2.18	1.94[a]
+ 10% Raw pigeon peas	1.55	1.63	1.70	2.16	2.25	1.96[a]
+ 15% Raw pigeon peas	1.60	1.64	1.81	2.20	2.22	2.00[a]
+ 20% Raw pigeon peas	1.55	1.73	1.83	2.36	2.42	2.10[b]
SEM	-	-	-	-	-	0.026

Means followed by different superscripts in the last column are different ($P < 0.05$).

Table 9: Mean pancreas weight (mg/g), at five weeks of age, of chicks fed diets containing varying levels of raw pigeon peas in Experiment 1.

Experimental diets	Mean pancreas weight (mg/g) at 5 weeks
+ 0% Raw pigeon peas	2.2045[a]
+ 10% Raw pigeon peas	2.8722[b]
+ 15% Raw pigeon peas	2.9456[b]
+ 20% Raw pigeon peas	3.2354[c]
SEM	0.072

Means followed by different superscripts are different (P< 0.05).

experimental period. The only three chicks which died during the second week, came from two of the replicates fed the diets containing 10 percent raw pigeon peas.

4.3 Experiment 2.

4.3.1 Proximate composition of the diets used in Experiment 2.

The analytical results for Experiment 2 diets are shown in Table 10. The four diets were approximately isonitrogenous as shown by their protein contents.

4.3.2 Body weight gains (g), Feed Intake (g), Feed Conversion Efficiency (F.C.E.) and Pancreas weight (mg/g).

Mean weekly body weight gains and the total weight gains attained per chick fed broiler starter diets containing 20% raw or the variously heat-treated pigeon pea meals from 0 to 5 weeks of age, are presented in Table 11. There were no significant differences in body weight gains of chicks fed the diet containing raw pigeon peas and those of chicks fed diets containing the heat-treated pigeon peas. However, chicks fed the diet containing 20% pigeon peas autoclaved for 15 minutes gained 33 g above the chicks fed the diet containing raw pigeon peas. The diets containing pigeon peas which were autoclaved or steamed for 30 minutes resulted in the lowest chick growth rates.

Figure 2 shows the graphical representation of the weekly mean body weight gains of chicks fed Experiment 2 diets.

Table 10: Proximate composition of the diets used in Experiment 2.

Experimental diets	Chemical composition (%)					
	Protein	Moisture	Ash	Fat	Fibre	NFE
+ 20% Raw pigeon peas	21.50	11.54	5.21	6.14	5.02	50.59
+ 20% Autoclaved pigeon peas[1]	21.47	10.64	5.28	6.00	5.75	50.86
+ 20% Autoclaved pigeon peas[2]	21.40	11.17	5.37	6.41	5.09	50.56
+ 20% Steamed pigeon peas[3]	21.42	10.82	5.25	6.44	5.03	51.04

[1]Autoclaved at 121°C, 1.05 kg/cm^2 pressure for 15 minutes.

[2]Autoclaved at 121°C, 1.05 kg/cm^2 pressure for 30 minutes.

[3]Steamed in a steam blancher for 30 minutes.

Table 11: Mean weekly body weight gains per chick fed diets containing 20% raw or the variously heat-treated pigeon peas from 0 to 5 weeks of age in Experiment 2.

Experimental diets	Mean body weight gains (g)					
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 1-5
+ 20% Raw pigeon peas	56	101	140	152	156	605[a]
+ 20% Autoclaved pigeon peas[1]	56	107	152	160	163	638[a]
+ 20% Autoclaved pigeon peas[2]	55	94	142	144	149	584[a]
+ 20% Steamed pigeon peas[3]	56	93	140	146	156	591[a]
SEM	-	-	-	-	-	22

Means followed by similar superscripts within the last column are not different ($P > 0.05$).

[1]Pigeon peas autoclaved at $121^{\circ}C$, 1 atmospheric pressure ($1.05\ kg/cm^2$). for 15 minutes.

[2]Pigeon peas autoclaved at $121^{\circ}C$, 1 atmospheric pressure ($1.05\ kg/cm^2$) for 30 minutes.

[3]Steamed in a steam blancher for 30 minutes.

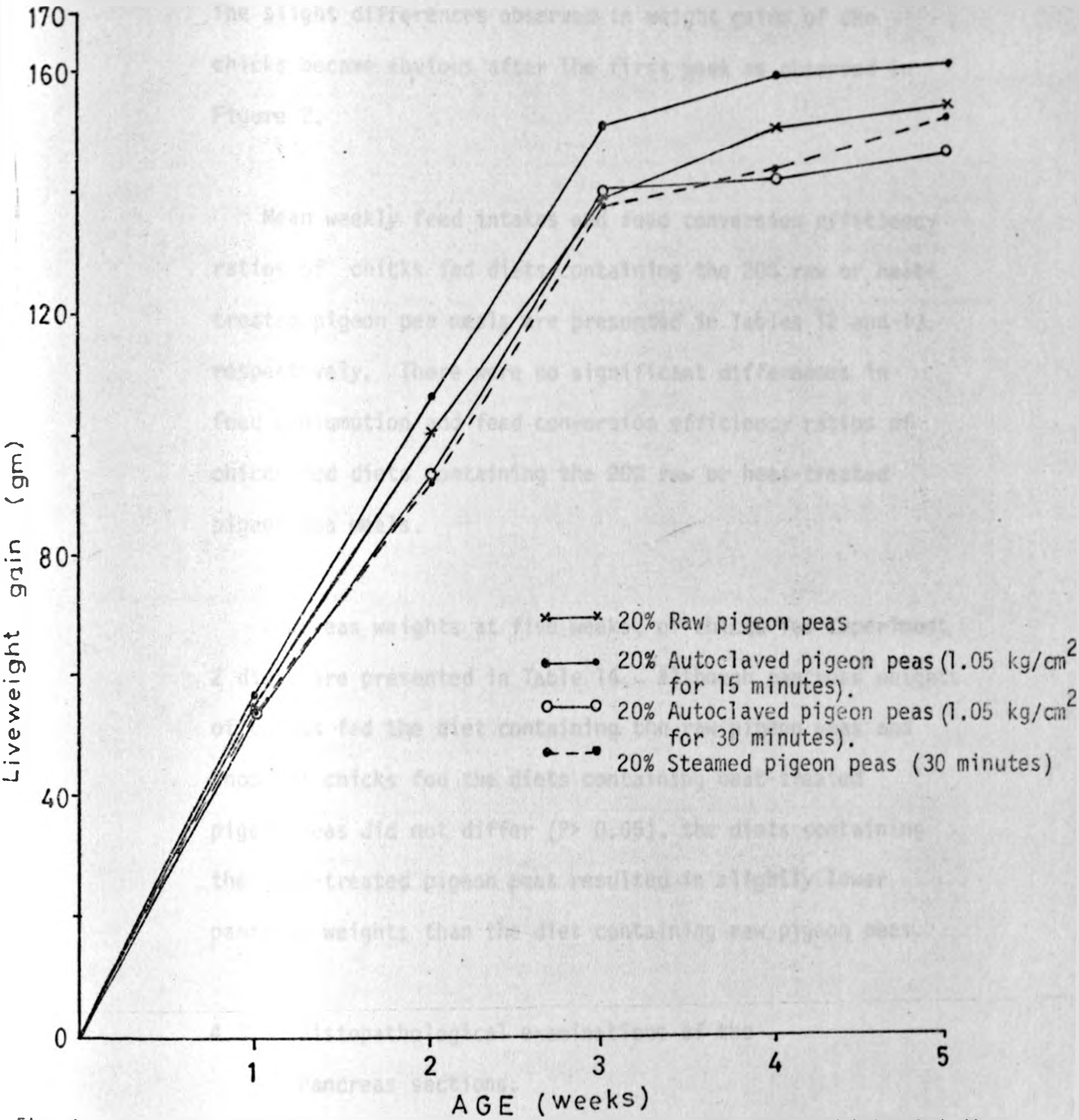

Fig. 2: Mean liveweight gains (g) versus age in weeks of broiler chicks fed diets containing 20% raw or the variously heat-treated pigeon peas in Experiment 2.

The slight differences observed in weight gains of the chicks became abvious after the first week as observed in Figure 2.

Mean weekly feed intakes and feed conversion efficiency ratios of chicks fed diets containing the 20% raw or heat-treated pigeon pea meals are presented in Tables 12 and 13. respectively. There were no significant differences in feed consumption and feed conversion efficiency ratios of chicks fed diets containing the 20% raw or heat-treated pigeon pea meals.

Pancreas weights at five weeks, of chicks fed Experiment 2 diets are presented in Table 14. Although pancreas weights of chicks fed the diet containing the raw pigeon peas and those of chicks fed the diets containing heat-treated pigeon peas did not differ ($P > 0.05$), the diets containing the heat-treated pigeon peas resulted in slightly lower pancreas weights than the diet containing raw pigeon peas.

4.3.3 Histopathological examinations of the Pancreas sections.

There were no notable differences in the histology of the pancreas obtained from chicks fed the diet containing the raw pigeon peas, or the diets containing pigeon peas autoclaved at a temperature of $121^{o}C$ and pressure of 1.05 kg/cm^2 for 15 or 30 minutes or steamed for 30 minutes. No

Table 12: Mean weekly feed consumption (g) of chicks fed diets containing 20% raw or the variously heat-treated pigeon peas in Experiment 2.

Experimental diets	Mean feed consumption (g)					
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 1-5
+ 20% Raw pigeon peas	96	198	277	360	417	1348[a]
+ 20% Autoclaved pigeon peas	90	192	273	353	405	1313[a]
+ 20% Autoclaved pigeon peas	92	175	265	327	381	1240[a]
+ 20% Steamed pigeon peas	92	181	267	348	415	1303[a]
SEM	-	-	-	-	-	77

Means followed by similar superscripts in the last column are not different (P> 0.05).

Table 13: Mean weekly feed conversion efficiency (F.C.E.) ratios of chicks fed diets containing 20% raw or the variously heat-treated pigeon peas in Experiment 2.

Experimental diets	Mean F.C.E. ratios					
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 1-5
+ 20% Raw pigeon peas	1.71	1.96	1.98	2.37	2.67	2.23[a]
+ 20% Autoclaved pigeon peas	1.61	1.79	1.80	2.21	2.48	2.06[a]
+ 20% Autoclaved pigeon peas	1.67	1.86	1.87	2.27	2.56	2.12[a]
+ 20% Steamed pigeon peas	1.64	1.95	1.91	2.38	2.66	2.20[a]
SEM	-	-	-	-	-	0.067

Means followed by similar superscripts in the last column are not different ($P > 0.05$).

Table 14: Mean pancreas weight (mg/g), at five weeks of age, of chicks fed diets containing 20% raw or the variously heat-treated pigeon peas in Experiment 2.

Experimental diets	Mean pancreas weight at 5 weeks (mg/g)
+ 20% Raw pigeon peas	3.61[a]
+ 20% Autoclaved pigeon peas	3.43[a]
+ 20% Autoclaved pigeon peas	3.26[a]
+ 20% Steamed pigeon peas	3.58[a]
SEM	0.195

Means followed by similar superscripts are not different ($P > 0.05$).

distinct pancreatic acinar atrophies were observed on the pancreas sections obtained from chicks fed the diet containing raw pigeon peas or the diets with the autoclaved or the steamed pigeon peas.

4.3.4 Morbidity and Mortality

There were no signs of morbid growth among the experimental chicks. A total mortality rate of 4.17% was recorded throughout the experimental period. Of the four chicks which died during the experimental period, one died during the fourth week, while three died during the fifth week. Three of the dead chicks came from two of the replicates which were fed on diets containing the pigeon peas which were autoclaved for 30 minutes, while the other dead chick came from the diet containing the steamed pigeon peas.

4.4 Experiment 3.

4.4.1 Proximate composition of the diets used in Experiment 3.

The analytical proximate compositions for Experiment 3 diets are presented in Table 15. The six experimental diets were approximately isonitrogenous with protein contents lying in the range of 21 percent. The diets contained approximately 9% moisture, 7% ash, 5 to 6% fat and 5% fibre.

4.4.2 Body weight gains (g), Feed Intake (g), Feed Conversion Efficiency (F.C.E.) ratios.

Mean weekly body weight gains per chick fed broiler starter diets containing 20% raw or autoclaved pigeon pea meals unsupplemented or supplemented with 0.2% DL methionine, or 0.2% DL methionine and 0.1% L tryptophan from 0 to 4 weeks of age are presented in Table 16. Chicks fed the diet containing the raw pigeon pea meal unsupplemented resulted in the lowest growth rate of the six treatment diets. However, there were no significant differences in weight gains of chicks fed the raw pigeon pea meals unsupplemented or supplemented with amino acids. Chicks fed the 20% raw pigeon pea meals supplemented with methionine or both methionine and tryptophan resulted in growth rates as good as the diet containing autoclaved pigeon peas unsupplemented

Table 15: Proximate composition of the diets used in Experiment 3.

Experimental diets	Chemical composition (%)					
	Protein	Moisture	Ash	Fat	Fibre	NFE
+ 20% Raw pigeon peas unsupplemented	21.45	9.58	7.24	5.74	5.35	50.64
+ 20% Raw pigeon peas + 0.2% DL-methionine	21.43	9.46	7.27	5.30	5.33	51.21
+ 20% Raw pigeon peas + 0.2% DL-methionine +0.2% L-tryptophan	21.49	9.46	7.19	5.48	5.22	51.16
+ 20% Autoclaved[1] pigeon peas unsupplemented	21.23	9.35	7.30	5.70	5.36	51.06
+ 20% Autoclaved[1] pigeon peas + 0.2% DL-methionine	21.36	9.38	7.42	5.86	5.20	50.78
+ 20% Autoclaved[1] pigeon peas + 0.2% DL-methionine + 0.1% L-tryptophan	21.45	9.27	7.10	5.63	5.46	51.09

[1]Pigeon peas autoclaved at 121°C, 1.05 kg/cm^2 pressure for 15 minutes.

Table 16: Mean weekly body weight gains per chick fed diets containing 20% raw or autoclaved pigeon peas unsupplemented or supplemented with 0.2% DL methionine or 0.2% DL-methionine and 0.1% L-tryptophan in Experiment 3.

Experimental diets	Mean body weight gains (g)				
	Week 1	Week 2	Week 3	Week 4	Week 1-4
+ 20% Raw pigeon peas	46	98	171	216	531^{a}
+ 20% Raw pigeon peas + 0.2% DL-methionine	46	103	179	218	546^{ab}
+ 20% Raw pigeon peas + 0.2% DL-methionine + 0.1% L-tryptophan	50	103	182	223	558^{ab}
+ 20% Autoclaved pigeon peas[1]	55	111	200	223	589^{bc}
+ 20% Autoclaved pigeon peas[1] + 0.2% DL-methionine	54	112	202	220	588^{bc}
+ 20% Autoclaved pigeon peas[1] + 0.2% DL-methionine + 0.1% L-tryptophan	60	124	212	225	621^{c}
SEM	-	-	-	-	14

Means followed by different superscripts in the last column are different ($P < 0.05$).

[1] Pigeon peas autoclaved at 121°C, 1 atmospheric pressure ($1.05\ kg/cm^2$) for 15 minutes.

or supplemented with 0.2% DL methionine. The diet containing the autoclaved pigeon pea meal supplemented with 0.2% DL methionine and 0.1% L tryptophan resulted in the highest body weight gains of the six treatments, and gave better ($P < 0.05$) growth rates than any of the three diets containing raw pigeon peas.

Figure 3 shows a graphical representation of the weekly weight gains of chicks fed Experiment 3 diets. The differences in weight gains between the six treatments are clearly seen during the first three weeks, but at the fourth week, the growth curves show a tendency to converge.

Mean weekly feed intakes of chicks fed Experiment 3 diets are presented in Table 17. There were no significant differences in feed consumption of chicks fed diets containing the raw pigeon peas unsupplemented or supplemented with 0.2% DL methionine or 0.2% DL methionine and 0.1% L tryptophan. The chicks fed the diet containing autoclaved pigeon peas unsupplemented had the highest feed consumption which differed from the rest of the diets.

Mean weekly feed conversion efficiency (F.C.E.) ratios resulting from feeding broiler chicks on Experiment 3 diets are presented in Table 18. Feed conversion efficiency was observed to improve with the addition of amino acids. The diets containing the raw or autoclaved pigeon peas unsupplemented resulted in the poorest F.C.E. ratios of the

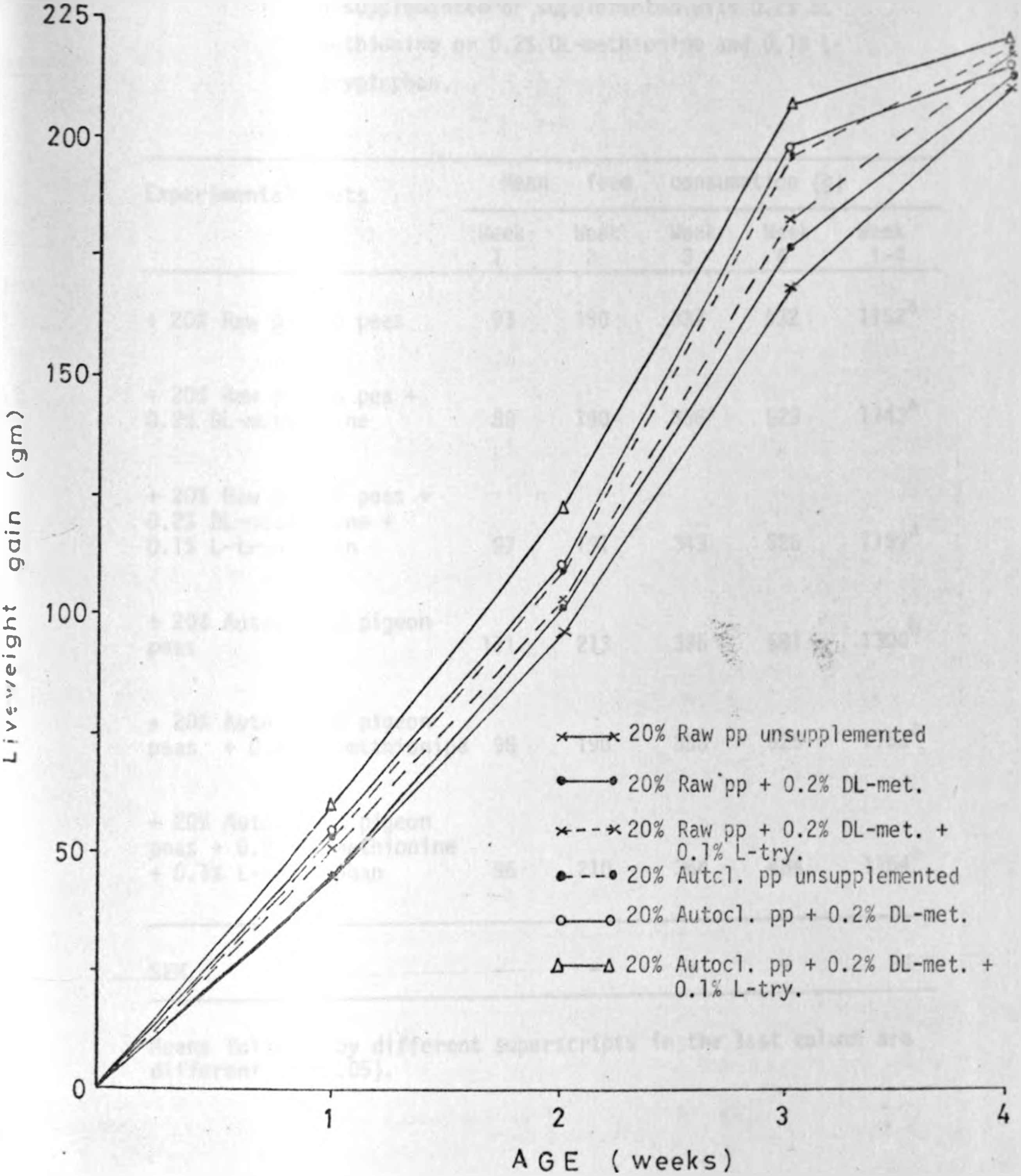

Fig. 3: Mean liveweight gains (g) versus age in weeks of broiler chicks fed diets containing 20% raw or autoclaved pigeon peas unsupplemented or supplemente with 0.2% DL-methionine or 0.2% DL methionine and 0.1% L-tryptophan.

Table 17: Mean feed consumption (g) of chicks fed diets containing 20% raw or autoclaved pigeon peas unsupplemented or supplemented with 0.2% DL-methionine or 0.2% DL-methionine and 0.1% L-tryptophan.

Experimental diets	Mean feed consumption (g)				
	Week 1	Week 2	Week 3	Week 4	Week 1-4
+ 20% Raw pigeon peas	93	190	337	532	1152[a]
+ 20% Raw pigeon pea + 0.2% DL-methionine	88	190	336	529	1143[a]
+ 20% Raw pigeon peas + 0.2% DL-methionine + 0.1% L-tryptophan	97	191	343	528	1159[a]
+ 20% Autoclaved pigeon peas	111	213	395	581	1300[b]
+ 20% Autoclaved pigeon peas + 0.2% DL-methionine	98	190	350	525	1163[a]
+ 20% Autoclaved pigeon peas + 0.2% DL-methionine + 0.1% L-tryptophan	96	210	364	484	1154[a]
SEM	-	-	-	-	38

Means followed by different superscripts in the last column are different ($P < 0.05$).

Table 18: Mean weekly feed conversion efficiency (F.C.E.) ratios of chicks fed diets containing 20% raw or autoclaved pigeon peas unsupplemented or supplemented with 0.2% DL-methionine or 0.2% DL-methionine and 0.1% L-tryptophan

Experimental diets	Mean F.C.E. ratios				
	Week 1	Week 2	Week 3	Week 4	Week 1-4
+ 20% Raw pigeon peas	2.02	1.94	1.97	2.46	2.17[a]
+ 20% Raw pigeon peas + 0.2% DL-methionine	1.91	1.84	1.88	2.43	2.09[ab]
+ 20% Raw pigeon peas + 0.2% DL-methionine + 0.1% L-tryptophan	1.94	1.85	1.88	2.37	2.08[ab]
+ 20% Autoclaved pigeon peas	2.02	1.92	1.97	2.61	2.21[a]
+ 20% Autoclaved pigeon peas + 0.2% DL-methionine	1.81	1.70	1.73	2.39	1.98[ab]
+ 20% Autoclaved pigeon peas + 0.2% DL-methionine + 0.1% L-tryptophan	1.60	1.69	1.72	2.15	1.86[b]
SEM :	-	-	-	-	0.074

Means followed by different superscripts in the last column are different ($P < 0.05$).

six diets. Chicks fed the diet containing autoclaved pigeon peas supplemented with 0.2% DL methionine and 0.1% L tryptophan had the best F.C.E. of the six diets.

4.4.3 Morbidity and Mortality

There were no signs of morbidity among the experimental chicks. A total mortality rate of 2.78% was recorded throughout the experimental period. The four chicks died during the third and fourth week of the experiment. No deaths were recorded among chicks fed diets containing 20% raw or autoclaved pigeon peas supplemented with 0.2% DL methionine and 0.1% L tryptophan.

5. DISCUSSION

The proximate composition values of the whole pigeon pea variety studied are quite similar to those reported by Johnson and Raymond (1964) and Oracca-Tetteh, (1976). The crude protein content of 22.30 percent in pigeon peas lies within the average values reported by Sharma et al., (1975). The relatively higher protein content of the dehulled pigeon peas concurs with the results reported by Hulse (1975), and is also supported by Bressani (1972) who indicated that cotyledons contribute the largest amount of protein in the legume seed. The high crude fibre content found in the pigeon pea hulls was as expected and, like other legumes, the hull is largely composed of crude fibre.

The protein contents of the experimental chick starter diets were in the range of 21 and 22 percent. These dietary protein values are however slightly lower than the values recommended by the United States National Research Council on nutrient requirements of poultry (NRC, 1971), but lie within the ranges given by Scott et al., (1969).

The raw pigeon pea meals were included only up to 20% of the starter diets because the protein content of pigeon peas is relatively low compared to that of the soy bean meal. The chicks fed the starter diets containing 10 or 15% raw pigeon pea meal showed growth rates as good as the control diet based on maize and soy bean meal. Raw pigeon peas can thus be safely included in broiler starter diets up to 15% of the diet without causing adverse effects on growth of the chicks. The chicks fed the control diet weighed an average of 924 g at five weeks, while those fed the diets containing 10%, 15% or 20% raw pigeon peas weighed 895 g, 899 g, and 849 g respectively. These body weights are within the range prescribed by NRC (1971) which states that broiler chicks of mixed sexes should weigh 750-1000 g at five weeks, if given a broiler starter diet of metabolizable energy content of 3200 Kcal/g and crude protein content of 23%.

The 8.51% depression in growth observed when the level of raw pigeon peas in the diets was increased to 20%, confirms the presence of some nutritional limitations in pigeon peas. Growth depressions of chicks or rats have been observed with feeding diets containing raw field peas (Maner and Pond, 1971), raw faba beans (Marquardt and Campbell, 1974), raw soy beans (Lyman and Lepkovsky, 1957; Alumot and Nitsan, 1961; Green and Lyman, 1972; Neiss et al., 1972), as well as raw pigeon peas (Dako, 1966; Springhall et al., 1974). In most cases, the growth depression has been attributed to protease inhibitors, phytohemagglutinins, and sulfur amino acid deficiencies in these legumes. Springhall et al. (1974) observed depression in growth of chicks when the level of raw pigeon peas in the starter diet was raised above 30 percent. They attributed the growth depression to a deficiency of cystine, tryptophan and phenylalanine.

There has not been much work conducted to study the effect of raw pigeon peas in chick nutrition. However, work done with soybeans and other grain legumes can to an extent be used to explain the effect of raw pigeon peas on the chick. Chernick et al., (1948), and Alumot and Nitsan (1961), studied the influence of raw soybean diet on the chicks' intestinal proteolysis in order to explain the growth retarding effect. They observed that intestinal proteolysis was almost completely inhibited up to three weeks of age. The presence or absence of antitryptic activity was closely correlated with depressed or normal proteolytic activity. Lyman and Lepkovsky (1957) and Booth et al., (1960) further suggested that the growth depression caused by the trypsin inhibitor may be aggravated by the endogenous loss of essential amino acids derived from a hyperactive pancreas which is responding in a compensatory fashion to the effects of the trypsin inhibitor.

The increase in size of the pancreas of the chicks observed as the level of pigeon peas in the diets was increased is in agreement with Dako (1966) who noted hypertrophy of the pancreas of rats fed raw pigeon pea diets. Chernick et al. (1948), Booth et al. (1960), Alumot and Nitsan

(1961), Nesheim et al. (1962), and Rackis, (1974), indicated that hypertrophy of the pancreas represents one of the physiological effects produced by feeding raw soybeans or the isolated inhibitor to rats and chicks.

Pigeon peas have been reported to contain trypsin inhibitors by Sohonie and Bhandarkar (1955), Tawde (1961), Liener (1973) and Bogere (1980). They have also been reported to be deficient in methionine and tryptophan by Orr and Watt (1957), Mtenga and Sugiyama (1974), Dako (1966), Ahmad and Shah (1975). Since raw pigeon peas, like soybeans and other legumes, contain trypsin inhibitors, growth depression observed at the inclusion of 20% raw pigeon peas in the starter diet could be partly attributed to the presence and effects of trypsin inhibitors. The levels of methionine and tryptophan in the diet containing 20% pigeon peas were lower than those recommended by the National Research Council (NRC, 1971). The above growth depression could thus be further attributed to methionine and tryptophan deficiencies which are likely to have been aggravated by the effects of trypsin inhibitors. Raw legumes are known to be of low palatability and digestibility and this might also have contributed to the growth depression observed at the inclusion of a high level of raw pigeon peas in the diet.

Mortality rate among chicks fed the control diet, or the diets containing 10%, 15% or 20% raw pigeon peas was not significant. The absence of morbidity or deaths among chicks fed the diet containing 20% raw pigeon peas indicated that pigeon peas did not contain any severely toxic constituents. Springhall et al., (1974) also noted that Cajanus cajan seed was not toxic to chickens.

The 5.45 percent improvement in body weight gain of chicks which resulted from autoclaving the ground pigeon peas at a temperature of 121^{o}C and a pressure of 1.05 kg/cm^2 for 15 minutes partly agrees with the findings of Pusztai (1967) who reported that the pigeon pea trypsin inhibitor could be destroyed by moist heat. The beneficial effect of heat on the utilization of legumes has been observed with soybeans (Osborne and Mendel, 1917; Liener 1969; Liener, 1972), with garden peas (Kieholz et al., 1962) with velvet beans, Lima beans, and common beans (Borchers, 1950). Jaffe' (1950) indicated that the widespread distribution of trypsin inhibitors in legumes provides the most likely explanation for the observation that heating improves the digestibility of many plant materials. Liener (1972) reported that autoclaving soybeans at a pressure of 1.05 kg/cm^2 for 10 or 15 minutes serves to inactivate the trypsin inhibitors of soybeans almost completely. However, autoclaving pigeon peas at the same pressure for 15 minutes only caused a small improvement in the utilization of pigeon peas in chick diets. This supports the findings of Tawde (1961) and Bogere (1980) who reported that the pigeon pea trypsin inhibitors are fairly heat resistant.

The 3.47 and 2.31 percent depressions in growth which were observed with birds fed diets containing 20 percent pigeon peas autoclaved or steamed for 30 minutes respectively, are in agreement with the findings of Bressani (1972), who suggested that cooking may affect the protein quality. Kadirvel and Clandinin (1974) observed reduced growth as the level of faba beans autoclaved for 30 minutes was increased from 5 to 20 percent, and he attributed these effects to a loss in the availability of some amino acids due to heat treatment. Pushpamma (1975) also indicated that excessive heat causes a decrease in the nutritive value of legumes. Excessive heating, in terms of time or temperature, to destroy the rather heat resistant protease inhibitors in legumes, could thus result in reduced protein quality.

The absence of significant differences in feed consumption, feed conversion efficiency, and pancreas weight of chicks fed the diet containing raw pigeon peas, and those of chicks fed diets containing pigeon peas autoclaved at 1.05 kg/cm^2 pressure for 15 minutes, or 30 minutes, or steamed for 30 minutes, is another indication that autoclaving or steaming did not have a significant effect on the utilization value of the pigeon peas. However, the diet containing pigeon peas autoclaved at 1.05 kg/cam^2 pressure for 15 minutes again showed a better, though not significant, feed conversion efficiency compared to the rest of the diets.

Although pancreas weights of the chicks fed the diets containing the raw pigeon peas or pigeon peas autoclaved at 1.05 kg/cm^2 pressure for 15 minutes or 30 minutes, or steamed for 30 minutes did not differ significantly, pancreas weights of chicks fed diets containing the autoclaved or the steamed pigeon peas were slightly lower than those of chicks fed the diet containing the raw pigeon peas. Marquardt and Campbell (1974) reported similar onservations when they fed raw faba beans versus autoclaved faba beans. This was clear indication that the presence of some heat labile substances in raw legumes contributed to the hypertrophy of the pancreas.

The diets used in Experiment 3 were found to be deficient by 0.11% methionine/cystine and 0.07% tryptophan. Supplementation levels of 0.2% DL methionine and 0.1% L tryptophan were meant to meet methionine, cystine, and tryptophan deficiencies and to make up for any losses caused by the effects of trypsin inhibitors in the pigeon peas. Supplementation of the diets containing 20% raw pigeon peas with 0.2% DL-methionine or 0.2% DL methionine and 0.1% L tryptophan produced growth rates as good as those of chicks fed diets containing the pigeon peas autoclaved at 1.05 kg/cm^2

for 15 minutes unsupplemented or supplemented with 0.2% DL methionine. This suggests that methionine and tryptophan supplementation to diets containing raw pigeon peas improved the utilization of pigeon peas to nearly the same extent as autoclaving the pigeon peas. Devadas et al., (1967) also reported improvements in weight gain of rats fed raw red gram protein to which 0.3 % DL methionine and 0.2% L tryptophan had been added.

Supplementation of the diets containing the raw or autoclaved pigeon peas with 0.2% DL methionine did not cause significant improvements in the growth rate of chicks. Similar observations were reported by Dako (1966) who noted that methionine was not the first or the only limiting amino acid in pigeon peas. Rogers (1976) defined a limiting amino acid as the one most effective in satisfying requirements.

The diet containing pigeon peas autoclaved for 15 minutes and supplemented with 0.2% DL-methionine and 0.1% L tryptophan resulted in growth rates which were 16.95 percent better than those of chicks fed the diet containing the raw pigeon peas unsupplemented. This was a clear indication of the combined beneficial effect of autoclaving, and methionine and tryptophan supplementation on the utilization of the pigeon peas diets. The above significant improvement in growth rates resulting from supplementing the diet containing autoclaved pigeon peas with 0.2% DL methionine and 0.1% L tryptophan concurs with the results of Dako (1966) and Devadas *et al.*, (1967) whose results also suggest that both methionine and tryptophan were limiting in the pigeon pea protein. Bressani (1972) reported experiments in which 0% methionine and 0% tryptophan, 0.1% DL methionine, 0.3% DL methionine, 0.1% L tryptophan, or 0.2% DL methionine plus 0.1% DL tryptophan were supplemented to *Cajanus cajan* and fed to rats. The 0.1% DL methionine and 0.3% DL methionine depressed average weight gain of rats by 27.08 percent and 37.50 percent respectively. Addition of 0.1% DL tryptophan improved average weight gain of the rats by 20.83 percent, while the addition of 0.2% DL methionine plus 0.1% L tryptophan improved average weight gain of the rats by 145.83 percent. Bogere (1980) did not achieve a significant improvement in the growth rate of rats by supplementing rats diets containing autoclaved pigeon peas with 0.1% tryptophan. This confirms that both methionine and tryptophan are about equally limiting in *Cajanus cajan* and that it is only when both amino acids are added to the pigeon pea diets that a significant improvement in the utilization value is realized.

The convergence of the growth rate curves of chicks observed at the fourth week, indicated that the chicks became less sensitive to amino acid deficiencies as they grew older. This is supported by Calet (1976) who noted that amino acid requirements by broilers decrease as the birds mature.

The absence of significant differences in feed intake between chicks fed diets containing the raw pigeon peas unsupplemented, and those fed diets containing raw pigeon peas supplemented with 0.2% DL methionine or 0.2% DL methionine and 0.1% L tryptophan, indicated that the amino acid supplementation to raw pigeon peas did not affect feed intake. However, chicks fed diets containing autoclaved pigeon peas had slightly better feed intakes than those fed the diets containing raw pigeon peas. A similar observation was made by Marquardt and Campbell (1974) when they fed raw faba beans to chick diets. Autoclaving of the legumes apparently improves feed intake.

The 14.29% improvement in feed conversion efficiency observed with chicks fed the diets containing autoclaved pigeon peas supplemented with 0.2% DL methionine and 0.1% L tryptophan confirms that the utilization of pigeon peas is improved by autoclaving followed by methionine and tryptophan supplementation. Dako (1966) reported that methionine and tryptophan combined improved the protein efficiency ratio (PER) of the raw and cooked pigeon peas by about 100% but did not specify the levels of methionine and tryptophan supplementation.

Judging from the notable improvements in growth rates and feed conversion efficiency of chicks fed the diet containing autoclaved pigeon peas and supplemented with

0.2% DL methionine and 0.1% L tryptophan, one may conclude that these levels of supplementation are fairly adequate. However, since the amounts of amino acid losses from a pancreas hyperactivated by trypsin inhibitors are unknown a wider range of methionine and tryptophan supplementation levels should be tested to determine the optimum levels of supplementation.

6. CONCLUSIONS

Raw pigeon peas can be included in broiler starter diets up to a maximum level of 15 percent of the diet.

Autoclaving raw pigeon peas at a temperature of 121^{o}C, and pressure 1.05 kg/cm^2 for 15 minutes or 30 minutes, or steaming them for 30 minutes does not cause a significant improvement in their feeding value.

Supplementing raw pigeon peas with 0.2% DL methionine or 0.2% DL methionine and 0.1% L tryptophan does not produce a significant improvement in their feeding value. However, addition of 0.2% DL methionine and 0.1% L tryptophan to chick diets containing pigeon peas which have been autoclaved at 121^{o}C, and 1.05 kg/cm^2 pressure for 15 minutes produces a very significant improvement in the feeding value of pigeon peas. Therefore the combined effects of autoclaving pigeon peas at 121^{o}C, and 1.05 kg/cm^2 pressure for 15 minutes, and supplementing the diets with the methionine and tryptophan deficiency levels are essential if levels of pigeon peas higher than 15 percent are to be included in chick feeds.

7. SCOPE FOR FURTHER WORK

The work and findings reported in this thesis are by no means conclusive regarding the best possible methods to improve the utilization of pigeon peas in chick feeds. There is need to look into simpler methods of processing of pigeon peas which can be easily applicable to farmers and yet improve the utilization of pigeon peas. There is also scope for testing a wider range of tryptophan and methionine levels of supplementation to determine the optimum levels. Since the pigeon peas have a fairly wide range of protein and amino acid variations, it may be useful to study the effects of inclusion of different varieties of pigeon peas in chick feeds. The effects of phytates in pigeon peas upon the availability of minerals especially phosphorus, zinc, magnesium, iron and calcium in chick nutrition need to be investigated.

Additional studies also need to be done to establish the metabolizable energy value of pigeon peas for chickens.

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APPENDICES

Appendix A.1: Proximate composition of the feedstuffs

Feedstuffs	Chemical composition (%)					
	Protein	Moisture	Ash	Fat	Fibre	NFE
Maize	8.56	11.59	1.02	2.88	3.51	72.44
	8.56	11.90	1.04	3.04	3.26	72.20
Mean	8.56	11.74	1.03	2.96	3.38	72.33
Fish meal	60.30	9.75	16.27	9.71	0.64	3.33
	60.23	10.02	16.48	9.42	0.95	2.90
Mean	60.26	9.88	16.37	9.56	0.80	3.13
Meat and bone meal	49.29	6.70	24.02	10.20	3.56	6.23
	49.11	6.44	24.14	10.36	3.00	6.95
Mean	49.20	6.57	24.08	10.28	3.28	6.59
Soybean meal	43.25	10.02	6.16	1.01	6.72	32.84
	43.07	10.04	6.19	1.07	6.95	32.68
Mean	43.19	10.03	6.17	1.04	6.83	32.74
Sunflower meal	37.38	8.28	6.14	2.21	15.60	30.39
	38.43	7.92	6.44	2.06	13.26	31.89
Mean	37.90	8.10	6.29	2.13	14.43	31.15
Pigeon peas	22.00	11.15	4.25	2.15	8.40	52.05
	22.60	11.11	4.23	2.46	7.92	51.68
Mean	22.30	11.13	4.24	2.30	8.16	51.87

Appendix A.2: Proximate composition of the diets used in Experiment 1.

Experimental diets	Chemical composition (%)					
	Protein	Moisture	Ash	Fat	Fibre	NFE
0% Raw pigeon peas	21.80	11.10	5.15	6.48	5.14	50.33
(Control diet)	22.20	11.40	5.23	6.56	5.02	49.59
Mean	22.00	11.25	5.19	6.52	5.08	49.96
+10% Raw pigeon peas	21.65	11.55	5.25	5.95	5.32	50.28
	21.59	11.09	5.23	6.33	5.16	50.60
Mean	21.62	11.32	5.24	6.14	5.24	50.44
+15% Raw pigeon peas	21.50	11.42	5.05	6.26	5.42	50.35
	21.70	11.37	5.19	6.58	5.34	49.82
Mean	21.60	11.40	5.12	6.42	5.38	50.08
+20% Raw pigeon peas	21.95	10.84	5.18	6.12	5.58	50.33
	21.21	11.56	5.36	6.34	5.70	49.83
Mean	21.58	11.20	5.27	6.23	5.64	50.08

Appendix A.3: Proximate composition of the diets used in Experiment 2.

Experimental diets	Chemical composition (%)					
	Protein	Moisture	Ash	Fat	Fibre	NFE
+20% Raw pigeon peas	21.16	11.80	5.18	6.08	5.11	50.67
	21.84	11.28	5.24	6.20	4.93	50.51
Mean	21.50	11.54	5.21	6.14	5.02	50.59
+20% Autoclaved pigeon peas ($121^{o}C$, 1.05 kg/	21.42	10.56	5.40	6.05	5.56	51.01
cm^2 for 15 min.)	21.52	10.72	5.16	5.95	5.94	50.71
Mean	21.47	10.64	5.28	6.00	5.75	50.86
+20% autoclaved pigeon peas ($121^{o}C$, 1.05 kg/	21.00	10.98	5.49	6.39	5.20	50.94
cm^2 for 30 min.)	21.80	11.36	5.25	6.43	4.98	50.18
Mean	21.40	11.17	5.37	6.41	5.09	50.56
+ 20% steamed pigeon peas (Steamed for	21.35	10.60	5.40	6.36	5.15	51.14
30 min.)	21.49	11.04	5.10	6.52	4.91	50.94
Mean	21.42	10.82	5.25	6.44	5.03	51.04

Appendix A.4: Proximate composition of the diets used in Experiment 3

Experimental diets	Chemical composition (%)					
	Protein	Moisture	Ash	Fat	Fibre	NFE
+20% Raw pigeon peas	21.35	9.77	7.11	5.69	5.37	50.71
Unsupplemented	21.55	9.39	7.37	5.79	5.33	50.57
Mean	21.45	9.58	7.24	5.74	5.35	50.64
+20% Raw pigeon peas +	21.47	9.42	7.26	5.32	5.24	51.29
+ 0.2% DL-methionine	21.39	9.50	7.28	5.28	5.42	51.13
Mean	21.43	9.46	7.27	5.30	5.33	51.21
+ 20% Raw pigeon peas + 0.2% DL-	21.36	9.37	7.30	5.45	5.18	51.34
methionine + 0.1% L-try.	21.62	9.55	7.08	5.51	5.26	50.98
Mean	21.49	9.46	7.19	5.48	5.22	51.16
+ 20% Autoclaved pigeon pea	21.32	9.34	7.28	5.67	5.35	51.04
Unsupplemented	21.14	9.36	7.32	5.73	5.37	51.08
Mean	21.23	9.35	7.30	5.70	5.36	51.06
+ 20% Autoclaved[1] pigeon peas	21.35	9.30	7.44	5.89	5.20	50.82
+ 0.2% DL-methionine	21.37	9.46	7.40	5.83	5.20	50.74
Mean	21.36	9.38	7.42	5.86	5.20	50.78
+20% Autoclaved[1] pigeon peas	21.40	9.25	7.00	5.55	5.4L	51.39
+0.2% DL-meth. +0.1% L-try.	21.50	9.29	7.20	5.71	5.51	50.79
Mean	21.45	9.27	7.10	5.63	5.46	51.09

[1]Autoclaved at 121^{O}C, 1.05 kg/cm^2 for 15 minutes.

Appendix A.5: Mean weekly body weight gains (g) of broiler chicks fed broiler starter diets containing varying levels of raw pigeon peas from 0 to 5 weeks in Experiment 1

Treatments	Replicate	Mean body weight gain (g) per chick				
		Week 1	Week 2	Week 3	Week 4	Week 5
0% Raw pigeon peas	1	67	135	200	235	285
	2	65	136	180	215	265
	3	67	140	180	210	265
	Mean	66	137	187	220	272
+ 10% Raw pigeon peas	1	74	101	182	206	262
	2	57	144	180	195	275
	3	69	133	183	222	274
	Mean	67	126	182	208	270
+ 15% Raw pigeon peas	1	64	157	170	240	280
	2	65	107	185	205	270
	3	65	121	175	200	265
	Mean	65	128	177	215	272
+ 20% Raw pigeon peas	1	64	133	150	185	260
	2	63	119	190	195	230
	3	64	127	175	210	255
	Mean	64	126	172	197	248

Analysis of Variance

Source	df	SS	F
Total	11	18184.300	
Treatments	3	8771.633	2.49
Error	8	9412.667	

Appendix A.6: Mean weekly feed consumption (g) of broiler chicks fed diets containing varying levels of raw pigeon peas in Experiment 1.

Treatments	Replicates	Mean feed consumption (g) per chick				
		Week 1	Week 2	Week 3	Week 4	Week 5
0% Raw pigeon peas peas	1	107	215	345	515	640
	2	90	210	330	435	555
	3	100	215	315	480	580
	Mean	99	213	330	477	592
+ 10% Raw pigeon peas	1	105	169	306	425	606
	2	90	220	320	435	580
	3	117	227	300	489	634
	Mean	104	205	309	450	607
+ 15% Raw pigeon peas	1	98	240	340	525	625
	2	90	180	310	435	595
	3	125	210	310	455	595
	Mean	104	210	320	472	605
+ 20% Raw pigeon peas	1	110	225	305	450	595
	2	87	205	325	460	590
	3	100	225	315	485	615
	Mean	99	218	315	465	600

Analysis of variance

Source	df	SS	F
Total	11	64209.00	
Treatments	3	2669.00	0.116
Error	8	61540.00	

Appendix A.7: Mean weekly feed conversion efficiency (F.C.E.) ratios of broiler chicks fed diets containing varying levels of raw pigeon peas in Experiment 1.

Treatments	Replicates	Mean F.C.E. ratio per chick				
		Week 1	Week 2	Week 3	Week 4	Week 5
0% Raw pigeon peas	1	1.60	1.60	1.72	2.19	2.25
	2	1.38	1.54	1.83	2.02	2.09
	3	1.49	1.54	1.75	2.29	2.19
	Mean	1.49	1.56	1.77	2.17	2.18
+ 10% Raw pigeon peas	1	1.41	1.67	1.69	2.06	2.31
	2	1.57	1.53	1.78	2.23	2.11
	3	1.72	1.71	1.64	2.20	2.31
	Mean	1.56	1.63	1.70	2.16	2.24
+ 15% Raw pigeon peas	1	1.52	1.53	2.00	2.19	2.23
	2	1.40	1.67	1.68	2.12	2.20
	3	1.91	1.73	1.77	2.27	2.25
	Mean	1.61	1.63	1.81	2.19	2.23
+ 20% Raw pigeon peas	1	1.73	1.69	2.03	2.43	2.29
	2	1.39	1.73	1.71	2.25	2.56
	3	1.56	1.61	1.80	2.31	2.41
	Mean	1.56	1.73	1.83	2.35	2.42

Analysis of variance

Source	df	SS	F
Total	11	0.0631670	
Treatments	3	0.0468336	7.65*
Error	8	0.0163334	

Appendix A.8: Mean weekly body weight gains (g) of broiler chicks fed diets containing 20% raw or the variously heat-treated pigeon peas from 0 to 5 weeks in Experiment 2.

Treatments	Replicates	Mean body weight gains (g) per chick				
		Week 1	Week 2	Week 3	Week 4	Week 5
+20% Raw pigeon peas	1	62	97	125	150	175
	2	41	106	138	144	163
	3	64	101	156	163	131
	Mean	56	101	140	152	156
+20% Autoclaved pigeon peas (121^{0}C, 1.05 kg/cm^2 for 15 mins.)	1	48	105	156	175	175
	2	72	118	150	169	171
	3	49	98	150	137	144
	Mean	56	107	152	160	163
+20% Autoclaved pigeon peas (121^{0}C, 1.05 kg/cm^2 for 30 minutes)	1	55	92	125	144	151
	2	51	89	156	150	155
	3	58	101	144	138	140
	Mean	55	94	142	144	149
+20% Steamed pigeon peas (30 minutes)	1	58	96	150	163	169
	2	50	90	119	131	144
	3	59	94	150	144	155
	Mean	56	93	140	146	156

Analysis of variance

Source	df	SS	F
Total	11	17397.000	
Treatments	3	5533.666	1.24
Error	8	11863.334	

Appendix A.9: Mean weekly feed consumption (g) of broiler chicks fed diets containing 20% raw or the variously heat-treated pigeon peas in Experiment 2.

Treatments	Replicates	Mean feed consumption (g) per chick				
		Week 1	Week 2	Week 3	Week 4	Week 5
+20% Raw pigeon peas	1	112	200	262	375	437
	2	75	194	262	319	400
	3	100	200	306	387	413
	Mean	96	198	277	360	417
+20% Autoclaved pigeon peas (121°C, 1.05 kg/cm² for 15 minutes)	1	88	194	269	400	475
	2	106	206	281	364	414
	3	75	175	269	294	325
	Mean	90	192	273	353	405
+20% Autoclaved pigeon peas (121°C, 1.05 kg/cm² for 15 minutes)	1	94	169	231	319	386
	2	87	162	263	331	371
	3	94	194	300	331	386
	Mean	92	175	265	327	381
+20% steamed pigeon peas (30 minutes)	1	106	181	288	419	513
	2	75	181	237	300	331
	3	94	181	275	325	400
	Mean	92	181	267	348	415

Analysis of variance

Source	df	SS	F
Total	11	160365.00	
Treatment	3	18183.00	0.34
Error	8	142182.00	

Appendix A.10: Mean feed conversion efficiency (F.C.E.) ratios of broiler chicks fed diets containing 20% raw or the variously heat-treated pigeon peas in Experiment 2.

Treatments	Replicates	Mean F.C.E. ratio per chick				
		Week 1	Week 2	Week 3	Week 4	Week 5
+20% Raw pigeon peas	1	1.82	2.05	2.10	2.50	2.50
	2	1.82	1.83	1.91	2.22	2.46
	3	1.55	1.98	1.96	2.38	3.14
	Mean	1.72	1.95	1.98	2.37	2.67
+20% Autoclaved pigeon peas (121°C, 1.05 kg/cm² for 15 mins)	1	1.82	1.85	1.72	2.29	2.71
	2	1.47	1.75	1.87	2.16	2.42
	3	1.54	1.78	1.79	2.14	2.26
	Mean	1.59	1.79	1.79	2.20	2.48
+20% Autoclaved pigeon peas (121°C, 1.05 kg/cm² for 15 mins)	1	1.70	1.84	1.85	2.22	2.38
	2	1.71	1.82	1.68	2.21	2.39
	3	1.61	1.91	2.09	2.41	2.75
	Mean	1.67	1.86	1.87	2.28	2.56
+20% Steamed pigeon peas (30 minutes)	1	1.85	1.90	1.92	2.58	2.04
	2	1.50	2.00	2.00	2.29	2.30
	3	1.58	1.93	1.83	2.26	2.57
	Mean	1.65	1.94	1.91	2.39	2.66

Analysis of variance

Source	df	SS	F
Total	11	0.1627670	
Treatments	3	0.0563003	1.41
Error	8	0.1064667	

Appendix A.11: Mean weekly body weight gains (g) of broiler chicks fed diets containing 20% raw or autoclaved pigeon peas unsupplemented, or supplemented with 0.2% DL methionine or 0.2% DL-methionine and 0.1% L-tryptophan from 0 to 4 weeks in Experiment 3

Treatments	Replicates	Mean body weight gains (g) per chick			
		Week 1	Week 2	Week 3	Week 4
+20% Raw pigeon peas unsupplemented	1	52	81	142	226
	2	47	118	174	217
	3	38	94	197	206
	Mean	46	98	171	216
+20% Raw pigeon peas + 0.2% DL-methionine	1	46	106	182	225
	2	44	105	190	214
	3	47	98	165	215
	Mean	46	103	179	218
+20% Raw pigeon peas + 0.2% DL-methionine + 0.1% L-tryptophan	1	47	105	190	246
	2	55	114	183	220
	3	49	90	172	202
	Mean	50	103	182	223
+20% Autoclaved pigeon peas unsupplemented	1	52	97	212	235
	2	65	122	180	225
	3	49	113	209	209
	Mean	55	111	200	223
+20% Autoclaved pigeon peas + 0.2% Dl-methionine	1	59	123	197	223
	2	60	116	210	217
	3	44	96	198	220
	Mean	54	112	202	220
+20% Autoclaved pigeon peas + 0.2% DL-methionine + 0.1% L-tryptophan	1	60	124	210	229
	2	56	116	215	220
	3	65	131	210	227
	Mean	60	124	212	225

Analysis of variance

Source	df	SS	F
Total	17	23786.000	
Treatments	5	16662.666	5.61*
Error	12	7123.334	

Appendix A.12: Mean weekly feed consumption (g) of broiler chicks fed diets containing 20% raw or autoclaved pigeon peas unsupplemented, or supplemented with 0.2% DL-methionine or 0.2% DL-methionine and 0.1% L-tryptophan in Experiment 3.

Treatment	Replicates	Mean feed consumption (g) per chick			
		Week 1	Week 2	Week 3	Week 4
+20% raw pigeon peas unsupplemented	1	110	149	279	470
	2	99	203	324	539
	3	69	217	407	587
	Mean	93	190	337	532
20% Raw pigeon peas + 0.2% DL-methionine	1	80	191	331	521
	2	91	192	353	534
	3	92	188	325	531
	Mean	88	190	336	529
20% Raw pigeon peas + 0.2% DL-methionine + 0.1% L-tryptophan	1	109	202	362	541
	2	104	188	316	489
	3	79	183	350	553
	Mean	97	191	343	528
20% Autoclaved pigeon peas unsupplemented	1	125	220	425	541
	2	97	198	344	607
	3	111	221	417	596
	Mean	111	213	395	581
20% Autoclaved pigeon peas + 0.2% DL-methionine	1	90	197	341	516
	2	98	119	361	529
	3	106	175	348	529
	Mean	98	190	350	525
20% Autoclaved pigeon peas + 0.2% DL-methionine + 0.1% L-tryptophan	1	95	216	365	492
	2	95	196	365	468
	3	99	219	361	491
	Mean	96	210	364	484

Analysis of variance

Source	df	SS	F
Total	17	107269.00	
Treatments	5	54525.66	2.48
Error	12	52743.34	

Appendix A.13: Mean feed conversion efficiency (F.C.E.) ratios of broiler chicks fed diets containing 20% raw or autoclaved pigeon peas, unsupplemented or supplemented with 0.2% DL-methionine, or 0.2% L-tryptophan

Treatment	Replicate	Mean F.C.E. ratio per chick			
		Week 1	Week 2	Week 3	Week 4
+20% Raw pigeon peas	1	2.12	1.84	1.96	2.08
	2	2.09	1.72	1.86	2.47
	3	1.82	2.31	2.07	2.85
	Mean	2.03	1.94	1.97	2.46
20% Raw pigeon peas + 0.2% DL-meth.	1	1.73	1.81	1.82	2.32
	2	2.04	1.83	1.86	2.50
	3	1.92	1.92	1.97	2.47
	Mean	1.91	1.85	1.88	2.43
20% Raw pigeon peas + 0.2% DL-meth. +0.1% L- try.	1	2.32	1.92	1.91	2.20
	2	1.89	1.64	1.73	2.22
	3	1.61	2.03	2.03	2.75
	Mean	1.93	1.85	1.89	2.37
20% Autoclaved pigeon peas unsupplemented	1	2.41	2.26	2.00	2.30
	2	1.50	1.63	1.91	2.70
	3	2.27	1.95	2.00	2.86
	Mean	2.01	1.92	1.97	2.61
20% Autoclaved pigeon peas + 0.2% DL-meth.	1	1.53	1.60	1.73	2.31
	2	1.62	1.71	1.72	2.43
	3	2.43	1.83	1.76	2.41
	Mean	1.80	1.70	1.74	2.38
20% Autoclaved pigeon peas + 0.2% DL-meth. + 0.1% L-try.	1	1.58	1.73	1.74	2.15
	2	1.69	1.69	1.70	2.13
	3	1.52	1.67	1.72	2.15
	Mean	1.59	1.70	1.72	2.15

Analysis of variance

Source	df	SS	F
Total	17	0.443645	
Treatment	5	0.248645	3.06
Error	12	0.195000	