AVAILABILITY OF NUTRIENTS IN VEGETABLE PROTEIN SUPPLEMENTS FOR THE CHICK

by

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ABSTRACT

Content and availability of nutrients in four vegetable protein supplements (palm kernel, soybean, cottonseed and rapeseed meals) were determined using growing chicks. Average availability of sixteen amino acids in these feedstuffs ranged from 84.5% (palm kernel meal) to 97.3% (soybean meal). Palm kernel meal was lowest and soybean meal highest in content of essential amino acids.

Results of mineral availability (calcium, phosphorus, magnesium, manganese, zinc and copper) indicated high content and availability of calcium, phosphorus and magnesium; low content and availability of zinc and copper. Average availability of minerals varied from 50.0% (palm kernel meal) to 74.3% (soybean meal). Among mineral elements tested, phosphorus (78.0%) and calcium (72.6%) showed the highest availability while zinc (44.0%) was least available. Crude fibre and phytic acid were implicated as factors depressing availability of minerals tested. Crude fibre content was inversely related to availability of all six minerals tested while phytic acid content significantly ($P \leq 0.01$) affected availability of phosphorus, calcium, zinc and magnesium.

Metabolizable energy (ME) of the feedstuffs determined using three week old broiler chicks, ranged from 1957 kcal/kg dry matter (rapeseed meal) to 2796 kcal/kg dry matter (palm kernel meal).

Chemical constituents, available carbohydrate and metabolizable energy content of seven different rapeseed meals

were determined. Metabolizable energy values ranged from 1492 kcal/kg (Span A) to 1957 kcal/kg (commercial RSM). Of all chemical constituents tested, ether extract, sugar and starch content were most significantly ($P \leq 0.01$) related to metabolizable energy and were incorporated into equations to predict ME of rapeseed meal from their chemical constituents.

Content and availability of six minerals (Ca, P, Mg, Mn, Zn, Cu) were determined using the test rapeseed meals. Samples were high in calcium, phosphorus and magnesium and low in copper in comparison to other vegetable protein supplements. Average availability of minerals ranged from 52.2% (Span A) to 64.0% (commercial RSM). Among minerals tested, phosphorus (75.3%), copper (74.3%) and calcium (68.0%) showed the highest availabilities. Zinc was least available (44.1%).

Treatment of palm kernel meal with 3%, 5% or 7% NaOH in an attempt to delignify the material and improve its nutritive value, caused a reduction in protein, acid detergent fibre and acid detergent lignin content of the meal. There was considerable amino acid destruction, the extent being directly related to the severity of the alkali treatment. Incorporation of alkali-treated meal at 30% level into broiler starter rations depressed growth rate and feed efficiency of chicks.

Inclusion of palm kernel meal at 10%, 20% or 30% into a standard broiler starter diet significantly ($P \leq 0.05$) increased average daily gain of chicks over controls. Highest growth rate and feed efficiency were observed in chicks on the 10% PKM ration. Increased level of PKM incorporation slightly depressed feed efficiency but not growth rate of chicks. The

need for increased utilization of vegetable protein supplements in chick rations especially in the developing countries was discussed.

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INTRODUCTION

In current practice, the nutritive value of a feedstuff is determined by the content of the various nutrients in that feed ingredient, and feed formulation is based on these values. Amino acid content in rations for various types of livestock are calculated on total quantities of the various amino acids in the mixed ration. Mineral content of rations is similarly calculated on the sum of the various minerals in feed ingredients. Recent research has however indicated that what is present is not all available and there is a significant difference between total content of nutrients and quantities available. Just as gross energy is not a true indication of energy available to an animal for metabolism, so is total lysine or phosphorus content not a reliable indication of the amounts available to livestock. For most animals including man the minimum requirements and recommended levels of amino acids were determined with synthetic amino acids or high quality easily digestible proteins. More recently, increasing amounts of unconventional, vegetable or low quality proteins are being incorporated into rations for livestock. Unless it can be shown that availability of amino acids from these low quality proteins equals that from the more conventional proteins and from amino acid mixtures, it makes no sense to use without modification, these minimum requirements and recommended levels of amino acids as published by the National Research Council. Similarly, minimum requirements and recommended levels of various minerals for different livestock have been determined using total mineral content in mixed

rations. This practice assumes that all minerals in the ration are highly available. With increasing use of vegetable and other feed ingredients in ration formulation, it is necessary to determine how much of the total mineral content is really available to animals.

Certain feedstuffs (e.g. soybean meal) enjoy almost universal acceptance in ration formulation. Others (e.g. palm kernel meal) are not so well accepted mostly as a result of paucity of information concerning their nutritive value. Palm kernel meal is produced in large quantities in the countries of Africa and South East Asia. Yet in these and other countries only about 10% of the production is used in animal feeds, the rest of it being incorporated into the soil as fertilizers. Rapeseed meal produced commercially in Canada is currently gaining increased recognition as a protein supplement in poultry rations. In feed formulation, its contribution is however restricted to about 15% of the protein in broiler rations, and is not essentially used in starter rations. Cottonseed meal, produced principally in southern United States and in the tropical and subtropical parts of the world, is also used sparingly in both layer and broiler rations.

In an attempt to stimulate the utilization of lesser known vegetable protein supplements in poultry rations, these experiments were conducted to determine the availability of amino acids and minerals in palm kernel, soybean, cottonseed and rapeseed meals. The level of inclusion of alkali-treated and untreated palm kernel meal in poultry ration, consistent with optimal growth rate and feed conversion was determined.

LITERATURE REVIEW

Methods of determining amino acid availability

Chemical methods of determining amino acid availability are by their very nature, rapid and simple. Their accuracy has however not been fully established. Dye binding (Moran et at., 1963; Mossberg, 1968) has been used to estimate the protein quality of processed and unprocessed feed ingredients. Carpenter (1960) reacted 1-fluoro-2:4-dinitrobenzene with the epsilon amino group of lysine in feedstuffs to demonstrate availability of lysine. Because of problems associated with the Carpenter - FDNB method, a modification was suggested by Rao et al. (1963). This was further investigated by Roach et al. (1967) who determined total lysine in the sample and residual lysine in the hydrolysate following acid hydrolysis of the FDNB treated sample. The difference was taken as free epsilon lysine and regarded as available lysine. Kakade and Liener (1969) proposed the TNBS methods in which they used 2, 4, 6-trinitrobenzene sulfonic acid to react with the epsilon amino group of lysine to form epsilon-TNP lysine which was measured colorimetrically and regarded as available lysine.

The methods and importance of enzymatic digestion in qualitative estimation of protein quality and amino acid availability were reviewed by Mauron (1968) who suggested that rate and order of release of the individual amino acids in the digestive tract might be a factor determining the biological value of a protein. He therefore justified the enzymatic digestion procedure. In another review article, Meade (1972) suggested that although enzymatic liberation of amino acids

was useful in determining the relative availabilities of amino acids, limiting amino acids and the limitations of total amino acid values, the method must be developed to the point that values would be useful in formulation of diets for animals and man.

The observation that the consumption of a protein deficient in an amino acid led to a reduced plasma level of that amino acid (Almquist, 1954) led Goldberg and Guggenheim (1962) to study the digestive release of amino acids and their concentrations in the portal plasma of rats after protein feeding. Smith and Scott (1965c) observed in overheated fish meal, that the plasma concentrations of lysine and threonine were depressed, implying that availability was reduced. This was similar to the observation of Goldberg and Guggenheim (1962). In another study, Stockland and Meade (1970) reported differences in availability of isoleucine, threonine and phenylalanine to the rat. These studies were qualitative and no quantitative estimates of per cent availability were reported. Such quantitative estimation would be difficult using this procedure.

Microbiological tests have been proposed for estimating amino acid availability. Ford (1962) using Streptococcus zymogenes measured "available amino acids" as the amounts liberated by the micro-organisms after partial enzymatic hydrolysis, in comparison to "total amino acids" released following acid or alkaline hydrolysis. This method reflected differences in availability of amino acids as associated with differences in protein quality and with heat treatment. Stott and Smith (1966) used Tetrahymena pyriformis W for measuring availability of lysine, methionine, arginine and histidine in various plant

and animal protein feedstuffs. In contrast with Streptococcus zymogenes assays of available amino acids, assays with Tetrahymena pyriformis do not require partial enzymatic hydrolysis and offer the convenience of estimation of two nutritionally important amino acids, lysine and methionine with the same organism (Guggenheim, 1968). Meade (1972) suggested that these techniques would have to be useful for a large number of essential amino acids and the accuracy of their availability values in predicting usefulness of protein sources for animals would have to be determined.

The fecal analysis method as developed by Kuiken and Lyman (1948) measures the retention of dietary amino acids. This procedure differentiates between fecal amino acids of dietary and endogenous origin and therefore yields a value for amino acid availability. Bragg et al. (1969) compared surgically modified chicks and normal chicks in a modification of this procedure to determine amino acid availability of a feedstuff protein. They observed that normal chicks yielded more consistent results than surgically modified chicks and calculated amino acid availability as follows:

$$\% \text{ amino acid (AA) availability} = \frac{\text{Total AA intake} - \text{Total Fecal AA protein diet} - \text{Total Fecal AA non protein diet}}{\text{Total AA intake}} \times 100$$

The observed that amino acid availability represented the fraction of dietary amino acids actually taken up from the gut. Eggum (1968) reported true digestibility of soybean amino acids for rats and pigs comparable to those of Bragg et al. (1969) and Carlson and Bayley (1970). Amino acid availability values

obtained by the fecal analysis method are uniformly high and values greater than 90% commonly occur. Meade (1972) attributed this in part to the correction for metabolic fecal amino acids with resultant determination of true digestibility coefficients for individual amino acids.

Smith and Scott (1965a,b,c) described a chick growth assay for estimating biological availability of amino acids in intact proteins. A crystalline amino acid standard reference diet shown by Dean and Scott (1964) to meet the amino acid requirements of two-week old chicks was used as the basal diet. The amino acids were tested individually. For each amino acid being tested, a standard response curve was obtained by incorporating the amino acid at any of six levels (2,4,6,8,10,12 gm/chick/day in the basal diet). The test proteins were incorporated into the basal diet at the expense of corn starch. The test protein was added at 5% level to a basal diet of the same composition as the reference basal diet but devoid of the amino acid under test. They reported that it was necessary to add small increments of the test amino acid in crystalline form to bring chick growth up to the linear portion of the response curve. The standard response curve was tested for linearity and where necessary, points at the extreme ends of the curve were dropped. The regression equation for the best fitting line so obtained was used to calculate the amounts of amino acids consumed in diets containing the test proteins. Availability was estimated by comparing the calculated intake to actual intake of the test amino acid.

Other methods have also been used to estimate availability

of amino acids in feed ingredients. Gain/feed ratio (Gupta et al., 1958), and carcass nitrogen gained (Calhoun et al., 1960) have been employed in amino acid availability determination. Price et al. (1953) evaluated dietary amino acids and proteins by chick carcass analysis. DeMuelenaere et al. (1967) estimated lysine availability of cereal products by fecal and growth analysis while Sarwar et al. (1975) evaluated the availability of amino acids in processed and unprocessed soybean and rapeseed meal by a combination of fecal and carcass analysis.

A general problem common to all methods of estimating amino acid availability is the use of strong acids and alkalis to hydrolyse proteins before chromatography. During such acid hydrolysis, tryptophan is completely destroyed and must be determined by a different procedure. Methionine, cystine, threonine, tyrosine and serine suffer considerable destruction unless hydrolysis is with 3N Hcl for sixteen hours. Methionine and cystine are usually oxidised with performic acid before acid hydrolysis. Chemical methods for estimating amino acid availability are rapid and simple and have the high degree of reproducability common to most chemical procedures. They do not however have a high correlation with animal performance and their accuracy has not been fully established. This is typified by the DNFB - available lysine value of 3.0 g/16 gN for cod fillet, which is very high in comparison with a value of 1.3 g/16 gN measured with rats and 2.2 g/16 gN measured microbiologically following prolonged proteolytic digestion (Ford and Salter, 1966). The plasma free amino acid method is both simple and rapid. Its criticism has been based on the

suggestion (Ford and Salter, 1966) that endogenous protein is digested and reabsorbed and buffers changes in the pattern of amino acids passed to the portal blood. Hence a measure of plasma free amino acids will not be a true indication of availability of amino acids from dietary protein. It is believed that the mucosal barrier may similary exercise a regulatory effect during active transport of amino acids from the gut. Nasset (1956) concluded that the digestive tract imposed a set pattern on the amino acid mixture available for absorption after ingestion of a test meal; consequently the plasma free amino acid pattern would fail as an indicator of availability of amino acids from a test protein source. The microbiological assay of Ford (1962) using Streptococcus zymogenes required partial enzymatic hydrolysis of the test protein, while the procedure of Stott and Smith (1966) utilizing Tetrahymena pyriformis W eliminated the need for predigestion with proteolytic enzymes. The latter assay is capable of simultaneously estimating availability of many essential amino acids including lysine and methionine. Both methods are rapid and easy assays to carry out but are however reported to underestimate amino acid availability. Stott and Smith (1966) observed that lysine availability values estimated microbiologically were much lower (about 60%) than those obtained by the FDNB method while Ford (1964) observed that lysine availability in leaf proteins was lower with microbiological assays than with the FDNB method.

The chick growth assay is a popular test for amino acid availability of proteins. It measures that fraction of the ingested amino acids that have been actually utilized for growth

and consequently such an estimate would be lower than availability estimates by the fecal analysis method. It is however a long and tedious procedure for evaluating amino acids individually. It penalises the test amino acid whenever optimal growth fails to occur and does not take into consideration the fact that in a low energy protein supplement, substitution even at 5% can depress growth due to insufficient metabolizable energy. The procedure also fails to consider the contribution of other amino acids in the test protein in inducing either amino acid imbalance (and therefore reduced growth) or increased growth. The practice of dropping extreme points in the standard response curve, the use of amino acid mixtures which are not in optimal balance for the age of the test chicks and the use of racemic mixtures of amino acids for deriving standard response curves, are possible sources of error when this procedure is employed to estimate amino acid availability. The fecal analysis method of Kuiken and Lyman (1948) and the availability procedure of Bragg et al. (1969) offer a rapid, easy and accurate method of estimating amino acid availability.

Measurement of endogenous amino acid excretion differentiates these methods from apparent digestibility assays and estimates the disappearance of amino acids from ingested proteins. The methods afford an opportunity to measure availability of twenty amino acids simultaneously and because the test period is short, the nitrogen equilibrium of the test birds is not unduly disturbed. In addition, because a large number of chicks can be utilized, stringent statistical tests can be applied, an impossibility in many biological assays.

Availability of amino acids in plant protein feedstuffs

Estimates of per cent availability obtained with the various methods differ. Those obtained with the fecal analysis method are generally higher than those obtained by any of the biological assay techniques. The per cent availabilities of amino acids in soybean meal are higher than in cottonseed meal, rapeseed meal, peanut meal or other commonly used vegetable protein supplements.

True digestibility of amino acids in soybean meal was reported by Eggum (1968) to range from 85.8% to 96.2% for non ruminants. Cho and Bayley (1970) using pig fecal analysis estimated mean apparent digestibilities of amino acids in soybean meal in the range of 70.0% to 92.7%. The apparent digestibility of all amino acids was 88.5%. Flipot et al. (1971) using chickens observed a range of 87.0% to 97.0% for availability of constituent amino acids of soy protein. Ivy et al. (1971) evaluated eight commercial samples of soybean meal. For all samples, the range in availability was 92.0% to 100.0%. Sarwar et al. (1975) using rats, reported a range of 85% to 95% for availability of amino acids in commercial soybean meal. Using a chick growth assay, Smith (1968) reported a range of 51.9% to 103.0%. He observed that in general, availabilities of amino acids were high with the exception of valine (51.9%), phenylalanine (59.2%), and isoleucine (65.4%). Carlson and Bayley (1970) using piglets observed a range of 82.2% to 92.6% for true digestibilities of amino acids in soybean meal.

Kuiken and Lyman (1948) reported a range of 63.6% to 93.7%

for true digestibility of essential amino acids in cottonseed flour. They showed that marked variations in amino acids occurred for this feedstuff. In another study, Kuiken (1952) estimated the availability of essential amino acids in commercial cottonseed products. The range for amino acid availabilities of the various cottonseed products were as follows: hydraulic meal 67.0% to 95.0%; hydraulic meal with 2% sulfasuxidine 68.0% to 93.0%; screw press meal 79.0% to 95.0%; hexane extracted meal 84.0% to 98.0%; hexane extracted degossypolized meal 83.0% to 97.0%; gland free meal 85.0% to 97.0%. Meals with lowest gossypol content gave the highest amino acid availabilities. Thyong (1967) reported lysine availability in cottonseed cake and cottonseed meal as 67.3% and 72.5% respectively. It is of considerable interest to note that cottonseed products have a high level of essential amino acids which are well utilized. With the current technology now available in the processing industry, there should be increased use of cottonseed meal in non ruminant rations.

Cho and Bayley (1970) determined the apparent digestibility coefficients of amino acids in rapeseed meal by pig fecal analysis. Their results (77.5% to 91.0%) were lower than the range of 81.0% to 92.0% reported by Sarwar et al. (1975). Using chickens, Tao et al. (1971) had observed that true amino acid digestibility of rapeseed meal ranged from 59.8% to 81.9%. Some of these differences in published values for amino acid availabilities may be due to variations in content of toxic or other substances in samples assayed.

The availability of amino acids in other protein supple-

ments have also been estimated. Kuiken and Lyman (1948) observed high availability of ten essential amino acids in peanut flour (range of 94.8% to 99.5%). Eggum (1968) also reported high availability of sixteen amino acids in peanut meal (range of 87.8% to 95.4%) and sunflower meal (range of 86.9% to 96.3%). No information was discovered in the literature on availability of amino acids in palm kernel meal.

Factors affecting availability of amino acids

It is known that the nutritive value of a protein depends not only on its pattern of amino acids but also on the biological availability of these amino acids. The amounts of amino acids present in a feed ingredient are not necessarily the same amounts available to the animal. Factors reducing amino acid availability include incomplete digestion and absorption, processing conditions, presence of inhibitors of digestive enzymes, crude fibre, tannins and other physical and chemical binding agents.

Southgate and Durnin (1970) reported that as the intake of dietary fibre increased, the apparent digestibility of other constituents in the diet (protein, fat, energy) was reduced. Southgate (1973) suggested that the increased bulk of non-assimable material in the large and small intestine had an effect on transit time, so that there was less time for the processes of digestion and absorption. Several workers (Dammers, 1965; Tao et al., 1971; Flipot et al., 1971) have also implicated crude fibre as a factor reducing amino acid digestibility in protein feedstuffs. Toxic constituents in feed (Stephenson, 1972) and phytate (Nelson, 1967) have been suggested as factors which reduce digestion and absorption of proteins. Any factor which affects digestion and absorption of proteins will certainly affect amino acid availability.

The presence of tryptic and other inhibitors of proteolytic enzymes has been established in many legumes. They lower the digestibility of proteins (Lepkovsky et al., 1965) and may

reduce availability of amino acids.

Protein-carbohydrate interactions occur between amino groups of the protein and reducing carbohydrates present, to form compounds which render amino acids unavailable to animals. Lea and Hannon (1950) using a casein-glucose system as a model showed that in appropriate conditions, nearly all the lysine could be rendered unavailable. The amino acid-carbohydrate complex cannot be hydrolysed by digestive enzymes and are a loss to the animal. Nesheim (1965) stated that protein-carbohydrate reactions could proceed to the point where complete destruction of the component amino acids took place.

Reactions between the terminal amino group of lysine and the carbonyl secondary decomposition products of auto oxiding fats may reduce amino acid availability, by forming linkages resistant to the action of digestive enzymes. The type of damage done depends on the conditions. Lea et al. (1960) reported that at temperatures below 100°C, lysine was lost by reaction with auto oxidising fat, while at higher temperatures (115-130°C) the loss was apparently independent of the presence of fat.

Damage to amino acids is proportional to the time and temperature applied beyond a critical point. Greaves et al. (1938) had pointed out that casein was heat damaged at 120°C but not at 100°C and above this critical temperature, the amount of damage was proportional to the time of heating.

Lea and Hannon (1949) observed that 10% to 14% moisture was the point of highest protein damage when protein was heated while Carpenter et al. (1962) reported that loss of

available lysine in heated herring meal was greatest at 5% to 14% moisture.

Tannins have also been implicated in reduced amino acid availability. Glick and Josyln (1970) observed a three to fourfold increase in level of activity of intestinal proteolytic enzymes of rats fed tannic acid and also concluded that endogenous proteins accounted in part for the high fecal nitrogen observed when tannic acid was fed to rats. Similarly, Rostagno et al. (1973) observed a fourfold increase in endogenous amino acid excretion when 1.41% tannic acid was added to a protein free diet. These workers using sorqhum grain, demonstrated decreased average amino acid availabilities (73.0%, 41.5%, 25.6% and 22.2%) as the tannic acid content increased (0.33%, 0.59%, 1.10% and 1.41% respectively). This was in agreement with the observation of Stephenson et al. (1971) that amino acid availability values of high tannin sorghum (Georgia 609) were much lower than values of sorghum RS610. Rostagno et al. (1973) could not however explain the apparent depression of amino acid availability by tannins.

Methods of determining metabolizable energy of feed ingredients

A satisfactory basic diet and procedure for determining the metabolizable energy content of feed ingredients for poultry was worked out by Hill and associates (Hill and Anderson, 1958; Hill et al., 1960). They proposed a wheat-synthetic basal diet in which the experimental material was incorporated at a level of 40 per cent at the expense of glucose. This procedure has been used extensively to determine the metabolizable energy of grain and grain products (Hill et al., 1960), soybean products (Hill and Renner, 1960), peanut meal, sesame meal, cottonseed meal, safflower meal and copra meal (Zablan et al., 1963). Sibbald and Slinger (1962) reported a procedure utilizing a practical type basal diet into which graded amounts of the test ingredient were substituted. A tremendous amount of investigation into the metabolizable energy content of various feed ingredients has been carried out using these procedures or with slight modifications indicating the importance of the methods. Feed intake and fecal output have been determined by total collection or by use of a marker (Lindahl, 1963). Indicator methods have the advantage that measurement of feed intake or fecal output is unnecessary. However, Moore (1957) observed that partial sampling procedures in digestibility experiments using index substances were only valid when the fecal excretion curves for nutrient and indicator were similar and there was no settling out or loss of index substance from the feed.

Carew (1973) noted that the determination of chromium was

tedious, time consuming and the results were not always satisfactory. Kotb and Luckey (1973) observed that the use of silica as an indicator could be unreliable. McCarthy et al. (1974) and Vogtmann et al. (1975) reported the possibility of using acid insoluble ash to determine metabolizable energy in non ruminants. These workers observed that the ash remaining after treatment of the sample with 4N HCl and ashing the residue could be a suitable index for determining digestibility of feeds. This method is rapid and less tedious than the total collection or chromic oxide procedure and has been reported by these workers to be accurate. When its accuracy is confirmed through repeated experimentation, it has the potential of dominating other research methods for metabolizable energy determination.

More recently, Sibbald (1975, 1976) proposed a bioassay for determination of true metabolizable energy of feedingstuffs. He observed that conventional metabolizable energy results were affected by the level of feed intake and because the combined metabolic and endogenous losses were charged against the energy intake, at low levels of feed consumption, negative metabolizable energy could be obtained. He proposed a procedure involving force feeding of previously starved adult roosters and collection of voided excreta. Using various feedingstuffs, he reported a linear relationship between energy voided as excreta in 24 hours (Ye) and feed input (X). True metabolizable energy (TME) values were calculated as follows:

$$TME\,(kcal/kg) = \frac{(G.E._f \times X) - (Ye - 9.84)}{X}$$

where $G.E._f$ = Gross energy of feed

X = Feed input

Ye = Total energy voided as excreta in 24 hours

9.84 = Sum of metabolic fecal energy (FE_m) and endogenous urinary energy (UE_e) excreted independently of the feed intake during 24 hours

The assay appears to be rapid and involves few chemical analyses. Sibbald (1975) notes that development work on the procedure will be required before it can be widely accepted and observes that it offers potential advantages in respect of time, cost and validity of data obtained.

Metabolizable energy of vegetable feed ingredients

Hill and Renner (1960) first investigated the metabolizable energy content of various soybean products for the chick. They reported metabolizable energy values of 44% and 50% protein meals as 2244 kcal/kg and 2530 kcal/kg respectively. Depressed metabolizable energy was observed for the low protein mill feed (770 kcal/kg) or high protein mill feed (1254 kcal/kg). Soybeans, raw (2420 kcal/kg) or autoclaved (3168 kcal/kg) gave higher metabolizable energy values. Raw extracted soybean flakes had a metabolizable energy value of 616 kcal/kg while autoclaved soybean flakes were higher (2122 kcal/kg). Renner and Hill (1960) showed that mild heat treatment (ten minutes at 107^{o}C) gave the highest metablizable energy value of soybeans, or soybean flakes for chickens. This was due to the inactivation of one or more trypsin inhibitors (Borchers et al., 1948) and the destruction of heat labile soyin (Liener, 1953). Hill and Totsuka (1964) reported a metabolizable energy value of 2780 kcal/kg for commercial soybean meal while Lautner and Zenisek (1965) obtained a value of 2603 kcal/kg. Rojas and Scott (1969) reported the average metabolizable energy of 50% protein commercial solvent extracted soybean meal as 2770 kcal/kg. In another study, they observed that treatment of soybean meal with phytase enzyme improved the metablizable energy of 44% and 50% protein soybean meal by 6.5% and 11% respectively.

Lodhi et al. (1969a) determined the available carbohydrate content of soybean and rapeseed meals in an attempt to explain differences in metabolizable energy between the meals. They

observed that in soybean meal, soluble sugars and starch comprised 67% of the nitrogen-free extract as compared to 40% in rapeseed meal. Assuming an energy value of 3.75 kcal/g for the carbohydrate in the two meals, they concluded that 19% of the difference in metabolizable energy between soybean and rapeseed meals could be accounted for by the difference in amount of available carbohydrates. Bolton (1957) observed that sugars and starch in soybean meal were 100% digestible and using a chemical method, showed that the level of sugar plus starch in 49% protein meal was 17.6% of dry matter. The high metabolizable energy values reported for commercial soybean meal is due to a unique combination of high available carbohydrate content, low crude fibre content and extensive denaturation of toxic compounds during processing.

Until recently, the use of cottonseed meal was not popular in poultry diets. It is known to contain gossypol, gossypol-like pigments and cyclopropene fatty acids, and it is deficient in lysine (Phelps, 1966). These factors contributed to the restricted use of cottonseed meal in poultry rations. An earlier study on the metabolizable energy of cottonseed meal (Zablan et al., 1963) had indicated the possibility of using cottonseed meal in poultry rations due to the metabolizable energy content. Hill and Totsuka (1964) recognised that the nutritive value of cottonseed meal to poultry was influenced by such factors as gossypol toxicity, extent of heat damage during processing and the possible presence of a heat labile inhibitory factor in glandless cottonseed. They suggested that decreased metabolizable energy of cottonseed meal was due

to interference of gossypol with digestion and/or absorption of protein or carbohydrate components of cottonseed meal. They reported metabolizable energy values of 2190, 2280 and 2240 kcal/kg for hexane extracted glandless cottonseed meal, heated hexane extracted or mixed solvent extracted cottonseed meal respectively. They observed a moderate (but non significant) inverse correlation between crude fibre content of the meals and their observed metabolizable energy and suggested that difference in crude fibre content could account for about a third of the difference in metabolizable energy between the meals. The remainder of the difference was attributed to differences in protein and carbohydrate utilization of the meals. They suggested that metablizable energy of cottonseed meal could be closely related to the extent of heat damage to protein of the meal. Rojas and Scott (1969) studied the metabolizable energy of commercial, glanded and glandless cottonseed meals produced by screw pressing, solvent extraction, prepress solvent extraction and solvent extraction using a mixed azeotropic solution. These workers reported a range of 1375 kcal/kg (41% protein, experimental solvent extracted meal) to 2490 kcal/kg (52% protein, experimental glandless solvent extracted meal) with a mean of 2182 kcal/kg for all samples of cottonseed meal tested. The metabolizable energy of the glandless, screw press and mixed solvent extracted cottonseed meals were not statistically different. The metabolizable energy of glandless and screw press meals were superior to those of glanded and prepress solvent extracted meals. The average metabolizable energy content of 50% protein solvent extracted soybean meal

was 2770 kcal/kg and it was suggested that the difference in metabolizable energy between cottonseed meal and soybean meal could be attributed to differences in chemical composition in regard to protein, fat and fibre, in protein solubility and to the presence of gossypol in cottonseed meal. Rojas and Scott (1969) and Miles and Nelson (1974) implicated content of phytic acid as a factor depressing metabolizable energy values of cottonseed meal. Metabolizable energy values were improved by treatment with a phytase enzyme. Phytase enzyme treatment apparently improved the metablizable energy by complete hydrolysis of phytin, releasing some proteins from protein-phytate complexes and reduction in gossypol toxicity of glanded cottonseed meals.

Considerable variation has been reported in results of meatabolizable energy of rapeseed meal. Factors implicated as being responsible for observed variation include age of the experimental birds (March et al., 1973), method of assay (Potter, 1971), tannins (Yapar and Clandinin, 1972), available carbohydrate content (Lodhi et al., 1969a) and goitrogen content (Lodhi et al., 1970). Lodhi et al. (1969b) observed metabolizable energy of 1104 kcal/kg while March and Biely (1971) reported a range of 1120 to 1730 kcal/kg for rapeseed meals. In other studies, March et al. (1973) reported metabolizable energy values of 1510 and 1465 kcal/kg for rapeseed meal fed to broiler and white leghorn chicks respectively. Rao and Clandinin (1971) using semi purified or practical diets reported metabolizable energy values of 1126 or 1586 kcal/kg respectively for three-week old chicks while Clandinin (1973)

estimated the metabolizable energy of rapeseed meal as 1760 kcal/kg. Yapar and Clandinin (1972) observed that extraction of tannins improved the metabolizable energy of rapeseed meal from 1171 to 1844 kcal/kg for two-week old chicks and from 1171 to 1766 kcal/kg for six-week old chicks. Seth and Clandinin (1973) reported average metabolizable energy of 2327 kcal/kg for three varieties of low hull rapeseed meal containing 7.76% to 10.30% fibre and 1730 kcal/kg for regular rapeseed meal containing 15% to 17% fibre. The metabolizable energy values of two varieties of rapeseed meal were reported as 1755 and 1860 kcal/kg for four-week old chicks (March et al., 1975) while Sell (1966) reported a value of 2120 kcal/kg for commercial rapeseed meal fed to laying hens.

Very little information is available in the literature on the metabolizable energy of palm kernel meal to chicks. Gohl (1975) reported that metabolizable energy of palm kernel meal for poultry varied from 2150 kcal/kg (mechanical press, 6% ether extract) to 3070 kcal/kg (mechanical press, 10% ether extract). Solvent extracted palm kernel meal was lower in metabolizable energy (2110 kcal/kg). Metabolizable energy values reported for other animals (Latin American Tables of Feed Composition, 1974) were swine (2310-2517 kcal/kg) sheep (2450-2520 kcal/kg) and cattle (2850-3040 kcal/kg) using meals of varying fibre, protein and ether extract content.

Techniques for estimating mineral availability

The apparent digestibility method measures the intake as well as fecal and urinary output of the test minerals and according to Mitchell (1964) was one of the more common methods of determining mineral utilization. It did not account for the metabolic fecal and endogenous urinary losses and tended to underestimate utilization of the test minerals. This procedure assumed that endogenous mineral losses were minimal and ignored them since there were not entirely satisfactory methods of estimating these losses. Early work on mineral availability in ruminants was very simple, all that was required being an estimate of the intake and fecal excretion of the minerals tested. Rook and Campling (1962) observed that a lot of the information published on magnesium availability for ruminants was obtained in balance studies in which apparent digestibility of magnesium was calculated as intake less fecal loss, expressed as a percentage of intake. It soon however became evident that apparent digestibility results were not indicative of the availability of minerals to livestock and a more precise estimate was needed.

The availability or true digestibility method takes into account the observation that not all the mineral in fecal or urinary excretion is of feed origin. Estimation of endogenous mineral excretion involves use of purified mineral free diets or the use of regressions of retention of the element on its intake. The purified diets are so formulated as to exclude all minerals being tested. Duration of the test is short, so

as not to substantially disturb the mineral equilibrium of the test animals. Because endogenous excretion is taken into account in calculating true digestibility, the results obtained are usually higher than apparent digestibility results and are a more realistic estimate of mineral availability.

The carcass analysis technique involves the use of litter mates, some of which are slaughtered at the beginning of the experiment to determine the ratios of body weight to test minerals. The other members of the litter are fed a controlled diet in which the test ingredient is the only source of the minerals under study. Feed intake records are kept. At the end of the experimental period, the test animals are slaughtered, ashed and mineral content determined. Minerals retained expressed as a fraction of mineral intake is an indicator of availability. Armstrong and Thomas (1952) reported no significant differences between calcium availability results obtained by other methods or by the carcass analysis method.

The isotope dilution technique involves injecting intravenously, single (Hansard et al., 1952; 1954) or multiple (Visek et al., 1953) doses of radioisotopes of the test element. At equilibrium, if there is no endogenous excretion of the mineral, the specific activities of the feces and plasma should be identical. Dilution of the total element in the feces by endogenous excretion can be measured by difference in the plasma and fecal specific activities.

Pairs of animals are used in the comparative balance technique. One is dosed orally while the other is injected intravenously with a radioisotope of the test element. It is

assumed that the oral dose completely labels the dietary source of the element. Endogenous excretion is estimated from the intravenously injected animal. True digestibility can therefore be calculated. Aubert et al. (1963) proposed a modification of this procedure, eliminating the use of paired animals by injection of two different isotopes of the same element.

A biological assay technique commonly used in estimating mineral availability is the bone ash method of Gillis et al. (1954). The assay involved the establishment of a standard response curve using a semi purified basal diet and graded levels of an inorganic salt of the test element (assumed to be 100% utilized at low dietary levels). A plot of per cent bone ash of solvent extracted left chick tibia and the logarithm of the percentage dietary mineral gave a straight line. The test ingredient was substituted for a small fraction of the basal diet. Biological availability was defined as the ratio, expressed as a percentage, of the amount of the inorganic salt to the amount of test ingredient which produced the same bone ash when each was added to the basal diet. Per cent bone ash is the most commonly used test for estimating mineral availability in feeds. Nelson (1967) noted that it was one of the most sensitive, practical criteria for evaluating the availability of dietary phosphorus. It is more accurate than body weight measurement and is little affected by other dietary variables that influence growth (Nelson and Walker, 1964).

Another biological assay technique which has been used in estimating mineral availability is the body weight method of

O'Dell and coworkers (1972). Standard response curves are established by supplementing basal diets with graded levels of the test element in inorganic form (assuming 100% utilization). A plot of weight or weight gain versus the logarithm of the supplemental element gives a linear response curve at lower levels of supplementation. The test ingredients are analysed and subsequently substituted for carbohydrate in the basal diet at low levels. The quantity of biologically available mineral is estimated from the standard curve and divided by the content of the test mineral in the ingredient. Nelson (1967) however observed that body weight was not an accurate measure of phosphorus utilization and its use has led to misleading conclusions.

A number of other biological assay techniques have been utilized in estimating mineral availability. Availability of iodine from various forms (dried kelp, iodized linseed meal, potassium iodide) have been studied in the laying hen by observing their effects on the iodine content of the egg (Wilder et al., 1933) and in albino rats by prevention of enlargement of the thyroid gland (Mittler and Benham, 1954). Availability of magnesium and iron have been studied based on ability to regenerate hemoglobin in test rats. Thompson and Raven (1959) estimated iron availability from different herbage species by their ability to regenerate hemoglobin in anemic rats. Kirchgessner and Grassmann (1971) using rats also studied availability of copper using ceruloplasmin as a test enzyme. Restoration of ceruloplasmin in depleted rats was taken as an indication of copper availability.

Availability of minerals in vegetable protein sources

Various protein sources have been reported to interfere with the availability of minerals in diets. These include peas (Kienholz et al., 1959; Kienholz et al., 1962), isolated soybean protein (O'Dell and Savage, 1960), sesame meal (Lease et al., 1960; Lease, 1966), amino acid and casein diets (Likuski and Forbes, 1964), safflower, cottonseed and soybean meals (Lease and Williams, 1967a,b). Isolated soybean protein reduces the availability of molybdenum (Reid et al., 1956), zinc (O'Dell and Savage, 1960), and manganese and copper (Davis et al., 1962). In these studies however the minerals were supplementary and not derived from the vegetable or animal feedstuffs. There are a few studies on the availability of minerals of plant origin to non-ruminants. Armstrong and Thomas (1952) estimated that calcium availability of lucerne, red clover and wild white clover were 84.89%, 83.11% and 79.95% respectively. In another study, Armstrong et al. (1953) reported that availability of calcium in three herbs of grassland (burnet, chicory and narrow leaved plantain) were 80.38%, 87.73% and 95.28% respectively. The calcium availability of three grasses; timothy, perennial rye grass and cocksfoot, were 78.99%, 76.53% and 69.02% respectively (Armstrong et al., 1957). Devadatta and Appana (1954) reported the availability of calcium in amaranthus (74-78%), sesbania grandiflora (85%) and moringa oleifera (69%). The availability of phytate phosphorus has also been studied. The committee on animal nutrition (NAS-NRC, 1960) reported that approximately 30% of the

phosphorus in plant materials could be utilized by non-ruminants. Ashton et al. (1960) observed that four-week old chicks retained approximately 20% of phytate phosphorus while six-week old chicks retained 36% to 49% of this phosphorus. Temperton and Cassidy (1964) reported that chicks utilized approximately 60% of the phytate phosphorus and only 50% of the non phytate phosphorus. Salman and McGinnis (1968) observed that phosphorus utilization in rations containing 0.3% plant phosphorus was not significantly different from its utilization in rations containing either 0.6% plant phosphorus or 0.3% plant plus 0.3% inorganic phosphorus. Utilization of phosphorus from plant material was therefore quite high. It is reasonable to believe that chickens can utilize greater amounts of phosphorus of plant origin than is currently suggested. Guenter and Sell (1974) using intramuscular injection of radioactive Mg-28 reported availability value of 61.2% for magnesium in soybean meal. O'Dell et al. (1972) using the growth response of chicks evaluated the availability of zinc in feedstuffs of animal and plant origin and reported availabilities of 57%, 67% and 75% for sesame meal, soybean meal and fishmeal respectively. No report was available in the literature reviewed on the availability of minerals in palm kernel meal.

Factors affecting mineral availability

Phytic acid (Inositol hexaphosphoric acid) chelates mineral elements, reducing their availability in whole or in part (Nelson et al., 1968). These workers suggested that it probably chelated to some extent, all the cations required by animals. Bruce and Callow (1934) in an earlier work suggested that in diets with natural calcium-phosphorus ratio, the main action of phytic acid would be to render calcium unavailable. Phytic acid has been reported to render calcium unavailable in dogs (Hoff-Jorgensen, 1946), man (Bronner et al., 1954) and chicks (Nelson et al., 1967). The inability of chicks to utilize a significant amount of phytate phosphorus has been reported by Gills et al. (1957) and in a review by Nelson (1967). In contrast to this, the addition of phytate as bran (Roberts and Yudkin, 1961) or as a mixture of pentacalcium phytate and sodium phytate (Hoff-Jorgensen, 1946) was reported to increase availability of phosphorus from cereal based rations. Phytic acid has been reported to reduce availability of iron (McCance et al., 1943), magnesium (Roberts and Yudkin, 1960), and zinc (O'Dell and Savage, 1960). Kratzer and Vohra (1966) suggested that part of the interference in zinc absorption by phytic acid may be due to the formation of zinc phosphate rather than zinc phytate.

Smith (1961) reported that net absorption of calcium and magnesium decreased in milk fed calves ingesting high levels of fibre as wood shavings. Armstrong et al. (1953) in a study on the availability of calcium in three herbs of grassland,

observed evidence of an inverse relationship between calcium availability and content of crude fibre. Southgate (1973a) suggested that in man, dietary fibre acted as a weak ion exchanger which bound bile salts and prevented their reabsorption from the gut. Heaton (1973) also suggested that binding of lithocholate in the gut could account for reduced incidence of gallstones in rats fed high fibre diets. Kritchevsky and Story (1974) demonstrated that dietary fibre exerted a binding effect on bile salts in vitro. Vegetable fibre consists of a heterogenous complex of polysaccharides and lignin capable of sequestering water, cations or anions depending on the chemistry of the constituent macromolecules (Eastwood, 1973). It appears evident that dietary fibre sequesters minerals, rendering them unavailable.

Mitchell (1939) suggested that oxalic acid in food would lead to poor calcium utilization as a result of formation of poorly absorbable calcium oxalate. Skorkowska-Zieleniewska et al. (1974) using rats reported reduced calcium, magnesium and iron absorption from diets containing oxalic acid. Similar results were reported for calcium (Murillo et al., 1973) and phosphorus (Compere, 1966). Brune and Bredehorn (1962) however observed that pigs utilized calcium oxalate as effectively as other calcium sources. Patel et al. (1967) reported that most concentrates and vegetable leaves had practically no oxalates. It would seem therefore that oxalates are not a real problem in practical diets for non-ruminants. This view was also held by Fassett (1966) who critically evaluated the literature pertaining to possible oxalate

interference with calcium metabolism and came to the conclusion that there was very little danger associated with ingesting oxalate containing plants.

Influence of chelating agents on mineral availability has been reported. Kratzer et al. (1959) observed recovery from zinc deficiency symptoms in turkey poults when small amounts of ethylene diamine tetra acetic acid (EDTA) were included in their isolated soybean protein diet. Similar effects of EDTA have been observed in chickens (O'Dell et al., 1964) and rats (Oberleas et al., 1966). Larsen et al. (1960) reported that EDTA decreased iron availability to rats. Suso and Edwards (1968) studied the influence of various chelating agents on absorption of ^{60}Co, ^{59}Fe, ^{54}Mn, and ^{65}Zn by chickens. They observed significant increases in ^{65}Zn absorption and non-significant increases in ^{54}Mn absorption with increasing levels of EDTA. Addition of EDTA decreased absorption of ^{59}Fe and ^{60}Co. Other chelating agents were not as effective as EDTA in improving zinc availability (Vohra and Kratzer, 1964).

The amino acids cysteine and histidine which are natural chelating agents have beneficial effects on the zinc deficiency syndrome (Nielsen et al., 1966). In zinc deficient chicks fed isolated soybean protein, a supplement of 0.5% cysteine alleviated all signs of zinc deficiency (Nielsen et al., 1966) They reported increased body weight, improved feathering and increased tibia zinc concentration, possibly due to improved zinc availability in the diet. Supplementation of histidine to a soybean diet allieviated the leg abnormality but did not increase growth, improve feathering or increase tibia zinc

concentration. A supplement of 2% arginine hydrochloride fed to zinc deficient chicks aggravated both the leg abnormality and the feather defects and tended to depress growth (Coleman et al., 1969). It seems that in the chick, cysteine, histidine and arginine are possible antagonists of zinc in some aspects of its metabolism.

The availability of minerals in swine rations is improved by administration of antibiotics (Kirchgessner et al., 1961; Kirchgessner, 1965). In eighteen balance trials using pigs and poultry, the daily retentions of cobalt and zinc were more than doubled and copper retention tripled by an antibiotic supplement. They also reported increased manganese and iron retention in animals receiving antibiotics. Kirchgessner et al. (1961) using balance methods, showed that retention of silicon, phosphorus, magnesium, cobalt, zinc, copper, manganese and iron was increased in young but not mature pigs.

The influence of vitamin D on the absorption of various cations has been reported by earlier investigators. Meintzer and Steenbock (1955) reported that absorption of magnesium was depressed in rats fed low vitamin D diets. Sobel and Burger (1955) observed that vitamin D increased the levels of lead in blood while Greenberg (1945) demonstrated an increase in strontium absorption due to vitamin D administration. Worker and Migicovsky (1961a,b) showed that vitamin D increased absorption of calcium, strontium, berrylium, magnesium, barium, zinc and cadmium. Wasserman (1962) extended the list to include cobalt and to a lesser extent cesium but reported that sodium, potassium, copper, iron and zinc were not influenced by

vitamin D. Masuhara and Migicovsky (1963) showed that iron and cobalt absorption were enhanced by vitamin D. A slight increase in phosphorus absorption and no increase in copper absorption was reported by Wasserman (1962).

Studies on mineral interrelationships date from early observations that low calcium rations inhibited phosphorus balance. Later investigators revealed fundamental interdependencies between copper and molybdenum, zinc and calcium, magnesium and phosphorus, calcium and manganese, cadmium and zinc (Hill et al., 1963; Forbes, 1963). A considerable degree of competition is for a binding site in or on the mucosal cells and for others it is competition for carrier molecules. The biological antagonism between copper and zinc was demonstrated by Smith and Larson (1946). Van Reen (1953) showed that copper supplementation alleviated the effects of zinc toxicity while the reverse was reported by Ritchie et al. (1963). Van Campen (1969) observed that copper-induced depression in ^{65}Zn absorption was mediated at the intestinal level possibly due to direct competition between zinc and copper for a common carrier. Kirchgessner and Grassmann (1969) reported that high levels of copper sulfate supplementation in pig rations produced greater retention of iron, zinc, manganese and cobalt. Diets high in calcium have a lower zinc availability (Suttle and Mills, 1966). Increased dietary calcium was reported to enhance manganese absorption in rats (Lassiter et al., 1969), while Alcock and MacIntyre (1960) observed that increased manganese in the diet enhanced calcium absorption. Nugara and Edwards (1962) noted that high dietary phosphorus reduced magnesium

retention at the absorption or excretion site in chicks, while O'Dell et al. (1960) showed with balance studies that a high dietary phosphorus level decreased magnesium absorption in guinea pigs. Forbes (1963) reported that calcium and phosphorus depressed magnesium absorption and high calcium levels drastically affected phosphorus absorption irrespective of magnesium levels in the diet, while Hill et al. (1963) showed that there were copper, zinc and iron components of cadmium toxicity.

Some miscellaneous factors have also been linked to mineral availability. Davis et al. (1962) reported that isolated soybean protein contained a component which combined with zinc, manganese and copper, causing chicks to develop the respective deficiency symptom because of unavailability of these minerals. The addition of EDTA to such a diet reduced the chicks' requirement for these elements. Kienholz (1962) presented evidence to indicate the presence of a factor (not phytate) in peas which interfered with the availability of zinc for chick growth. Autoclaving the peas eliminated the requirement for supplemental zinc. This heat labile factor would very likely be a protein which interfered with digestion or absorption of zinc, reducing its availability.

Current information on nutritive value of palm kernel meal

Palm kernel meal is a commercial by-product of the mechanical extraction of palm kernel oil from the kernel of the oil palm tree, Elaeis guineensis (Jacq). The possible use of palm kernel meal in livestock rations has been known for some time. However, very limited work has been completed relative to the nature of the protein and no significant attempts have been made to estimate the availability of nutrients in the meal following digestion. While the gross energy, amino acid and mineral content of the meal are known, few studies have been reported on determination of metabolizable energy and no studies on amino acid and mineral availability were discovered in the literature reviewed. Palm kernel meal was extensively used during the Second World War as a livestock feed due to its low cost, ease of availability and nutritive value. Since the late 1940's, use of palm kernel meal in livestock feeding has declined primarily because it is considered to be gritty, dry in texture and unpalatable (Collingwood, 1958). Palm kernel meal has been fed successfully to cattle (Schmidt and Vogel, 1932; Vogel, 1932), pigs (Carstenen, 1932) and to a lesser extent poultry (Temperton and Dudley, 1941). During the Nigerian Civil War (1967-1970), palm kernel meal was successfully incorporated into rations for all types of livestock as a protein supplement. Palm kernel meal production from tropical countries has shown an upward trend in recent years (FAO, 1975), however limited amounts of this product go into non-ruminant animal diets. The high fibre and low

protein content of the meal have usually been the reason for its low level of inclusion in non-ruminant diets. It is commonly forgotten that palm kernel meal can supply significant amounts of energy, protein and minerals and with judicious ration formulation can be utilized to a greater extent than is currently practised in monogastric diets (5% to 10% of the ration).

Delignification of high fibre feedstuffs

Considerable interest has been generated in recent years on the use of high fibre crop residues and by-products as feedstuffs. Beckmann (1921) first demonstrated that by treating roughages with delignifying agents, their nutritive value could be improved. The Beckmann procedure involved soaking roughages in large vats of alkali, followed by a wash to remove the residual alkali. Loss of dry matter following this treatment was 20-30%, but increased digestibility was reported (Ferguson, 1942). Wilson and Pigden (1964) suggested a spray method involving lower concentrations of alkali and no washing of the treated roughage. This procedure has been shown to be effective with such roughages as corn cobs, wheat and paddy straws, sorghum stover and sugar cane tops (Chandra and Jackson, 1971), and for other crop residues (Ololade et al., 1970; Rounds et al., 1976). The main alkali utilized has been sodium hydroxide (Chandra and Jackson, 1971; Singh and Jackson, 1971; Ololade et al., 1970) but other alkalis have been used. These include potassium hydroxide (Klopfenstein and Woods, 1970), ammonium hydroxide (Garrett et al., 1974; Rounds et al., 1976), calcium hydroxide (Rounds et al., 1976). Bleaching powder (Chandra and Jackson, 1971) and irradiation (Huffman, 1970) have also been successfully utilized.

These studies have been restricted to coarse roughages and the procedure has not been applied to more nutritive-high-fibre ingredients. The materials so treated have not been fed to non-ruminants and no attempt has been made to estimate the destruction of nutrients in these feedstuffs.

MATERIALS AND METHODS

Palm kernel meal (PKM) utilized in these trials was imported from Nigeria. The meal was produced by a screw press process followed by pulverization. The commercial soybean meal (SBM) and rapeseed meal (RSM) were produced in Canada by a solvent extraction process and purchased locally in Vancouver. Commercial solvent extracted cottonseed meal (CSM) was obtained from Mayflower Farms, Portland, Oregon, USA.

Triplicate samples of each feed ingredient were analyzed for gross energy, crude protein (%N x 6.25), ether extract, crude fibre, total ash and dry matter content (A.O.A.C., 1965). Acid detergent fibre and lignin analyses were by the method of Van Soest (1963). All analytical results were expressed on a dry matter basis. The experimental arrangement was a completely randomized design with replicate groups of four chicks each per group. The broiler chicks utilized in these experiments (3-4 weeks old) were uniform in size and were housed in stainless steel thermostatically controlled metabolism cages. Feed and water were provided ad libitum in stainless steel feeders and waterers. Data were subjected to analyses of variance (Snedecor, 1956) and differences between means determined by a multiple range test (Duncan, 1955).

Trial 1. Amino acid availability

Availability of amino acids in palm kernel, soybean, cottonseed and rapeseed meals was determined using growing chicks. The experimental arrangement was a completely randomized design involving four experimental diets fed to four replicate groups of four chicks each. The feeding trial and analysis were carried out according to the procedure of Bragg et al. (1969). The method included analysis of endogenous amino acids excreted by the chick. The amount of endogenous amino acids was significant and correction for this factor was necessary in availability calculations to clearly distinguish availability from apparent digestibility. Test chicks were fed commercial starter diets to three weeks of age. At the beginning of the test, they were supplied with starter feed containing 0.3% ferric oxide marker for four hours, fasted for sixteen hours and fed a synthetic diet (Table 1) for a four hour period. They were subsequently fasted for two hours and returned to the starter ration containing the marker. Feces from the synthetic diet were collected (unmarked feces). Next day, the same procedure was repeated, except that the test diet (Table 2) replaced the synthetic diet. Different levels of test ingredients were incorporated into the test diet to equalise nitrogen content. Dry matter consumption and fecal dry matter output during the experiment were recorded. Amino acids in palm kernel, soybean, cottonseed and rapeseed meals and feces collected from each diet were determined by amino acid analysis (Moore et al., 1958) following hydrolysis with 3N HCl for fifteen hours at 121^{o}C.

Table 1. Composition of synthetic diet
(Trials 1, 3 and 6)

Ingredients	g/kg (D.M)
Sucrose	810.17
Cellulose*	89.83
Corn oil	100.00

*Cellu-flour, Nutritional Biochemical Corporation, Cleveland, Ohio.

Table 2. Composition of test diets
(Trials 1 and 3)

	Diets (g)			
Ingredients	PKM	SBM	CSM	RSM
Palm Kernel meal	1000g	-	-	-
Soybean meal	-	500g		-
Cottonseed meal	-	-	750g	-
Rapeseed meal	-	-	-	750g
Synthetic diet	500g	1000g	750g	750g

Amino acid availability was calculated by the equation presented by Bragg et al. (1969)

$$\% \text{ Amino acid (A.A.) availability} = \frac{\text{Total A.A. consumed} - (\text{Total A.A. protein feces} - \text{Total A.A. non protein feces})}{\text{Total A.A. consumed}} \times 100$$

Amino acid availability represented the percentage of amino acids actually retained by the chick after correction for endogenous amino acids measured on excreta from the amino acid-free diet.

Trial 2. Metabolizable energy

Metablizable energy (ME) of palm kernel, soybean, cottonseed and degummed rapeseed meal was determined using broiler chicks. There were four replicates of four chicks each per treatment. The test diets contained either palm kernel, soybean, cottonseed or rapeseed meal at a level of 30% in substitution for an equal weight of the reference diet (Table 3). The assay period was five days and sampling of the excreta and feed was in the last two days of the experiment. All samples of feed and feces were composited and subsampled for analysis. Feed consumption and excreta output were determined by the acid insoluble ash method of Vogtmann et al. (1975). Gross energy and nitrogen content of feed and feces were determined (A.O.A.C., 1965). The excreta were frozen and lyophilized prior to analysis. Nitrogen retention was determined and ME values were calculated with a correction of 8.22 kcal/g nitrogen retained (Hill and Anderson, 1958).

Table 3. Composition of reference diet (Trial 2)

Ingredient	Per cent of ration
Soybean meal	27.50
Wheat	63.00
Meat meal	2.00
Alfalfa meal	1.00
Animal tallow	2.30
Limstone	1.00
Dicalcium phosphate	1.00
Vitamin premix[1]	0.50
Mineral premix[2]	0.50
D.L. Methionine	1.10
L. Lysine	0.10

1 Vitamin premix supplied per kg: Vitamin A, 11,000 I.U.; Vitamin D_3, 880 I.C.U.; Vitamin E, 10 I.U.; Vitamin K, 2.2 mg; Vitamin B_{12}, 13.2 mcg; Riboflavin, 4.4 mg; Calcium pantothenate, 24.2 mg; Niacin, 36.2 mg; Biotin, 0.04 mg; choline chloride, 500 mg.

2 Mineral premix supplied per kg: NaCl, 3.52 g; Mn, 86 mg; Zn, 49 mg; Cu, 7.7 mg; Fe, 34 mg.

Trial 3. Mineral availability

Retention of calcium, phosphorus, magnesium, manganese, zinc and copper was determined with four-week old broiler chicks in each of palm kernel, soybean, cottonseed and rapeseed meals. There were four replicates (four chicks each) per dietary treatment. Test birds were fed a starter diet containing known nutritional requirements from one day to 24 days of age. Chicks were maintained in a battery brooder during the first 21 days and thereafter groups of four were transferred to metabolism cages. On the 24th day of age, all chicks were supplied with feed (starter diet) containing 0.3% ferric oxide marker for four hours, fasted for sixteen hours and fed a synthetic diet (Table 1) for four hours. They were subsequently fasted for two hours and returned to the starter diet containing the marker. Feces from the synthetic diet were collected (starting at the end of the first batch of marked excreta and ending at the beginning of the second batch of marked excreta).

On the 25th day of age, the same procedure was repeated except that the test feed (Table 2) replaced the synthetic diet. Different levels of feedstuffs were utilized to provide isonitrogenous test diets for amino acid availability studies carried out simultaneously with mineral availability. Feces were again collected following the same procedure. Consumption of both synthetic and test diets was measured. Total marker-free feces were collected and the feces were dried at 85^{o}C for 24 hours. The mineral contents of the feed ingredient, the test diet, the feces from the synthetic diet

and from the test diet were determined by atomic absorption spectrophotometry following wet digestion with perchloric and nitric acids by the method of Johnson and Ulrich (1959). The phosphorus content of all samples was determined on a Spectronic 20 spectrophotometer following development of color with ammonium molybdate. Mineral content of all samples was expressed on a dry matter basis.

The following formula was used to calculate the per cent mineral availability following analysis of feed and excreta:

$$\text{Per cent mineral availability} = \frac{TMI - (TFME - EFME)}{TMI} \times 100$$

where TMI = Total Mineral Intake from ingredient (Test Feed)

TFME = Total Fecal Mineral Excreted

EFME = Endogenous Fecal Mineral Excreted (purified diet excreta)

Trial 4. Crude fibre and phytic acid as factors affecting mineral availability of vegetable protein supplements for the chick.

Triplicate samples of palm kernel, soybean, cottonseed and rapeseed meals were analysed for total phosphorus (Johnson and Ulrich, 1959), phytate phosphorus and phytic acid (Wheeler and Ferrel, 1971) and crude fibre (A.O.A.C., 1965). Mineral availability of the test ingredients was determined by the procedure outlined in trial 3, using broiler chicks (four replicates of four chicks each, per treatment). The procedure involved determination of endogenous mineral excretion using a purified mineral-free diet. The test ingredients were subsequently substituted for a fraction of the purified diet and mineral excretion was determined. Availability was calculated as true deigestibility of minerals in the feedstuffs. Correlation coefficients were calculated between the content of crude fibre or phytic acid in the test diet and the availabilities of six minerals (calcium, phosphorus, magnesium, manganese, zinc and copper) in the test diets.

Trial 5. Factors affecting the metabolizable energy content of rapeseed meals.

Cultivars of three varieties of rapeseed meal (Span, Tower and Bronowski) as well as commercial rapeseed meal were evaluated in these experiments. The various samples identified as Span (A, S and P), Tower (Sask 940, Sask 1788) and Bronowski were obtained by courtesy of the Rapeseed Association of Canada. Commercial rapeseed meal was purchased from local feed manufacturers. The experimental arrangement was a completely randomized design involving seven experimental diets fed to four replicate groups of four broiler chicks (three weeks of age). The procedure was as outlined in trial 2, according to Sibbald and Slinger (1962). Feed consumption and excreta output were determined by the acid insoluble ash method of Vogtmann et al. (1975). Gross energy and nitrogen content of feed and feces were determined (A.O.A.C., 1965). Nitrogen retention was determined and metabolizable energy values were calculated with a correction of 8.22 kcal/g nitrogen retained (Hill and Anderson, 1958). Ether extraction, dry matter, crude protein and crude fibre determinations were carried out on triplicate samples (A.O.A.C., 1965). Determination of available carbohydrates was by the method of Clegg (1956). Correlation analysis between metabolizable energy and chemical constituents was according to Snedecor (1956).

Trial 6. Availability of minerals in various rapeseed meals.

The test ingredients were the same as in trial 5. Content and availability of calcium, phosphorus, magnesium, manganese, zinc and copper were determined according to the procedure presented in trial 3.

Trial 7. Effects of alkali treatment on digestibility, metabolizable energy and destruction of amino acids in palm kernal meal (PKM).

Ground PKM samples (1000g) were sprayed with one litre of 3, 5 or 7% W/V NaOH solution. The samples were sealed in plastic bags for twenty four hours to facilitate the alkali reaction. Samples were subsequently dried at 60°C for forty eight hours and reground. Representative samples were analysed for acid detergent fibre (ADF), acid detergent lignin (ADL) by the method of Van Soest (1963), and for crude protein (CP), dry matter (DM) and gross energy (GE) according to A.O.A.C. (1965). Loss of protein due to alkali treatment was calculated. Amino acid composition of the samples was determined by the procedure of Moore et al., (1958), following hydrolysis with 3N HCl for fifteen hours at 121°C. Destruction of sixteen amino acids following alkali treatment was calculated.

Digestibility

Digestibility of dry matter and energy was determined in PKM and alkali-treated PKM using the nylon bag technique (Lowry, 1969). Ten grams of each air dry sample was put into a previously weighed oven-dry double bag (each of 100 mesh nylon). Six bags were attached to the cap of each 250 ml polyethylene bottle and submerged in the rumen ingesta of a fistulated steer. All samples were in triplicate. The experiment was terminated after forty eight hours. The bottle assemblies were removed from the rumen, adhering ingesta was rinsed free and the bags detached. Bags containing samples

were dried overnight at 80°C, transferred to a 110°C oven for eight hours and weighed. Digestibility coefficients were determined on the digested samples for dry matter and energy.

Metabolizable energy

Metabolizable energy of PKM and alkali treated PKM was determined using three week old broiler chicks. The experimental arrangement was a completely randomized design with four replicates (four chicks each) per treatment. The test diets contained either PKM or alkali-treated PKM at a level of 30% in substitution for an equal weight of the reference diet (Table 3). The procedure was as presented in trial 2.

Feeding trials

PKM was substituted for 10%, 20% or 30% of a broiler starter ration for two week old chicks in a twelve day feeding trial. The control was a standard wheat-soybean diet (Table 3). Test and control diets were approximately isocaloric and isonitrogenous, and equalised for lysine and methionine. Growth rate and feed conversion ratio were calculated and birds were examined daily for signs of ill-health.

Alkali treatment

PKM, 3%, 5% or 7% alkali treated PKM was incorporated at 30% into a starter ration (Table 4), for two week old chicks in an eight day feeding trial. The control was a standard wheat-soybean ration (similar to that used in experiment 3). Test rations were isonitrogenous but not isocaloric. Supple-

Table 4. Composition of control and test diet
(Trial 7, Experiment 4)

Ingredient (g/kg)	Control	PKM	Alkali-treated PKM Diets		
			3%	5%	7%
PKM	-	300.0	-	-	-
PKM + 3% NaOH	-	-	300.0	-	-
PKM + 5% NaOH	-	-	-	300.0	-
PKM + 7% NaOH	-	-	-		300.0
Soybean meal	275.0	225.0	225.0	225.0	225.0
Wheat	635.0	325.0	316.0	314.5	308.0
Meat meal	20.0	20.0	20.0	20.0	20.0
Fish meal	-	10.0	12.0	13.0	14.5
Alfalfa meal	10.0	10.0	10.0	10.0	10.0
Animal tallow	30.0	80.0	85.5	86.0	91.0
Limestone	10.0	10.0	10.0	10.0	10.0
Calcium phosphate	10.0	10.0	10.0	10.0	10.0
Vitamin premix[1]	5.0	5.0	5.0	5.0	5.0
Mineral premix[2]	5.0	5.0	5.0	5.0	5.0
D.L. methionine	1.5	1.5	1.5	1.5	1.5
L. lysine	0.1	0.1	0.1	0.1	0.1

1 Vitamin premix supplied per kg: Vitamin A, 11,000 I.U.; Vitamin D_3, 880 I.C.U.; Vitamin E, 10 I.U.; Vitamin K, 2.2 mg; Vitamin B_{12}, 13.2 mcg; Riboflavin, 4.4 mg; Calcium pantothenate 24.2 mg; Niacin, 36.2 mg; Biotin, 0.04 mg; Choline chloride 500 mg.

2 Mineral premix supplied per kg: NaCl 3.52 g; Mn, 86 mg; Zn, 49 mg; Cu, 7.7 mg; Fe, 34 mg.

mentary lysine and methionine were incorporated where necessary to meet recommended levels. Chicks were examined daily for signs of ill-health. Growth rate and feed conversion ratio were calculated.

RESULTS AND DISCUSSION

Trial 1

The proximate analysis of PKM, SBM, CSM and RSM is presented in Table 5. PKM had the lowest protein (21.3%) and highest crude fibre (17.5%) content while SBM showed the highest protein (48.0%) and lowest crude fibre (6.5%) content. Ether extract content of PKM was highest (7.8%) because the meal was processed by a screw press method. The ash content was uniformly high in all ingredients.

The amino acid composition of the feed ingredients is presented in Table 6. A comparison of individual amino acid levels in PKM to SBM showed that lysine was lowest (23% of SBM) and arginine was highest (77% of SBM) whereas content of methionine and threonine was low in comparison to amino acids in SBM. PKM is low in content of many amino acids and deficient in essential amino acids, therefore adequate supplementation with an amino acid source is required to facilitate effective utilization of this product in the chick diet.

The amino acid composition of SBM, CSM and RSM agree well with values in the literature (NAS-NRC, 1969). Among the essential amino acids of SBM, there is a high content of leucine, arginine and lysine, moderate content of threonine but low content of methionine. It provides an excellent source of dietary amino acids for chick diets when combined with a supplementary source of methionine and adequate levels of energy, vitamins and minerals.

Cottonseed meal is high in lysine, moderate in threonine

Table 5. Proximate analysis of PKM, SBM, CSM and RSM (dry matter basis).

Ingredient	% D.M.	% Protein	% Fibre	% Ash	% Ether Extract
PKM	92.0	21.3	17.5	5.0	7.8
SBM	91.1	48.0	6.5	6.0	0.6
CSM	92.4	41.0	13.6	7.0	2.0
RSM	90.5	38.0	12.0	7.2	1.5

Table 6. Amino acid composition of PKM, SBM, CSM and RSM (dry matter basis).

(Trial 1)

Amino Acids	Protein Source (%)			
	PKM	SBM	CSM	RSM
Lysine	0.69	2.95	2.19	2.08
Histidine	0.41	1.23	1.37	0.98
Arginine	2.68	3.45	5.60	1.93
Aspartic acid	1.69	5.64	4.74	2.38
Threonine	0.66	1.88	1.51	1.48
Serine	0.90	2.48	2.15	1.48
Glutamic acid	3.62	9.01	10.32	6.22
Proline	0.50	1.21	1.58	2.16
Glycine	0.91	2.16	2.31	1.79
Alanine	0.81	2.16	2.04	1.58
Valine	0.43	1.02	1.68	0.75
Methionine	0.47	0.75	0.70	0.84
Isoleucine	0.60	1.92	1.22	1.30
Leucine	1.23	3.71	2.85	2.57
Tyrosine	0.58	1.84	1.45	1.09
Phenylalanine	0.82	2.44	2.48	1.49

but low in methionine. Of the four protein supplements tested, CSM was highest in glutamic acid and the essential amino acid arginine. It has a good pattern of amino acids and can contribute significantly to dietary amino acids in poultry rations.

Rapeseed meal is lower than SBM in histidine, arginine, lysine and threonine but is slightly higher in methionine. Considering that the protein content of RSM is lower than SBM and CSM, rapeseed meal has a good amino acid pattern and can be utilized efficiently in poultry rations as a major supplier of amino acids.

Availability of amino acids in the protein supplements is presented in Table 7. Amino acid availability from PKM averaged 84.5% (with a range of 63.3% and 93.2%). The essential amino acids glycine (63.3%) and valine (68.4%) showed exceptionally low availability compared to other amino acids. Availability figures for lysine (90.0%), threonine (86.5%) and methionine (91.4%) indicated effective utilization of these amino acids. The low availability of glycine and valine, coupled with the relatively low levels of these amino acids in PKM, necessitates amino acid supplementation or the use of considerable amounts of other protein sources when PKM is incorporated into chick rations. In comparison to other protein supplements tested, the amino acids in PKM showed generally reduced availability. Nesheim (1965) suggested that factors responsible for lowered amino acid availability from feed ingredients included protein-sugar interactions in feedstuffs with low levels of protein, protein-fat interactions

Table 7. Amino acid availability in PKM, SBM, CSM and RSM fed to chicks.
(Trial 1)

Amino Acid	Protein Source (%)				
	PKM	SBM	CSM	RSM	Average
Lysine	90.0^{a}	99.0^{c}	89.0^{a}	94.4^{b}	93.1
Histidine	90.1^{a}	98.8^{c}	93.8^{b}	94.2^{b}	94.2
Arginine	93.2^{a}	98.8^{b}	95.7^{a}	95.8^{a}	95.9
Aspartic acid	87.6^{a}	98.3^{c}	93.6^{b}	91.7^{b}	92.8
Threonine	86.5^{a}	97.9^{c}	89.8^{b}	90.8^{b}	91.2
Serine	88.7^{a}	98.1^{c}	93.0^{b}	91.4^{ab}	92.8
Glutamic acid	90.1^{a}	98.9^{c}	96.3^{b}	94.9^{b}	94.3
Proline	68.0^{a}	93.0^{b}	90.9^{b}	91.2^{b}	85.8
Glycine	63.3^{a}	92.9^{b}	91.7^{b}	89.4^{b}	84.1
Alanine	85.5^{a}	97.4^{d}	89.2^{b}	94.2^{c}	91.6
Valine	68.4^{a}	92.9^{b}	91.1^{b}	90.9^{b}	85.6
Methionine	91.4^{a}	98.7^{b}	93.3^{b}	78.4^{c}	90.4
Isoleucine	86.1^{a}	97.7^{c}	91.3^{b}	91.6^{b}	91.7
Leucine	88.5^{a}	98.4^{d}	92.4^{b}	94.0^{c}	93.3
Tyrosine	85.0^{a}	98.0^{c}	94.2^{bc}	92.8^{b}	92.5
Phenylalanine	90.5^{a}	98.6^{c}	95.2^{b}	94.8^{b}	94.8
Average	84.5	97.3	92.5	91.9	-

Means with different superscripts among protein sources are significantly different ($P \leq 0.01$).

involving carbonyl products reacting with free amino groups, inhibitors of plant origin and heat treatment during processing. Southgate and Durnin (1970) reported that as the intake of dietary fibre increased, the apparent digestibility of protein (and therefore amino acids) and other dietary constituents decreased. Several workers (Dammers, 1965; Tao et al., 1971; Flipot et al., 1971) have also implicated crude fibre as a dietary factor reducing amino acid digestibility in protein feedstuffs, while Nelson (1967) suggested that phytate content could reduce digestion and absorption of proteins. PKM is high in crude fibre and ether extract, has a considerable carbohydrate content and undergoes extensive heat treatment during processing. It is moderately high in phytic acid content, although no growth inhibitor of plant origin has been reported. Although it is difficult to explain the remarkedly low glycine and valine availability, it is suggested that a combination of low protein, high ether extract and high levels of crude fibre is probably responsible for the generally reduced amino acid availability observed in PKM.

The availability of amino acids in SBM averaged 97.3% (with a range of 92.0% and 99.0%). This result was in agreement with those reported by Flipot et al. (1971) and by Ivy et al. (1971) for SBM, but higher than values reported by Cho and Bayley (1970) using pig fecal analysis. This would be expected due to the absence of a correction for endogenous amino acids in the latter study. The results of this study were also slightly higher than true digestibility values reported by Eggum (1968) but agreed closely with those by Sarwar et al. (1975) for

soybean meal fed to rats. The three usually limiting essential amino acids lysine (99.0%), methionine (98.7%) and threonine (97.9%) were highly available as were the other essential amino acids. Glycine and valine (92.9% each) showed reduced availability in comparison to other amino acids of soybean meal. Commercial solvent extracted SBM utilized in this study was high in protein (48.0%), low in crude fibre (6.5%), ether extract (0.6%) and phytic acid content (0.85%) and was processed to minimise heat damage, the content of trypsin inhibitors, phytohemagglutinins, goitrogens, saponins and other toxic constituents normally present in raw soybeans. Results indicate that commercial soybean meal is an excellent source of dietary amino acids for the chick. It has an excellent pattern of amino acids, being well endowed with both essential and non essential amino acids. It is high in availability of amino acids, particularly those considered as usually limiting in practical poultry rations.

Amino acid availability of CSM averaged 92.5% with a range of 89.0% and 96.3%. Lysine (89.0%) in CSM was lower in availability than was shown for other protein supplements, while methionine availability (93.3%) was higher than values for PKM and RSM. Threonine availability (89.8%) was lower than observed for SBM and RSM. Most amino acids were approximately 5.0% lower in availability for CSM than was observed for SBM. Kuiken and Lyman (1948) reported the availability of essential amino acids from hydraulic press CSM to vary from 67% to 93%, screw press meal from 79% to 95% and hexane extracted meal from 84% to 98%. Results obtained in this study

agreed closely for solvent extracted CSM with those reported by Kuiken and Lyman (1948). Lysine availability was higher than 67.3% and 72.5% reported by Thyong (1967) for cottonseed cake and cottonseed meal respectively. It is of considerable interest to note that CSM has a high concentration of essential amino acids which are well utilized by poultry. High levels of residual gossypol in processed meals would limit the use of cottonseed meal. However it must be noted that as a result of ever improving technology, considerable success has been achieved in both removal of gossypol in commercial processing as well as production of glandless cottonseed meals. In many tropical countries where cotton is produced and processed, CSM can effectively replace the more expensive soybean meal in the diet of growing monogastric animals. Cottonseed meal will however have to be used in combination with other protein sources or amino acid mixtures as it is low in methionine content.

Information on the availability of amino acids in RSM is limited and only a few studies have been reported. The availability of amino acids in RSM varied from 78.4% to 95.9% with an average of 91.9%. With the exception of methionine which was 78.4% available, the essential amino acids showed relatively high availability, although most were significantly lower than in SBM. Lysine (94.4%) and threonine (90.8%) showed higher availability than in CSM and PKM.

Results reported in this study were considerably higher than amino acid digestibility observed by Cho and Bayley (1970) and by Tao *et al.* (1971) for RSM but agreed closely with those

of Sarwar et al. (1975). Cho and Bayley (1970) employing pig fecal analysis reported a range of 74% and 86% for RSM amino acid digestibility. Tao et al. (1971) using colostomized broiler chicks showed that true digestibility coefficients for sixteen amino acids of rapeseed meal varied from 59.8% to 81.9%. However, Bragg et al. (1969) had earlier demonstrated that normal chicks provided higher values with greater reproduceability than colostomized chicks. Sarwar et al. (1975) used balance trials to show amino acid availability of 83% to 92% for rapeseed meal. The lower apparent digestibility coefficients for amino acids observed by Cho and Bayley (1970) appear to be the result of procedure utilized. Apparent digestibility trials do not include a method for measuring endogenous amino acids. Therefore an endogenous amino acid correction factor is not utilized in calculating digestibility. A lower value consequently results from the apparent digestibility procedure as compared to the true digestibility or availability method. Successful methods of detoxification of rapeseed meal have been developed in recent years and the product provides a good source of essential amino acids at a relatively high level of availability and therefore rapeseed meal can be incorporated as a major protein source in the diet of growing animals. It certainly has a greater potential for providing dietary amino acids than is presently utilized (approximately 5% in layer diets and 15% in broiler diets).

Trial 2

The metabolizable energy (ME) values of PKM, SBM, CSM and RSM are presented in Table 8 and range from 1957.0 kcal/kg (RSM) to 2796.0 kcal/kg (PKM). There were no significant differences ($P \leq 0.05$) between ME of PKM and the ME of SBM (2681.9 kcal/kg). The ME of SBM was also not significantly different ($P \leq 0.05$) from the ME of CSM. RSM however was significantly lower ($P \leq 0.05$) in ME than all ingredients tested.

PKM, despite its high crude fibre content, had a high metabolizable energy value. This would be expected since PKM has a high content of nitrogen free extracts, and a high ether extract level. PKM processed by a solvent extraction method would be expected to show reduced metabolizable energy content. Results obtained in the present study agreed closely with reports by Gohl (1975) that metabolizable energy of palm kernel meal for poultry varied from 2150 kcal/kg (mechanical press, 6% ether extract) to 3070 kcal/kg (mechanical press, 10% ether extract). PKM utilized in this study has an ether extract content of 7.8% and metabolizable energy of 2796 kcal/kg. The metabolizable energy result obtained in this study indicates that PKM is a high energy feed ingredient comparable to soybean meal and is capable of contributing significantly to meeting the energy requirements of chicks in practical rations.

Metabolizable energy of soybean meal observed in this study was slightly higher than 2530 kcal/kg reported by Hill and Renner (1960) for 50% protein SBM, but was in agreement

Table 8. Metabolizable energy of PKM, SBM, CSM and RSM (dry matter basis).
(Trial 2)

Ingredient	Metabolizable energy (kcal/kg)
Palm kernel meal	2796.0[a]
Soybean meal	2681.9[ab]
Cottonseed meal	2531.2[b]
Rapeseed meal	1957.0[c]

Means with different superscripts are significantly different $P \leq 0.05$.

with values of 2603 and 2770 kcal/kg reported by Lautner and Zenisek (1965) and Rojas and Scott (1969) respectively.

Cottonseed meal utilized in this study had a metabolizable energy value of 2531.2 kcal/kg, a value slightly higher than results of Hill and Totsuka (1964) for heated hexane extracted and mixed solvent extracted cottonseed meal. These results were also slightly higher than values reported by Rojas and Scott (1969) for various cottonseed meals.

Metabolizable energy of rapeseed meals assayed in this study (1957.0 kcal/kg) was higher than values reported by previous workers (March and Biely, 1971; Rao and Clandinin, 1973; Clandinin, 1973). Seth and Clandinin (1973) however observed average ME of 2327 kcal/kg for three varieties of low hull rapeseed meal containing 7.76% to 10.30% fibre and ME of 1730 kcal/kg for regular rapeseed meal containing 15% to 17% fibre. The rapeseed meal assayed in this study was degummed Tower rapeseed meal with 12.0% fibre. This may explain why a fairly high metabolizable energy content was observed.

Trial 3

The mineral content of PKM, SBM, CSM and RSM used in the experiment is presented (Table 9). These meals show a high content of calcium, phosphorus and magnesium and a low level of manganese, iron, zinc and copper. The content of mineral elements in the protein sources will not meet the minimal nutritional requirements of chicks at dietary levels of the protein supplements used in a balanced diet. Palm kernel meal is, however, exceptionally high in manganese and iron in comparison to SBM, CSM and RSM.

Results (Table 10) show per cent availability of each of the mineral elements in the protein sources. Mineral elements in SBM showed the highest average availability (74.3%) while those in PKM were least available (50.0%). Mineral availability from CSM (62.1%) and RSM (64.0%) were intermediate. Calcium (72.6%) and phosphorus (78.0%) were highly available in all feedstuffs. Magnesium and manganese were highly available from SBM and CSM, moderately available from RSM and lowest from PKM. Zinc was highly available from SBM (66.5%), moderately available from RSM (57.6%) and poorly available from PKM and CSM (13.9% and 38.0% respectively). Copper was moderately available from RSM (62.7%) and SBM (51.0%) with lowest availability of the mineral from PKM and CSM (44.7% and 42.3% respectively).

Calcium Results indicate that calcium was highly available from the feedstuffs tested, although a considerable variation among feedstuff was observed. The low calcium content of most cereals and other feed ingredients (relative to dietary require-

Table 9. The mineral content of palm kernel meal, soybean meal, cottonseed meal and rapeseed meal (dry matter basis).

(Trial 3)

Ingredient	Minerals						
	Ca (mg/g)	P (%)	Mg (mg/g)	Mn (mg/kg)	Fe (mg/kg)	Zn (mg/kg)	Cu (mg/kg)
Palm kernel meal	3.60	0.80	4.37	135.0	356.0	41.0	27.0
Soybean meal	3.87	0.87	4.13	27.0	164.0	49.0	27.0
Cottonseed meal	2.60	1.20	5.63	27.0	81.0	48.0	27.0
Rapeseed meal	8.50	1.25	4.66	55.0	110.0	55.0	33.0

Table 10. Per cent availability of minerals in palm kernel meal, soybean meal, cottonseed meal and rapeseed meal.
(Trial 3)

Mineral Element	Feedstuffs (%)				
	PKM	SBM	CSM	RSM	Average
Calcium	68.6^{b}	85.6^{c}	64.6^{a}	71.7^{b}	72.6
Phosphorus	70.8^{a}	89.3^{c}	76.9^{b}	74.8^{b}	78.0
Magnesium	56.4^{a}	77.4^{c}	74.6^{c}	61.1^{b}	67.5
Manganese	45.1^{7}	76.1^{c}	76.3^{c}	56.7^{b}	63.7
Zinc	13.9^{a}	66.5^{d}	38.0^{b}	57.6^{c}	44.0
Copper	44.7^{a}	51.0^{b}	42.3^{a}	62.2^{c}	50.0
Average	50.0	74.3	62.1	64.0	

Means with different superscripts among protein sources are significantly different ($P \leq 0.01$).

ments) and the absence of a rapid assay method have not stimulated feed calcium availability studies. However, results of this study compare well with dietary calcium retention studies using radioactive isotopes by Driggers and Comar (1949) and more recently by Bragg et al. (1971). These investigators indicated that approximately 70% of the dietary calcium was retained by the laying bird. Results reported here are also in agreement with those of Armstrong and Thomas (1952), Armstrong et al. (1953) and Armstrong et al. (1957), using various herbs of grassland. This study is also in agreement with results of Devadatta and Appana (1954) for calcium availability in various vegetables.

Phosphorus Phosphorus availability was the highest of all mineral elements tested, showing SBM (89.3%), CSM (76.9%), RSM (74.8%) and PKM (70.8%). Gillis et al. (1954) estimated available phosphorus from bonemeal, bone char, bone ash and dicalcium phosphate as 87%, 84%, 89% and 100% respectively.

Phosphorus of plant origin is considered poorly available due to the influence of phytates (Taylor, 1965). Available phosphorus values applied to feedstuffs of plant origin are between 30% and 40% (Taylor, 1965). Nelson et al. (1968) reported that phytate phosphorus of commercial SBM was completely unavailable. Ashton et al. (1960) observed that four week old chicks retained approximately 20% of phytate phosphorus while six week old chicks retained 36% to 49% of this phosphorus.

Temperton and Cassidy (1964) however reported that chicks utilized approximately 60% of phytate phosphorus. The utilization of phosphorus from vegetable sources is high as

demonstrated by Salman and McGinnis (1968) who reported that phosphorus utilization in rations containing 0.3% plant phosphorus was not significantly different from its utilization in rations containing either 0.6% plant phosphorus or 0.3% plant plus 0.3% inorganic phosphorus. Most results published on phytate phosphorus availability have been based on retention of phosphorus from the test vegetable source assayed by the ash content of the left tibia of the chick. The reason why the left tibia and not the entire animal is used has not been explained. Use of component parts of test animals would invariably over or underestimate availability of the minerals in the test ingredient. This may explain why previous results reported on availability of plant source phosphorus have been low. Results of this study indicate that phosphorus availability of protein supplements of plant origin have been greatly underestimated.

Magnesium Availability of magnesium in SBM, CSM, RSM and PKM were 77.4%, 74.5%, 61.1% and 56.4% respectively. Magnesium availability for SBM observed in this study was higher than 61.2% reported by Guenter and Sell (1974) using intramuscular injection of radioactive ^{28}Mg. No results were discovered in the literature on the availability of magnesium in CSM, RSM and PKM. Content and availability of magnesium was fairly high in all ingredients tested and this may explain why magnesium deficiency is not a common problem in practical rations for poultry.

Manganese Results indicate that manganese availability was 76.1% for SBM, 76.3% for CSM, 56.7% for RSM and 45.7% for PKM.

Gallup and Norris (1939a,b) and Wilgus and Patton (1939) reported that birds had a high requirement for manganese due to poor absorption of the mineral from the diet. While the recommended manganese requirement in poultry diets is 55 ppm (NAS-NRC, 1960), soybean meal contains 27 ppm, cottonseed meal 27 ppm, and rapeseed meal 55 ppm of total manganese. The problem with manganese seems to be low content in protein supplements rather than poor availability. At dietary levels used to meet the protein requirements of chicks, a high supplemental level of manganese would be necessary in most diets, even though manganese from cereal grains was effectively utilized.

Zinc The availability of zinc in PKM and CSM was low (13.9% and 38.0% respectively) and fairly high in SBM (66.5%) and RSM (57.6%). O'Dell et al. (1972) using the growth response of chicks, evaluated the availability of zinc in feedstuffs of animal and plant origin and reported availabilities of 57%, 67% and 75% for sesame meal, soybean meal and fishmeal respectively. Phytate content of vegetable feed ingredients has been implicated in reduced zinc availability (Lease et al., 1960; Likuski and Forbes, 1964; O'Dell et al., 1972). Results reported in this study for soybean meal agree closely with those of O'Dell et al. (1972). The phytic acid content of RSM and CSM (1.92% each) were equal and yet zinc availability differed in these meals. It is obvious therefore that some other factor affected zinc availability. One of the factors responsible for this difference in zinc availability may be crude fibre content.

Copper Copper absorption and utilization may be markedly affected by several other mineral elements and dietary components (Underwood, 1971). Little is known about the chemical form in which copper exists in foods. Large differences in copper availability have been reported by Mills (1954) and Farrer and Mistilis (1967). Phytate has been reported by Davis et al. (1962) to reduce absorption and assimilation of copper. Results of this study (Table 10) indicated poor copper availability in PKM, SBM and CSM. The copper in RSM was 62.2% available while that in SBM was 51.0% available. Lower values were observed for PKM (44.7%) and CSM (42.3%). The difference in copper availability from these protein supplements indicates that either it is present in different forms or there are other dietary factors associated with each ingredient which influence digestibility and absorption of copper.

Trial 4

Phytic acid and phytate phosphorus content of PKM, SBM, CSM and RSM are presented in Table 11. Among the vegetable protein supplements tested, phytic acid was 0.85% in SBM, 1.42% in PKM, 1.92% in CSM and RSM. Phytate phosphorus was lower in SBM (0.24%) and PKM (0.40%) and there was a higher percentage in CSM and RSM (0.54% each). Phytic acid content in some of the vegetable supplements used in this study was low in comparison to earlier reports. Nelson et al. (1968) reported phytic acid values of 2.70% for cottonseed meal (41% protein), 1.3% for soybean meal (44% protein) and 3.6% for sesame meal.

Results of the correlation analysis (Table 12) showed a significant inverse relationship (P 0.05) between phosphorus availability and crude fibre ($r = -0.91$) or phytic acid ($r = -0.93$) content of feed ingredients. This relationship was clearly expressed in the case of SBM in which the low crude fibre and phytic acid content resulted in a greater percentage of available phosphorus. There was a significant inverse relationship ($P \leq 0.05$) between calcium availability and crude fibre ($r = -0.73$) or phytic acid ($r = -0.93$) content of the feed ingredients. Calcium availability values (Table 12) ranged from 64.8% (CSM) to 85.6% (SBM). The relatively high phosphorus and calcium availability for these feedstuffs indicated that neither phytic acid nor crude fibre was of significant magnitude in the ingredients to severely affect availability of these minerals. Results (Table 12) indicated a significant inverse relationship ($P \leq 0.05$) between magnesium

Table 11. Crude fibre, phytic acid, phytate and total phosphorus content of PKM, SBM, CSM and RSM (dry matter basis).

(Trial 4)

Feed-stuffs	Dry Matter %	Crude Fibre %	Phytic Acid* %	Phytate Phosphorus %	Total Phosphorus %
PKM	92.5	17.5^{c}	1.42^{b}	0.40^{b}	0.80^{a}
SBM	91.2	6.5^{a}	0.85^{a}	0.24^{a}	0.87^{a}
CSM	92.4	13.6^{b}	1.92^{c}	0.54^{c}	1.20^{b}
RSM	90.5	12.0^{b}	1.92^{c}	0.54^{c}	1.25^{b}

Means with different superscripts are significantly different ($P \leq 0.05$) between feedstuffs.

*Calculated as 3.55 times the phytate phosphorus.

Table 12. Correlation coefficients between crude fibre and phytic acid content and availability of minerals in PKM, SBM, CSM and RSM.

(Trial 4)

Feedstuffs	Mineral Availability (%)					
	P	Ca	Mg	Mn	Zn	Cu
PKM	70.8	68.6	56.4	45.7	13.9	44.7
SBM	89.3	85.6	77.4	76.1	66.5	51.0
CSM	76.9	64.6	74.6	76.3	38.0	42.3
RSM	74.8	71.7	61.1	56.7	44.0	62.2
[1]Correlation coefficient						
(a) crude fibre	-0.91*	-0.73*	-0.81*	-0.78*	-0.98*	-0.56*
(b) phytic acid	-0.93*	-0.93*	-0.61*	-0.51	-0.77*	-0.53

1 Correlation coefficient between mineral availability and crude fibre or phytic acid content.

* Significant ($P \leq 0.05$).

availability and crude fibre ($r = -0.81$) or phytic acid ($r = -0.61$) content. Manganese availability was however significantly ($P \leq 0.05$) related to crude fibre ($r = -0.78$) but not to phytic acid content. There was a significant ($P \leq 0.05$) inverse relationship between zinc availability and crude fibre ($r = -0.98$) or phytic acid ($r = -0.77$) content of the feed ingredients. Influence of phytic acid in depressing zinc availability has been reported by O'Dell and Savage (1960) and Likuski and Forbes (1964). The availability of copper was significantly ($P \leq 0.05$) related to crude fibre content ($r = -0.56$), however phytic acid content of the feed ingredients had no influence on availability of copper.

The depressing influence of phytic acid on mineral availability was demonstrated with phosphorus, calcium, magnesium and zinc whereas the crude fibre content depressed the availability of all minerals tested. It would appear that while the influence of phytic acid on mineral availability has in the past been well emphasized, the effect of crude fibre has not been well documented.

Trial 5

The proximate constituents of the various rapeseed meals are presented in Table 13. Crude protein content averaged 37.3% with a range of 30.8% (Sask 940) to 41.9% (Bronowski). The average crude fibre content was 14.5% with a range of 12.0% for the commercial rapeseed meal and 16.1% for Span A. The mean ether extract content was 1.5% with the lowest content (0.3%) in Span A and the highest (3.3%) in Sask 940. The average dry matter content was 91.6% with a range of 90.6% (Span A) and 93.1% (Sask 940).

The metabolizable energy (ME) values of the various rapeseed meals are presented in Table 14. There were no significant differences ($P \leq 0.01$) between ME values of commercial rapeseed meal (1957 kcal/kg), Sask 940 (1953 kcal/kg) and Span P (1859 kcal/kg). There were also no significant differences ($P \leq 0.01$) between ME values of Span P and Bronowski (1787 kcal/kg) but ME values of commercial rapeseed meal and Sask 940 were significantly higher ($P \leq 0.01$) than ME of Bronowski. Span A and Span S were significantly lower ($P \leq 0.01$) in ME than all other meals tested. The metabolizable energy values of Span A and Span S were low and were comparable to RSM metabolizable energy values reported by various workers (Lodhi et al., 1969; March and Biely, 1971; Rao and Clandinin, 1971; March et al., 1973). The significantly higher ME values reported for commercial rapeseed meal and Sask 940 were compatible with reports by March et al. (1975) and by Seth and Clandinin (1973) using low hull rapeseed meals.

Table 13. Proximate constituents of various rapeseed meals (dry matter basis).
(Trial 5)

Sample	Dry Matter %	Crude Protein %	Crude Fibre %	Ether Extract %
Span A	90.6	39.5	16.1	0.3
Span P	91.9	36.5	15.3	2.1
Span S	91.0	36.6	14.5	0.8
Sask 940	93.1	30.8	12.4	3.3
Sask 1788	92.3	38.1	15.6	1.4
Bronowski	92.1	41.9	15.6	1.4
Commercial RSM	90.0	38.0	12.0	1.5
Average	91.6	37.3	14.5	1.5

Table 14. Gross and metabolizable energy of various rapeseed meals (dry matter basis).
(Trial 5)

Sample	Gross Energy (kcal/kg)	Metabolizable Energy (kcal/kg)
Span A	4791	1492[d]
Span P	4832	1859[ab]
Span S	4591	1565[d]
Sask 940	5137	1953[a]
Sask 1788	4676	1749[c]
Bronowski	4620	1787[bc]
Commercial RSM	4826	1957[a]
Average	4782	1766

Means with different superscripts are significantly different ($P \leq 0.01$).

Intermediate ME values observed for Sask 1788 and Bronowski were close to reports by Yapar and Clandinin (1972) and by Clandinin (1973).

Results of estimation of available carbohydrate (sugar plus starch) content of the various rapeseed meals are presented in Table 15. The average sugar content was 9.51% with a range of 5.14% (Span A) to 11.65% (Span P). High sugar content were also observed in commercial rapeseed meal (11.00%), Span S (10.64%), and Sask 1788 (10.26%) while low values were obtained in Bronowski (8.52%) and Span A. Sugar content in Sask 940 (9.36%) was approaching the observed average. The starch content averaged 5.69% with a range of 4.66% (Span P) to 6.66% (Bronowski). Sask 940 (6.59%) and commercial rapeseed meal (6.13%) were also high in starch content. Low starch content was observed in Span P, while Span A (5.42%), Sask 1788 (5.30%) and Span S (5.06%) were intermediate for the samples tested.

The average available carbohydrate content was 15.20% with a range of 10.56% (Span A) to 17.13% (commercial rapeseed meal). Span P (16.31%) was high and commercial rapeseed meal was exceptionally high. The average available carbohydrate content obtained in this study was comparable to 14.1% reported by Lodhi et al. (1969) for nine samples of rapeseed meal using the same chemical method as utilized in this study. It is interesting to note that Lodhi et al. (1969) reported a value of 23.6% for available carbohydrate content of soybean meal.

Table 15. Sugar, starch and available carbohydrate content of various rapeseed meals (dry matter basis)

(Trial 5)

Sample	Sugar %	Starch %	Available Carbohydrate %
Span A	5.14	5.42	10.56
Span P	11.65	4.66	16.31
Span S	10.64	5.06	15.70
Sask 940	9.36	6.59	15.95
Sask 1788	10.26	5.30	15.56
Bronowski	8.52	6.66	15.18
Commercial RSM	11.00	6.13	17.13
Average	9.51	5.69	15.20

Correlation coefficients between the proximate constituents as well as available carbohydrates and metabolizable energy of the various rapeseed meals are presented in Table 16. There were significant ($P \leq 0.01$) positive relationships between the energy components (starch plus sugar plus ether extract) and the metabolizable energy of the meals. There was however a significant ($P \leq 0.01$) inverse relationship between the crude fibre content of the meals and their metabolizable energy as indicated by the negative correlation coefficient. The content of crude protein was not related to the metabolizable energy content of the meals. Ether extract content was responsible for 62.4% of the variation in ME among the meals. Available carbohydrate content singly accounted for 57.8% of the variation observed between the ME values of the meals, whereas ether extract and available carbohydrate content were jointly responsible for 74.0% of the observed variation among the ME of the meals. Therefore it appears that energy components and crude fibre account for most of the differences between the ME of the various meals. Span A which is lowest in ether extract and available carbohydrate content and highest in crude fibre content, had the lowest metabolizable energy content. The highest metabolizable energy values were reported in commercial rapeseed meal and Sask 940 which were highest in content of the energy components and lowest in crude fibre content. Span P had a fairly high crude fibre content but the high level of energy components (ether extract, sugar and starch) were effective in improving the available energy of the sample. Consequently Span P had a high metabolizable

Table 16. Correlation of chemical constituents with metabolizable energy of rapeseed meals

(Trial 5)

Chemical constituents	Correlation with metabolizable energy
Ether extract + sugar + starch	0.86**
Ether extract	0.79**
Available carbohydrates (sugar + starch)	0.76**
Sugar	0.56
Starch	0.46
Crude fibre	-0.66**
Crude protein	-0.43

**Significant $P \leq 0.01$.

energy content. Span S, Sask 1788 and Bronowski were intermediate in their content of energy components. Their content of crude fibre was also approximately average. The combination resulted in metabolizable energy levels that were intermediate to other samples tested.

Previous workers (Carpenter and Clegg , 1956; Davidson et al., 1961; Sibbald et al., 1963) recognised the need for a rapid assay capable of measuring available energy and derived equations for predicting metabolizable energy from chemical composition of feedstuffs. The equation of Carpenter and Clegg (1956), confirmed by Sibbald et al. (1963) as capable of predicting metabolizable energy with sufficient precision was evaluated with the test ingredients as well as with soybean, cottonseed and palm kernel meals. Only the metabolizable energy of cottonseed meal was predicted with any degree of accuracy. ME of rapeseed meal was definitely overestimated. Carpenter and Clegg (1956) utilized mainly cereals and cereal by-products in deriving their equation. These ingredients have an extremely high content of starch and with the exception of oats, a fairly low content of crude fibre as compared to most vegetable protein supplements. Such a predictive equation cannot be applied to all classes of feed ingredients with a respectable degree of accuracy. Multiple linear regression equations derived with rapeseed meals and useful in predicting ME values of rapeseed meals were developed. Of the chemical constituents analysed, only the total energy components (% sugar + 1.1 x % starch + 2.25 x % ether extract) and crude fibre were significantly ($P \leq 0.01$ related to metabolizable energy.

The multiple linear equations

$$\hat{Y} = 954.75 + 41.73\ \%\ \text{sugar} + 1.1\left[(\%\ \text{starch}) + 2.25(\%\ \text{ether extract})\right]$$

and

$$\hat{Y} = 1241.54 - 14.57\ \%\ \text{C.F.} + 37.81\left[\%\ \text{sugar} + 1.1(\%\ \text{starch}) + 2.25\ (\%\ \text{ether extract})\right]$$

had an r^2 value of 0.77 and 0.79 respectively.
Both equations are capable of predicting metabolizable energy of rapeseed meals with a considerable degree of accuracy. Total energy components are highly significantly ($P \leq 0.01$) related to metabolizable energy ($r = 0.88$) and for most practical purposes, will afford a rapid method of estimating metabolizable energy of rapeseed meals.

It is suggested that instead of using broad-based predictive equations for estimating ME of feed ingredients from their chemical composition, specific equations derived from ingredients of the same class be used.

Trial 6

The mineral content of the various rapeseed meals is presented (Table 17). The average calcium content of the meals was 6.5 mg/g with a range of 5.6 mg/g (Sask 940) to 8.5 mg/g (commercial RSM). Calcium content of Sask 940, Sask 1788 (5.8 mg/g), Bronowski (6.1 mg/g) and Span P (6.2 mg/g) were lower than average for the meals, while Span A (6.6 mg/g) and commercial RSM had higher than average calcium content. The rapeseed meals had a high phosphorus content with an average of 1.22% and a range of 1.20% to 1.25%. Phosphorus content was comparable to that in cottonseed meal (1.20%) but higher than phosphorus content of palm kernel meal (0.80%) and soybean meal (0.87%). The magnesium content of the rapeseed meals averaged 5.0 mg/g with a range of 4.7 mg/g (commercial RSM) and 5.5 mg/g (Bronowski). The meals showed a high magnesium content, comparable to values reported for palm kernel, soybean and cottonseed meals in trial 3. Most vegetable protein supplements are high in magnesium content and in practical poultry rations, magnesium deficiency is not a common problem. The average manganese content of the meals (54 mg/kg) was higher than values observed in soybean and cottonseed meals (27 mg/kg each), but was much smaller than 135 mg/kg in palm kernel meal. Sask 940 and Sask 1788 had a slightly lower than average content of manganese while Bronowski had a higher than average content. Iron content of the various meals averaged 153 mg/kg with a range of 110 mg/kg for commercial RSM and 180 mg/kg for Bronowski. This was similar to the iron content of soybean meal (164 mg/kg), higher than in cottonseed meal (81 mg/kg) but

Table 17. Mineral content of rapeseed meals (dry matter basis).

(Trial 6)

Samples	Ca mg/g	P %	Mg mg/g	Mn mg/kg	Fe mg/kg	Cu mg/kg	Zn mg/kg
Span A	6.6	1.20	5.2	55	140	12	64
Span P	6.2	1.20	4.9	50	148	11	59
Span S	6.5	1.25	5.1	52	147	12	59
Sask 940	5.6	1.20	4.5	49	167	10	49
Sask 1788	5.8	1.25	5.1	49	177	11	55
Bronowski	6.1	1.20	5.5	67	180	14	62
Commercial RSM	8.5	1.25	4.7	55	110	33	55
Average	6.5	1.22	5.0	54	153	15	58

much lower than content of iron in palm kernel meal (356 mg/kg). The copper content of the meals (except commercial RSM) was lower than observed for palm kernel, soybean and cottonseed meals (27 mg/kg each). Copper content of commercial RSM (33 mg/kg) was much higher than observed in other rapeseed meals and was comparable to values reported in other vegetable protein supplements (NAS-NRC, 1969). Copper is toxic and this may explain the low content of copper in feed ingredients used in practical poultry rations.

The zinc content of the various meals averaged 58 mg/kg with a range of 49 mg/kg (Sask 940) and 64 mg/kg (Span A). The zinc content of the meals was comparable to values reported for soybean meal (49 mg/kg) and cottonseed meal (48 mg/kg) but slightly higher than zinc content of palm kernel meal (41 mg/kg) as shown in trial 3.

Per cent availabilities of six minerals in the various rapeseed meals are presented in Table 18. Average availability for all minerals varied from 52.2% (Span A) to 69.5% (Span S) with a mean of 62.9%. Of all rapeseed meals tested, Span A was low in availability of minerals while Span P showed approximately average availability. Average mineral availability was lower than 74.3% observed for soybean meal, but was higher than 50.0% and 62.1% shown for palm kernel meal and cottonseed meals respectively.

Calcium : Calcium availability ranged from 59.7% (Span A) to 75.6% (Span S) with a mean of 68.0%. Most meals showed a higher than average availability for calcium. Average calcium availability was lower than 85.6% reported for soybean meal but

Table 18. Availability of minerals in rapeseed meal samples (Trial 6)

Samples	Availability %						
	Ca	P	Mg	Mn	Cu	Zn	Ave.
Span A	59.7^{a}	65.0^{a}	52.5^{a}	45.5^{a}	67.5^{b}	23.0^{a}	52.2
Span P	68.9^{b}	75.0^{bc}	60.0^{b}	51.5^{ab}	73.0^{bc}	46.5^{c}	62.5
Span S	75.6^{b}	81.0^{c}	66.5^{b}	60.0^{c}	85.0^{d}	49.1^{cd}	69.5
Sask 940	70.3^{b}	79.5^{bc}	66.0^{b}	57.0^{bc}	82.0^{cd}	36.0^{b}	65.1
Sask 1788	61.0^{a}	74.5^{b}	62.0^{b}	53.1^{b}	77.0^{bcd}	51.2^{d}	63.1
Bronowski	69.1^{b}	77.0^{bc}	62.5^{b}	54.4^{bc}	73.6^{bc}	45.0^{c}	63.6
Commercial RSM	71.7^{b}	74.8^{b}	61.1^{b}	56.7^{bc}	62.2^{a}	57.6^{e}	64.0
Average	68.0	75.3	61.5	54.0	74.3	44.1	-

Means with different superscripts are significantly different between meals ($P \leq 0.05$).

was comparable to 64.6% and 68.6% observed for palm kernel and cottonseed meals respectively. These results were comparable to those reported by Devadatta and Appana (1954) for calcium availability in vegetables but slightly lower than figures reported for herbs of grassland (Armstrong and Thomas, 1952; Armstrong et al., 1953).

Phosphorus Availability of phosphorus in rapeseed meals varied from 65.0% (Span A) to 81.0% (Span S) with an average of 75.3%. This was much higher than availability of 30% to 40% usually associated with phosphorus from plant origin, and was comparable to results obtained for availability of phosphorus in palm kernel meal (70.8%), cottonseed meal (76.9%) and soybean meal (89.3%) in trial 3. It is however slightly higher than 60% availability reported by Temperton and Cassidy (1964) who observed that chicks could meet a considerable proportion of their phosphorus requirements from vegetable sources. It is also compatible with reports by Salman and McGinnis (1968) who reported that hens could utilize a substantial proportion of the phosphorus in plant materials. Rapeseed meal is high in phosphorus content, a significant portion of which is available to chicks. It is suggested therefore that this source of available phosphorus be taken into account in formulation of rations that meet the chicks requirement for phosphorus.

Magnesium Magnesium availability in rapeseed meals ranged from 52.5% (Span A) to 66.5% (Span S) with a mean of 61.5%. Most meals had a higher than average availability. Results reported in this study were higher than 56.4% observed for availability of magnesium in palm kernel meal but lower than

74.6% and 77.4% obtained in cottonseed and soybean meals respectively. Rapeseed meals, like palm kernel, soybean and cottonseed meals, showed a high content and availability of magnesium

Manganese Average manganese availability (54.0%) was lower than observed in soybean meal (76.1%) and cottonseed meal (76.3%) but was higher than 45.7% determined for palm kernel meal. Manganese availability ranged from 45.5% (Span A) to 60.0% (Span S). Of the rapeseed meals tested, only Span S, Sask 940 (57.0%) and commercial RSM (56.7%) had a higher than average availability. A combination of low content and poor availability of manganese from rapeseed meal may cause manganese deficiency problems in predominantly rapeseed meal diets for chicks.

Copper Rapeseed meals assayed in this experiment showed high copper availability. Average availability was 74.3% with a range of 62.2% (commercial RSM) and 85.0% (Span S). Copper content of commercial RSM was approximately thrice the content of the other rapeseed meals. In trial 3, palm kernel, soybean and cottonseed meals had the same copper content (27 mg/kg) yet the availability of their copper was 44.7%, 51.0% and 42.3% respectively. It seems therefore that not only copper content but also the physical or chemical nature of the copper could affect availability.

Zinc Zinc availability from rapeseed meals was low (44.1%) ranging from 23.0% (Span A) to 57.6% (commercial RSM). Availability of zinc has been shown to be similarly low in palm kernel meal (13.9%) and cottonseed meal (38.0%) but fairly high

in soybean meal (66.5%). O'Dell et al. (1972) reported zinc availabilities of 57% and 67% for sesame and soybean meals respectively. Results reported in trial 4 had implicated phytic acid and crude fibre content in reduced zinc availability. Because of the low zinc availability reported in these meals, zinc deficiency could be a problem in rations in which the protein source is predominantly rapeseed meal.

Trial 7

Proximate constituents of PKM and alkali-treated PKM are presented (Table 19). PKM is low in protein, high in acid detergent fibre (ADF) and acid detergent lignin (ADL). Alkali treatment of PKM was designed to reduce the fibre and lignin content of PKM and results of this treatment are shown (Table 20). Treatment with 3% NaOH caused a 25.8% reduction in ADF and 16.4% in ADL. Increasing the alkali levels to 5% or 7% caused a reduction of 38.0% or 48.6% respectively in ADF content. There was a corresponding reduction of 24.9% and 30.1% in ADL. Treatment with alkali also caused a decrease in crude protein content.

Amino acid composition of PKM and alkali-treated PKM is presented in Table 21 and changes in amino acid content following alkali treatment are shown in Table 22. Palm kernel meal is low in lysine, threonine, methionine and other essential amino acids. Treatment with 3% NaOH destroyed large amounts of lysine (42.0%), arginine (25.4%) and threonine (24.2%) with lower destruction of the other amino acids tested. Increasing the level of alkali treatments caused a severe destruction of all amino acids. Treatment with 7% NaOH showed increased destruction of arginine (78.7%), lysine (71.0%), serine (55.5%), threonine (51.5%) and histidine (46.3%). The large decrease in lysine, arginine and threonine precludes the utilization of 7% alkali-treated PKM as a source of protein in practical poultry rations

Dry matter disappearance (DMD) and digestible energy (DE)

Table 19. Chemical composition of PKM and alkali-treated PKM (dry matter basis).

(Trial 7)

Ingredient	DM (%)	CP (%)	ADF (%)	ADL (%)
PKM	92.0	21.30	43.70	21.10
PKM + 3% NaOH	95.0	18.94	32.40	17.60
PKM + 5% NaOH	94.9	17.80	27.08	15.80
PKM + 7% NaOH	95.0	17.76	22.46	14.73

Table 20. Per cent reduction in protein, ADF and ADL of PKM following alkali treatment.

(Trial 7)

Treatment	CP (%)	ADF (%)	ADL (%)
PKM + 3% NaOH	10.9^{a}	25.8^{a}	16.4^{a}
PKM + 5% NaOH	16.3^{b}	38.0^{b}	24.9^{b}
PKM + 7% NaOH	16.5^{b}	48.6^{c}	30.1^{c}

Means with different superscripts are significantly different ($P \leq 0.01$) between treatments.

Table 21. Amino acid composition of PKM and alkali-treated PKM (dry matter basis).
(Trial 7)

Amino acids	Alkali treatment of PKM			
	PKM	3%	5%	7%
Lysine	0.69	0.40	0.24	0.20
Histidine	0.41	0.35	0.27	0.22
Arginine	2.68	2.00	1.14	0.57
Aspartic acid	1.69	1.43	1.43	1.33
Threonine	0.66	0.50	0.50	0.32
Serine	0.90	0.80	0.59	0.40
Glutamic acid	3.62	3.35	3.18	2.75
Proline	0.50	0.42	0.42	0.42
Glycine	0.91	0.80	0.72	0.66
Alanine	0.81	0.70	0.68	0.65
Valine	0.43	0.40	0.35	0.32
Methionine	0.47	0.40	0.37	0.37
Isoleucine	0.60	0.60	0.53	0.46
Leucine	1.23	1.04	1.04	1.02
Tyrosine	0.58	0.48	0.37	0.33
Phenylalanine	0.82	0.75	0.70	0.50

Table 22. Per cent destruction of amino acids following alkali treatment

(Trial 7)

Amino acids	Alkali treatment of PKM		
	3%	5%	7%
Lysine	42.0	65.2	71.0
Histidine	14.6	34.1	46.3
Arginine	25.4	57.5	78.7
Aspartic acid	15.4	15.4	21.3
Threonine	24.2	24.2	51.5
Serine	11.1	34.4	55.5
Glutamic acid	7.5	12.2	24.0
Proline	16.0	16.0	16.0
Glycine	12.1	20.9	27.5
Alanine	13.6	16.0	19.8
Valine	7.0	18.6	25.6
Methionine	14.9	21.3	21.3
Isoleucine	0.0	11.7	23.3
Leucine	15.4	15.4	21.0
Tyrosine	17.2	36.2	43.1
Phenylalanine	8.5	14.6	39.0

of PKM and alkali-treated PKM are presented in Table 23. There were no significant differences ($P \leq 0.01$) between the DMD of PKM (81.1%) and 3% NaOH - treated PKM (80.5%). Treatment with 5% of 7% NaOH caused a significant increase ($P \leq 0.01$) in DMD of palm kernel meal. Furthermore significant increases ($P \leq 0.01$) were observed in digestible energy of alkali-treated PKM. Increasing the level of alkali treatment significantly ($P \leq 0.01$) improved the dry matter disappearance and digestible energy of PKM for the ruminant. Results observed in this study were in agreement with reports by previous workers (Ololade et al., 1970; Chandra and Jackson, 1971; Rounds et al., 1976). Levels of alkali used in the experiment showed no adverse effect on nutrient digestibility in the rumen. Alkali treatment is a proven method of improving the nutritive value of poor quality roughages for ruminants. Results from this study indicate that PKM and alkali-treated PKM have a greater potential in ruminant nutrition than has been previously recognised.

Metabolizable energy values for PKM and alkali-treated PKM determined with three week old chicks are presented in Table 24. Metabolizable energy of PKM (2796.0 kcal/kg) was significantly ($P \leq 0.01$) higher than ME of alkali-treated PKM. There were significant differences ($P \leq 0.01$) between metabolizable energy of 3% (1845.3 kcal/kg), 5% (1327.4 kcal/kg) and 7% (950.7 kcal/kg) alkali-treated PKM. The more severe the alkali treatment, the greater the depression observed in metabolizable energy of the sample. It appeared that alkali treatment adversely affected energy components such as carbohydrates and fats in addition to protein destruction. Depressed feed

Table 23. Digestible dry matter (DDM) and digestible energy (DE) of PKM and alkali-treated PKM

(Trial 7, Experiment 1)

Treatment	DDM (g/100g)	DE (kcal/g)
PKM	81.10[a]	3.710[a]
PKM + 3% NaOH	80.50[a]	3.765[b]
PKM + 5% NaOH	83.72[b]	3.881[c]
PKM + 7% NaOH	87.70[c]	4.060[d]

Means with different superscripts are significantly different ($P \leq 0.01$) between treatments.

Table 24. Gross and metabolizable energy of PKM and alkali-treated PKM (dry matter basis).

(Trial 7)

Ingredient	GE (kcal/kg)	ME (kcal/kg)
PKM	4673.0	2796.0[a]
PKM + 3% NaOH	4502.0	1845.3[b]
PKM + 5% NaOH	4500.0	1327.4[c]
PKM + 7% NaOH	4407.0	950.7[d]

Means with different superscripts are significantly different ($P \leq 0.01$) among ingredients.

intake was observed in chicks fed alkali-treated PKM, the higher the level of alkali treatment, the lower the feed intake. This indicated that residual alkali affected palatability and could partly explain the depression in metabolizable energy following alkali treatment.

Results (Table 25) indicate that inclusion of PKM at 10%, 20% or 30% into a standard starter diet (wheat-soybean) significantly ($P \leq 0.05$) increased total body weight gain and average daily gain of test chicks over controls. Total feed consumption was however significantly ($P \leq 0.05$) increased by inclusion of PKM in the diets. There were no significant differences ($P \leq 0.05$) between the feed conversion ratio (FCR) of chicks on the 10% PKM and control rations. Feed conversion ratio of chicks on the 20% and 30% PKM rations were not significantly different ($P \leq 0.05$) from each other but were significantly higher ($P \leq 0.05$) than those on the 10% PKM ration. Calculated nutrient composition of the test diets is shown in Table 26. All rations were approximately isocaloric and isonitrogenous and were balanced for content of lysine, methionine, threonine, calcium and phosphorus. Differences in growth rate would therefore be due to variations in nutrient intake. The average nutrient intake per bird (Table 27) indicated that feed, energy, protein and crude fibre intake was highest in the chicks on the 30% PKM diet and lowest in birds on the control diet. The differences in growth rate and feed conversion ratio between the PKM diets and the control diet may be explained by the hypothesis that increased level of dietary fibre in the test diets hastened transit time of the ingested feed in the digestive tract of the chicks, and

Table 25. Effect of level of PKM in ration on growth rate and feed conversion ratio of broiler chicks (Trial 7, Experiment 3).

Ration treatment	Body wt gain per bird	Feed consumption per bird	ADG	FCR
Control	219.8^{a}	366.0^{a}	18.3^{a}	1.67^{ab}
10% PKM	275.4^{b}	443.6^{b}	23.0^{b}	1.61^{a}
20% PKM	265.4^{b}	463.0^{b}	22.1^{b}	1.74^{bc}
30% PKM	271.2^{b}	496.6^{c}	22.6^{b}	1.83^{c}

Means with different superscripts between treatments are significantly different ($P \leq 0.05$).

Table 26. Effect of level of PKM in ration on growth rate and feed conversion ratio of broiler chicks.

Calculated nutrient composition of test diets (Trial 7, Experiment 3).

Ingredient	% of ration	ME	CP	Lys	Meth	Threo	Ca	P
			10% PKM					
Control ration	89.80	2526.0	20.5	1.13	0.41	0.71	0.92	0.63
PKM	10.00	257.2	2.0	0.07	0.05	0.07	0.04	0.08
Supple. Lys	0.05	-	-	0.05	-	-	-	-
Limestone	0.15	-	-	-	-	-	0.05	-
	100.00	2783.2	22.5	1.25	0.46	0.78	1.01	0.71
			20% PKM					
Control ration	79.70	2241.9	18.3	1.01	0.37	0.63	0.82	0.56
PKM	20.00	514.5	3.9	0.14	0.10	0.14	0.08	0.16
Supple. Lys	0.10	-	-	0.10	-	-	-	-
Limestone	0.30	-	-	-	-	-	0.10	-
	100.00	2756.4	22.2	1.25	0.47	0.77	1.00	0.72
			30% PKM					
Control ration	69.40	1952.1	16.0	0.88	0.32	0.55	0.71	0.49
PKM	30.00	771.7	5.9	0.21	0.15	0.21	0.12	0.24
Supple. Lys	0.15	-	-	0.15	-	-	-	-
Limestone	0.45	-	-	-	-	-	0.15	-
	100.00	2723.8	21.9	1.24	0.47	0.76	0.98	0.73

Table 27. Average nutrient intake per bird per day (Trial 7, Experiment 3).

Diets	Feed intake (g)	Energy intake (kcal)	Protein intake (g)	Crude fibre intake (g)
Control	30.50	85.79	6.95	1.08
10% PKM	36.97	102.89	8.32	1.83
20% PKM	38.58	106.34	8.56	2.45
30% PKM	41.38	112.71	9.06	3.20

consequently increased total feed consumption per day. This led to increased total protein and energy intake and retention and therefore to higher average daily gain. It appears that chicks need more dietary fibre for optimum growth than is supplied by the standard wheat-soybean starter ration. It also appears that in high fibre diets, there may be an increased requirement for protein or energy or both. Among the PKM diets, differences in growth rate and feed conversion ratio are harder to explain. It is however suggested that inclusion of PKM at 10% provides that level of dietary fibre at which growth rate and feed utilization are optimised.

The growth rate and feed conversion ratio of chicks fed PKM and alkali-treated PKM diets are presented in Table 28. Growth rate was initially depressed in the test diets but rapidly returned to normal in the PKM and 3% alkali-treated PKM rations. Lower growth rate was observed in the 5% and 7% alkali-treated PKM rations throughout the experiment, corresponding to depressed feed intake. Chicks on the PKM ration gained faster than those on the alkali-treated PKM rations, although no significant differences ($P \leq 0.01$) were observed in feed conversion ratio among these treatments. Average daily gain and feed conversion ratio were similar in control and PKM rations.

Delignification of alkali treatment did not improve the nutritive value of PKM for non-ruminants but rather confounded the already existing palatability problem.

Table 28. Growth rate and feed conversion ratio of chicks on PKM and alkali-treated PKM diets.

(Trial 7, Experiment 4)

Treatment	Cumulative weight gain per bird (g)					
	Days				*ADG	*FCR
	2	4	6	8		
Control	22.1	57.0	78.7	126.2	15.8^{a}	1.63^{a}
PKM	4.8	34.3	76.8	121.4	15.2^{a}	1.67^{ab}
PKM + 3% NaOH	8.8	40.7	76.8	116.8	14.6^{a}	1.80^{b}
PKM + 5% NaOH	4.0	33.8	67.7	103.1	12.9^{b}	1.83^{b}
PKM + 7% NaOH	3.5	23.8	48.0	72.6	9.1^{c}	1.83^{b}

*ADG and FCR were subjected to statistical analysis.

Means with different superscripts were significantly different ($P \leq 0.01$), between treatments.

Table 29. Calculated analysis of test diets (Trial 7, Experiment 4).

Diets	Lysine (%)	Methio-nine (%)	Threo-nine (%)	Calcium (%)	Phos-phorus (%)	Crude Protein (%)	Metabo-lizable Energy (kcal/kg)
Control	1.26	0.46	0.79	1.02	0.70	22.86	2812.85
PK	1.25	0.46	0.78	1.14	0.79	22.98	2837.16
PK + 3% NaOH	1.25	0.46	0.74	1.01	0.80	22.45	2702.10
PK + 5% NaOH	1.25	0.47	0.72	1.06	0.81	22.49	2565.35
PK + 7% NaOH	1.26	0.48	0.72	1.07	0.83	22.54	2500.00

The need for increased utilization of vegetable feedstuffs in chick diet formulation.

The problem of world food shortage is real, and everyday hundreds of thousands of human beings, especially in the developing countries, go to bed hungry and malnourished. Plant foodstuffs such as cereals, yam and cassava constitute a major fraction of the diets of the people, principally because animal protein is in short supply. But it does not have to be so. Increased utilization of vegetable protein supplements in animal feed formulation is a way to turn poor quality proteins into nutritionally superior animal proteins. Many tropical countries produce considerable quantities of peanut, coconut, palm kernel, soybean, cottonseed, sunflower seed and other vegetable meals capable of utilization in animal nutrition. The Food and Agriculture Organization of the United Nations (F.A.O., 1974) reported that in 1974 countries of Africa exported well over one million metric tons of oilseed cakes, earning an estimated $127.4 million. Nigeria exported 61,100 metric tons of oilseed cakes and earned $11.4 million in the process.

280,668 tons (metric) of peanut meal, 170,622 tons of cottonseed meal, 107,773 tons of palm kernel meal, 32,105 tons of rapeseed meal and 13,481 tons of coconut meal were exported by African countries in 1974. Most of these products were imported by European countries for feed and fertilizer production while the countries of Africa imported 96,825 metric tons of oilseed cakes principally cottonseed meal (13,356 metric tons), soybean meal (8,000 metric tons), and coconut meal (213 metric tons).

The use of soybean meal in livestock rations in tropical countries has been recognised for a long time. Soybean, peanut and fishmeals have traditionally been the main suppliers of dietary amino acids in non-ruminant rations in Nigeria. Nigeria does not however produce sufficient soybean meal to meet its requirements for animal nutrition. Locally produced soybean meal is so expensive that it is priced out of the reach of the average farmer, yet importation has until recently been curtailed.

Cottonseed meal is neither produced nor utilized in animal rations to any significant extent in Nigeria. Cottonseeds produced in Nigeria (11,126 metric tons in 1974) are strictly for export. Cottonseed meal has a proven record of utilization in animal rations. What is needed in Nigeria and other African countries is technology to process the meal and reduce its gossypol content. The product is well endowed with considerable quantities of highly available dietary amino acids and can contribute significantly to production of animal proteins in Nigeria.

Rapeseed meal is a relatively newcomer to the scene of non-ruminant nutrition. Recent research in Canada and the U.S. has indicated that commercial rapeseed meal is a good source of dietary amino acids and with judicious incorporation into rations, can contribute significantly to animal production.

Palm kernel meal is not considered a major feed ingredient in most tropical countries. The product is restricted to 5% to 10% of chick diets and a significant fraction of the total production is used for fuel production and soil fertilization.

Most tropical countries produce tremendous amounts of palm kernel meal which can be more efficiently utilized in livestock rations when mixed with synthetic amino acids or other protein sources. Palm kernel meal has a potential for contributing significantly to solving the perennial food problem of tropical countries.

In 1968/69, corn, millet and sorghum production in Nigeria were 1,039, 2,152 and 3,425 million tons. Of this amount only 1.96 thousand tons of each cereal was utilized in animal feed manufacture. The rest of the production was for human consumption, average daily intake per person of corn, millet and sorghum being estimated at 38.18, 83.04 and 129.84 grams. A lot more of these grains could have gone into manufacture of animal feeds, were they not so much part of the Nigerian diet. Olayide et al. (1972) projected that demand for corn, millet and sorghum for human consumption in 1980 would be 1.20, 2.75 and 4.31 million metric tons respectively. However the projected supply of these cereals would be 1.11, 2.03 and 2.88 million metric tons respectively. Projected demand would therefore exceed projected supply of corn, millet and sorghum by 0.09, 0.72 and 1.43 million metric tons respectively. They observed that at the existing compound rate of growth of food supply, Nigeria would not be able to feed its people in decades ahead, beginning from 1972 and warned that the food situation was a serious national disaster which required urgent solution and/or planned attack. Olayide and coworkers (1972) suggested that supply of cereals should increase at 6.5% and farm production at 8.0% per year to meet current and future demands for

cereal products for human and animal consumption.

The approximate costs of feed ingredients in Lagos, Nigeria and Vancouver, Canada are presented in Table 30. There is a $320 price differential in the cost of one ton of soybean meal between Lagos and Vancouver. Almost all the soybean utilized in animal feed formulation in Nigeria is produced locally and when demand far exceeds supply, prices rise. There is however only a $31 difference between wheat costs in Lagos and Vancouver. Because only a little wheat is grown in Nigeria, almost all the wheat used in feed manufacture is imported, and when bulk purchases are made especially at low export prices, cost of wheat in Lagos can compare favourably with cost in Vancouver.

The approximate ingredient costs of formulating one ton of standard wheat-soybean starter ration in Lagos and Vancouver are presented in Table 31. It is approximately $96 more expensive to formulate a ton of wheat-soybean starter ration in Lagos that it is in Vancouver. Because of the high cost of corn in Nigeria (₦100/ton), it would be less expensive to formulate a corn-soybean starter ration in Vancouver than to formulate the same ration in Lagos using corn grown in Nigeria. To relieve the pressure on these cereals, Olayide et al. (1972) suggested the utilization of other cereals and grain legumes for human consumption.

A possible alternative would be to meet a fraction of the protein and energy requirements of animals with less conventional feedstuffs like palm kernel meal. The approximate costs of rations formulated by substituting PKM at 10%, 20% or 30% into

Table 30. Approximate cost of feed ingredients at Lagos, Nigeria and Vancouver, Canada (1976).

Ingredient	Lagos price in Naira (₦)[1]/ton	Vancouver price Dollars ($)[1]/ton
Soybean	₦400	$224
Wheat	₦100	$110
Meat meal	₦143	$186
Alfalfa meal	₦ 63	$ 80
Tallow	₦250	$340
Limestone	₦8.50	$8.50
Calcium phosphate (Dibasic)	₦104	$146
Vitamin-Mineral premix	₦2/ton of finished feed	$3.50/ton finished feed
DL methionine	₦1/lb	$1.40/lb
L-lysine	₦2.75/lb	$3.85/lb
PKM	₦ 50	$105*

*Assuming a 50% mark up on Nigerian prices.

[1]Conversion rate is ₦1 = $1.41 Canadian.

Table 31. Approximate ingredient cost of formulating standard what-soybean starter rations in Lagos, Nigeria and Vancouver, Canada.

Ingredient	Lagos Nigeria (₦)	Vancouver Canada ($)
Soybean	98.18	61.60
Wheat	62.23	69.85
Meat meal	2.86	3.72
Alfalfa meal	0.63	0.80
Tallow	5.75	7.13
Limestone	0.12	0.12
Calcium phosphate (Dibasic)	1.04	1.46
Vitamin-Mineral premix	2.00	3.50
D-L methionine	2.80	3.92
L-lysine	4.48	6.16
	180.09	158.26

standard starter rations are presented in Table 32. Introducing PKM at 10% level, reduced ingredient costs per ton of feed by $14.78. Introduction at 20% or 30% reduced costs by $29.32 and $44.34 per ton respectively. Results in experiment 3, Trial 6 have shown that average daily gain of the birds on the PKM rations were not significantly different from each other ($P \leq 0.05$) but were significantly ($P \leq 0.05$) higher than controls. The lowest feed conversion ratio was shown by birds on the 10% PKM ration and the highest by those on the 30% PKM ration. All factors considered, the 20% PKM ration may be the best ration to feed.

Table 32. Approximate ingredient costs of rations formulated by substituting PKM at 10%, 20% or 30% into standard starter rations.
(Trial 7, Experiment 3)

Ingredients	Costs at Lagos Nigeria ₦	Costs at Vancouver Canada $
10% PKM diet		
Standard starter ration	161.72	142.12
PKM	5.00	50.50
L-lysine	2.80	3.85
Limestone	0.01	0.01
	169.53	156.48
20% PKM diet		
Standard starter ration	143.53	126.13
PKM	10.00	21.00
L-lysine	5.60	7.70
Limestone	0.02	0.02
	159.15	154.85
30% PKM diet		
Standard starter ration	124.98	109.83
PKM	15.00	31.50
L-lysine	8.40	11.55
Limestone	0.04	0.04
	148.42	152.92

SUMMARY AND CONCLUSIONS

Amino acid content and availability, mineral content and availability and metabolizable energy of palm kernel, soybean, cottonseed and rapeseed meals were determined using growing broiler chicks. Palm kernel meal was lowest and soybean meal highest in content of essential amino acids, of all vegetable protein supplements tested. Average amino acid availability varied from 84.5% (palm kernel meal) to 97.3% (soybean meal). Amino acid availability in cottonseed meal (92.5%) and rapeseed meal (91.9%) were similar.

Content of calcium, phosphorus and magnesium were high in all feedstuffs tested. Manganese was low in soybean and cottonseed meals but high in palm kernel meal. Content of iron was exceptionally high in palm kernel meal (356 ppm) and low in cottonseed meal (81 ppm). Copper content was low in all feedstuffs tested. Mean availability of minerals varied from 50.0% (palm kernel meal) to 74.3% (soybean meal). Mineral availability in cottonseed meal (62.1%) and rapeseed meal (64.0%) were similar. Among mineral elements tested, phosphorus (78.0%) and calcium (72.6%) showed the highest availability while zinc (44.0%) was least available.

Crude fibre content of the feedstuffs significantly ($P \leq 0.05$) depressed availability of all minerals tested while phytic acid content significantly ($P \leq 0.05$) affected availability of phosphorus, calcium, zinc and magnesium but not manganese and copper. It was suggested that while the influence of phytic acid on mineral availability was well

documented, the effect of crude fibre had not been previously well emphasized.

The metabolizable energy (ME) of the feedstuffs was determined using three week old broiler chicks. Metabolizable energy values were similar to those reported in the literature and ranged from 1957 kcal/kg dry matter (rapeseed meal) to 2796 kcal/kg dry matter (palm kernel meal). There were no significant differences ($P \leq 0.05$) between metabolizable energy content of palm kernel and soybean meals.

Chemical constituents, available carbohydrate and metabolizable energy of seven different rapeseed meals were determined. There were significant differences ($P \leq 0.01$) in metabolizable energy of the meals, the values ranging from 1492 kcal/kg (Span A) to 1957 kcal/kg (commercial RSM). Of all chemical constituents tested, ether extract, sugar and starch content were highly significantly ($P \leq 0.01$) related to metabolizable energy. Multiple linear regression equations were developed to predict metabolizable energy of rapeseed meals from their chemical constituents.

Content and availability of six minerals (Ca, P, Mg, Mn, Zn, Cu) were determined using the test rapeseed meals. Samples were high in calcium, phosphorus, and magnesium and low in copper content in comparison to palm kernel, soybean, cottonseed and other vegetable protein supplements. Average availability of minerals ranged from 52.2% (Span A) to 64.0% (commercial RSM). Among the minerals tested, phosphorus (75.3%), copper (74.3%) and calcium (68.0%) showed the highest availabilities. Zinc was least available (44.0%).

Palm kernel meal, delignified by treatment with 3%, 5% or 7% NaOH was analysed for amino acid destruction and subsequently utilized in growth and other trials. There was a considerable reduction in content of protein, acid detergent fibre and acid detergent lignin following alkali treatment of palm kernel meal. Reduction in proximate constituents was directly related to level of alkali used. Alkali treatment of palm kernel meal caused destruction of constituent amino acids. The level of destruction was similarly directly related to the severity of alkali treatment. Various amino acids were affected differently. Treatment with 7% alkali caused a 21.3% destruction in methionine content but 71.0% destruction of lysine. Alkali treatment depressed metabolizable energy of palm kernel meal. There were significant differences between metabolizable energy of untreated PKM (2796 kcal/kg) and 3% (1845 kcal/kg), 5% (1327 kcal/kg), and 7% (951 kcal/kg) alkali-treated PKM. Inclusion of alkali treated PKM at 30% level into a standard broiler starter ration depressed growth rate and feed efficiency of test chicks as compared to control chicks.

In another growth trial, it was shown that inclusion of palm kernel meal at 10%, 20% or 30% into a standard starter diet significantly ($P \leq 0.05$) increased total body weight gain and average daily gain of test chicks over controls on a standard starter diet. Chicks on the 10% PKM diet had the highest growth rate and feed efficiency. Increased level of PKM incorporation slightly depressed feed efficiency but not growth rate of test chicks.

Results obtained in the present study and in the literature

indicate that these vegetable protein supplements are an excellent source of dietary amino acids for the chick, when they are used in combination with other protein sources or amino acid mixtures since they are generally deficient in one or more essential amino acids. Plant protein feedstuffs are also a potential source of mineral elements for the chick. What is needed is more research to determine the availability of nutrients in plant feedstuffs.

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Appendix Table 1. Analysis of variance for proximate constituents of PKM, SBM, CSM and RSM.

Source of Variation	d.f.	Mean Squares				
		DM	CF	Phytic Acid	Phytate Phosphorus	Total Phosphorus
Treatment	3	1.7733*	41.613*	0.5191*	0.0408*	0.10387*
Replicates	2	0.7199	0.0799	0.0061	0.00045	0.0002
Error	6	0.3333	0.5733	0.0088	0.00085	0.0019

*Significant ($P \leq 0.05$).

Appendix Table 2. Analysis of variance for amino acid availability of PKM, SBM, CSM and RSM

Source of Variation	d.f.	Mean Squares																
		Lys.	Hist.	Arg.	Asp.	Threo.	Ser.	Glu.	Pro.	Gly.	Ala.	Val.	Meth.	Ile.	Leu.	Tyr.	Phe.
Treatment	3	0.0084	0.0050	0.0021	0.0079	0.0092	0.0063	0.0056	0.0863	0.0777	0.0112	0.0531	0.0298	0.0090	0.0068	0.01179	0.0044
Replicates	3	0.00019	0.00025	0.00003	0.000006	0.00003	0.00003	0.000008	0.0014	0.0001	0.00004	0.00058	0.00244	0.000081	0.000048	0.000031	0.00017
Error	9	0.00011	0.00017	0.00012	0.00008	0.00014	0.00016	0.00005	0.0037	0.00087	0.00005	0.0028	0.00376	0.00013	0.00004	0.00045	0.00015

Appendix Table 3. Analysis of variance for metabolizable energy of PKM, SBM, CSM and RSM (Trial 2).

Source of Variation	d.f.	Mean Square
Treatment	3	276760*
Replicates	3	16415
Error	9	188.13

*Significant ($P \leq 0.05$).

Appendix Table 4. Analysis of variance for mineral availability of PKM, SBM, CSM and RSM (Trial3).

Source of Variation	d.f.	Mean Squares					
		Ca	P	Mg	Mn	Zn	Cu
Treatment	3	332.01**	252.98**	416.87**	912.36**	2175.8**	316.57**
Replicates	3	1.461	2.888	7.731	6.058	6.263	2.268
Error	9	2.1045	2.694	3.510	2.489	3.538	5.299

**Significant ($P \leq 0.01$).

Appendix Table 5. Analysis of variance for metabolizable energy of rapeseed meals (Trial 5).

Source of variation	d.f.	M.S.
Treatment	6	13096.0**
Replicates	3	1991.5
Error	18	2436.9

**Significant ($P \leq 0.01$)

Appendix Table 6. Analysis of variance for mineral availability of rapeseed meals (Trial 6).

Source of Variation	d.f.	Mean Square					
		Ca	P	Mg	Mn	Cu	Zn
Treatment	6	108.80*	95.90*	77.83*	74.17*	122.79*	334.56*
Replicates	2	0.009	8.167	2.042	2.042	37.501	1.047
Error	12	16.403	9.867	12.142	12.143	27.401	5.644

*Significant ($P \leq 0.05$).

Appendix Table 7. Analysis of variance for proximate constituents of PKM and alkali-treated PKM (Trial 7).

Source of Variation	d.f.	Mean Squares					
		DM	CP	ADF	ADL	GE	ME
Treatment	3	4.405*	5.447*	166.66*	15.693*	0.0241*	1.2779*
Replicates	1	0.405	0.180	2.000	0.500	0.0133	0.00839
Error	3	0.458	0.140	2.573	0.513	0.0039	0.000142

*Significant ($P \leq 0.05$).

Appendix Table 8. Analysis of variance for growth rate and feed consumption of chicks fed diets containing 10%, 20% or 30% PKM (Trial 7).

Source of Variation	d.f.	Mean Squares			
		Body Weight	Feed Consumption	ADG	FCR
Treatment	3	66577*	306570*	463.28*	.0377*
Replicates	3	1586.2	10934	11.08	.0032
Error	9	3384.6	8068.0	23.51	.0056

*Significant ($P \leq 0.05$).

PUBLICATIONS

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