EXTRUSION OF CEREAL BASED-LEGUME BLEND: PROCESS AND PRODUCT CHARACTERISTICS

BY

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This Thesis is submitted to the University of Ghana, Legon in partial fulfilment of the requirement of the award of M.Phil in Food Science.

OCTOBER 2002.

DECLARATION

I declare that this thesis is the result of my own research work undertaken at the Department of Nutrition and Food Science, University of Ghana, Legon under the care and supervision of Professor Samuel Sefa-Dedeh. All references cited have been duly acknowledged.

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DEDICATION

This work is dedicated to

My parents and my entire family

ABSTRACT.

The evolution of extrusion into cereal processing has widened the available assortment of puffed snack foods and ready-to-eat (RTE) breakfast cereal formulations. In producing these nutritious products, cereals can be fortified with pulse proteins, as these legumes are important sources of food proteins and other nutrients. Response Surface Methodology (RSM) was used in investigating the effects of 3 process variables (viz. Cowpea level, groundnut level and feed moisture) on product indices of extruded rice-cowpea-groundnut and sorghum-cowpea-groundnut blend systems in a modified oil-expeller. The use of the RSM helped in relating product indices by regression equations to describe the interrelations between the input parameters and the product indices.

A Central Composite Rotatable design for K=3 examined the combined effect of groundnut (0 – 10%), cowpea (0 – 20%) and feed moisture(14 – 48.01% for rice blends; 12 – 44.06% for sorghum blend) on product indices such as product moisture, expansion ratio, bulk density, protein , fat, ash (minerals content- calcium, iron and phosphorus), crude fibre, water absorption capacity (at both 27°C and 70°C), swelling capacity, and psychrometric colour terms (L,a,b). The extrusion process was carried out at 165°C. Statistical analysis, development of models and response surface plots were performed using Statgraphics statistical package (STSC, version 4.1).

The models developed from the data was used to predict some product indices such as product's moisture, expansion ratio, bulk density, protein, fat, swelling capacity, water absorption capacity, swelling capacity and the psychrometric colour terms (of L ,a, b) of both rice and sorghum extrudates. Their R^2 values ranged between 52.03% - 86.49% and

42.43% - 87.83% for rice and sorghum systems respectively. Lack of fit test showed no significance hence models developed adequately fitted the data.

The physical indices of rice and sorghum blend extrudates such as the moisture content (which ranged between 8.43% - 13.67% and 7.90% - 10. 64% for rice blend and sorghum blend respectively), expansion ratio and bulk density, were affected by feed moisture and cowpea levels. Lower levels of feed moisture and cowpea addition resulted in good expansion, less bulk density and lower extrudate moisture content in both types of blend at the maximum concentration of groundnut (10%).

Increasing the levels of cowpea and groundnut also resulted in increasing levels of the protein (15.76% 19.54% for rice blend and 16.18% - 21.24% for sorghum blend); fat (0.76% - 4.52% for rice blend and 2.22% - 5.97% for sorghum blend); crude fibre (0.694% 1.5% for rice blend and 2.264 – 3.568% for sorghum blend); and ash (0.83% - 1.30% for rice blend and 2.03% 3.66% for sorghum blend; thus increased contents of minerals elements such as calcium, iron and phosphorus). The most remarkable observation was the protein content which increased by as much as between 53.81% - 62.74% and 37.58% - 52.45% in the rice-blend and sorghum-blend extrudates respectively when compared to the extrudates from only the cereals.

The water absorption capacity and swelling capacity of flours from both blends were most affected by the feed moisture level. Increasing cowpea addition only caused a slight increase and decrease in the water absorption capacity and swelling capacity respectively. The increasing addition of cowpea increased the brightness or lightness of sorghum blend

extrudates and the overall (total) colour change; but decreased both the redness and yellowness of sorghum bend extrudates. However, increasing groundnut addition increased the redness and decreased the yellowness in rice blend extrudates.

In the end the models developed, showed that extrusion condition optimal to produce puffed or direct expanded extrudates with spongy structure should be at low feed moisture. Thus low feed moisture together with increasing cowpea(up to 20%) and groundnut(up to 10%) likely to produce ready-to-eat puffed snack with enhanced nutrition from rice-cowpea-groundnut and sorghum-cowpea-groundnut blend extrudates (as shown in Figs. 3 - 12).

ACKNOWLEDGEMENT

I thank the almighty GOD for strength and how far He has brought me in my education. I am also beholden to all those people who in one way or the other made significant comments, suggestions, contributions and inputs directly or indirectly.

I recognize specifically the immense support of Prof. Samuel Sefa-Dedeh for his guidance and support (encouragement and financial assistance).

I say "thank you" to Prof. Danso and staff of the Ecological laboratory (Ecolab) of the Department of Geography and Resource Development, University of Ghana for the opportunity to use the Perkin Elmer Atomic Absorption Spectrophotometer (AAS) in my analysis.

I cannot forget the efforts of my Messers Emmanuel Ohene Afoakwa, Agnes Bram, George Annor, Sintim-Aboagye Eric, Christiana A. Ampadu and Wilhelmina Bentil. I say GOD richly bless you all!

The all staff and Technicians of the Nutrition and Food Science Department, colleagues, well wishers: you are all part of this success story.

Thank you all.

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1.0 INTRODUCTION

1.1 EXTRUSION.

The technology of extrusion is widely used in the plastic industry and has found use in the food industry. In the food industry it's known as extrusion cooking. This involves a continuous high temperature, short-time process whereby moistened expansible starchy and or proteinaceous material is physically modified (plasticised) through the unique combination of high temperature, pressure and shear forces (Frame, 1994; Stanley, 1986). The process combines several unit operations including mixing, cooking, kneading, shearing, shaping and forming resulting in the reduction of microbial contamination and enzyme inactivation. The process of extrusion cooking has become one of the fastest growing and popular processing technologies in recent years (Frame, 1994).

Extrusion equipment and the process have gained popularity as extrusion provides many basic design advantages that minimizes time, energy and cost whilst introducing versatility and flexibility not previously available to traditional processes. In this case the principal advantage being that, the ingredient undergoes a number of unit operations in one-energy efficient and rapid process (Huber and Rokey, 1990; Sefa-Dedeh and Saalia, 1995; Stanley, 1986).

In many instances, extrusion is replacing traditional processing methods and has become a unique and popular process for preparing weaning foods, snack foods and ready-to-eat(RTE) breakfast cereals due to the ability of the extruders to generate mixing shear forces in relatively short-resident time. The shear forces can generate significant heat and physical degradation of ingredients together with other process variables which may influence the physical properties and sensory attributes of the product. This requires some predictive modeling which are very difficult because ingredients are diverse and can vary considerably, thus making modeling product specific (Frame, 1994).

1.2. PRODUCTION AND IMPORTANCE OF CEREALS AND LEGUMES.

In Ghana, cereals and legumes are the bulk of agricultural produce consumed. Most of it is converted into a variety of staple edible forms using indigenous technologies for consumption. In the developed economies, the application of science and technology has led to the provision of safe food supplies and a wide array of processed food products on the market shelves. Some of these agricultural produce undergo efficient and effective post-production management system. The major legumes and cereals consumed are cowpeas, groundnuts; and maize, rice, millet, and sorghum respectively. The table below shows their production rates as well as yields of some of these commodities in Ghana.

Table 1 **Production and yield of some major cereals consumed in Ghana.**

CROP	**PRODUCTION (1000 MT)**			**YIELD (Kg / Ha).**		
	1997	**1998**	**1999**	**1997**	**1998**	**1999**
SORGHUM	333	387	302	767	1028	1007
GROUNDNUT	154	212	212	874	1093	1093
MAIZE	996	1035	1014	1529	1485	1449
RICE.	197	194	210	1675	1485	1613

Source: *FAO production yearbook, vol.53.,2000.*

In sub-Saharan Africa and for that matter Ghana, our food security problems could be enhanced through the efficient production and effective utilization of cereals and legumes- the bulk of our produce.

Legumes also contain significant amounts of thiamin, niacin, folic acid, phosphorus, calcium and iron. With the exception of germinated seeds, legumes as consumed are almost devoid of ascorbic acid. However, small amounts do exist in few varieties, but the vitamin oxidizes after long term storage. The cowpea continues to be an affordable and major source of dietary proteins, minerals, and vitamins as supplements to cereals and root crops, for the millions of poor people in less developed countries (Kordylas, 1991; Quin, 1997). In Ghana it is in the preparation of "*akara*", and also as a major dish or mixed with staples such as cereals and tubers.

The consumption of rice as a dietary staple has increased over the years. The increase has been attributed to increased income, good storability, and ease of cooking (Ntanteng, 1987). Apart from its source of carbohydrate, rice contains some amounts of protein, iron, calcium, thiamin, riboflavin, and niacin. Rice is consumed mainly as boiled whole grain to be eaten raw, or mixed with other staples especially legumes.

Sorghum and Millet are also used as cooked staple food; for brewing beer; and the dry grains can be ground into flour for making thin porridge or thick paste or dough by boiling in water (Onwueme and Sinha, 1991).

In cereal-legume supplementation, a ratio of 70 cereal to 30 legume is considered optimal to yield approximately 50% protein in the diet. A recent survey by Sefa-Dedeh (2001), revealed the dominance of cereals and legumes in most Ghanaian diets.

1.3 PROBLEMS OF CEREAL AND LEGUME UTILIZATION.

The poor post-harvest management of these crops results in its poor utilization. This is as a result of bad storage conditions and practices leading to pest infestations and disease attacks, thereby rendering the food useless, inedible and unworthy of utilization. The cowpea beetle, *Callobruchus maculata walp* has been identified as the principal storage pest in sub-Saharan Africa (Singh and Rachie, 1985). Sorghum on the other hand is affected by *Gontarinia sorghicola* and *Atherigona soccata Rondani* The greatest constraints to rice production are the ever-increasing bird and rodent population. The next most important problem being the most obnoxious weeds such as *Ischaemum rugopum, Echinochloa colonum, Cyperus rotundus,* and *Phyllanthus sp.*

The nutritional quality of legumes are reduced due to the inherent chemical composition of the grains, such as heat labile and heat stable anti-nutritional factors interfering with bioavailability and digestibility of proteins and other nutrients as well as the flatulence effect. The digestibility of protein is reported to be lower in legumes than in cereals (Bressani, 1993; Phillip, 1993). These constraints are however eliminated to a large extent through appropriate processing methods, which are either traditional (indigenous) or industrial methods. These processes are termed traditional because they have strong links with the rural environment. It is also known to be time consuming with low quality control of the products as well as a high variability in the processes employed (Sefa-Dedeh, 1993). In Ghana, some of the traditional processing methods include unit operations such as soaking, dehulling, steaming, boiling, roasting fermentation and sprouting.

1.4. EXTRUSION OF CEREALS AND LEGUMES.

In recent times, a considerable amount of work has been done on cereal-legume blends. Research work into the improvement of some traditional methods of processing cereals and legumes has led to the outcome of a number of improved technologies among which is the "low extrusion technology". This is believed to provide an alternative to the labourous and time-consuming traditional processing methods for the mass production of pre-cooked nutritious cereals and legume foods which are shelf stable (Harper and Jansen, 1985).

Saalia (1995) modified a Komet oil expeller into an inexpensive short-barrel single screw extruder by changing its structural feature. Slots on the expeller barrel (as oil passageways) were sealed off with galvanised steel plate to prevent material loss and to sustain a steady in-built pressure during the operation. Preliminary studies and standardisation of the equipment and process parameters using corn grits established a working temperature of 130°C – 200°C.

A more detailed study of the extrusion of maize-cowpea blend and dehydrated fermented maize dough-cowpea systems established a temperature range of 165°C 170°C as optimal for producing expanded extrudates. The fermented maize product was acceptable to both "*Hausa koko*" and regular consumers as a convenient substitute. Sefa-Dedeh and Saalia (1997) therefore recommended this condition and technology as an alternative to the addition of malt to reduce the viscosity of cereal gruels and porridge for infant feeding.

Tetteh (1998), extruded fermented maize blended with amylase and cowpea. The result was the production of a low viscosity, high-energy protein food, which could be used for infant feeding.

In another study, Ackom (1998) studied the extrusion of millet and millet-cowpea blend. They concluded that an acceptable expanded ready-to-eat cereal product could be produced from both systems using the modified short-barrel single screw extruder.

Breakfast cereals are a growing market everywhere and simple extrusion cooking technology can easily be used (Benadi, 1998).

Cereals and legumes are the main stay of the economies of developing countries and for that matter, Ghana. Therefore, properly designed convenience foods are expected to contribute to this society where social changes are altering traditional patterns of food preparation.

The extrusion of rice-cowpea-groundnut and sorghum-cowpea-groundnut blends is expected to yield a product of increased nutritional, better textural and other functional properties as well as consumer appeal. It is also expected to increase effectively and efficiently the usage of cereals and legumes.

However, a large number of process and ingredient variables generally influence these attributes. This therefore requires insight into how the variables interact to give the desired product characteristics through the use of appropriate statistical design.

1.5. MAIN OBJECTIVE

To study the effect of process variables on the product characteristics of extruded sorghum, and rice systems and determine the effects of the addition of legumes.

Specific objectives include:

1. To determine the extrusion characteristics of sorghum and rice extrudates.
2. To evaluate some quality parameters (colour) of extrudates using instrumental procedures.
3. To optimize the extrusion process using response surface methodology (RSM).

2.0. LITERATURE REVIEW.

2.1. RAW MATERIALS FOR EXTRUSION COOKING PROCESSES.

Although the ingredients used in extrusion cooking are similar in all respect to those used in other processes, special features of the extrusion technology require unique processing conditions such as compression, and shear of high temperature in utilizing the characteristics of the raw material which is not normally thought to influence food processes. Extrusion is a relatively low moisture process operating in the range of 10 to 40 percent moisture on a wet weight basis. The transformation and manipulation of natural biopolymers such as those of starch or certain types of proteins form the basic structure of extruded products. Among the commonly used cereals and legumes is, wheat, maize, rye, barley, oats, sorghum; and soybeans, cowpea, field and fava beans respectively.

However, it is worth noting that all materials added to a formulation tend to modify the process and affect the extrudate characteristics. This may be simply through the dilute the concentration of other components or ingredients, or to change the viscosity of the blend or mix. Some materials have more than one function, eg. Sugars, which dilute the mixture, acts as plasticisers in the solution and may also, take part in both flavour and colour forming reactions (Frame, 1994). Therefore the raw materials could be categorized based on their function or purpose for addition as follows:

2.1.1. Structure forming.

- Those based on starch – cereals (maize, rice, sorghum, oats, and millet).
- Those based on protein-rich materials (legume).

2.1.2. Fillers in or for extrudates.

These act to modify the behaviour of the dough as it flows through the die as well as the character of the cooled extrudate.

- **Proteins.**

Under the influence of shearing forces, proteins become macerated into smaller particles of roughly cylindrical and globular shapes. This reduces the die swell of starch polymer, causing decrease in the shape of the extrudate to a more isotropic form. In addition, they reduce the extensibility of the starch polymer foam during its expansion at the die exit, reducing extrudate expansion.

- **Starch.**

This creates a finer texture as a result of the increase in the nucleation of bubbles within the extrudate during expansion.

- **Fibrous materials.**

These materials do not breakdown during extrusion but retains their size and shape as added to the formulation. They have a significant effect on the shape, expansion and texture of the extrudate at levels of greater than 2 –3 %(Guy, 1992).

2.1.3. Plasticizers and lubricating materials.

- **Water.**

This reduces polymer interaction and also causes exponential decline in the energy input in the low moisture systems. At higher levels, water serves as solvent for the starch polymer to diffuse into from the granule causing them to become weaker and more easily disperse.

- **Oils and Fats.**

These provide powerful lubrication effect in the compressed polymer mix and also modify the eating quality of the extrudate. Sensory properties of oils and fats are mainly related to their flavour characteristics where the natural flavours of groundnut oil or dairy fats can be used to enhance the profile of certain types of products.

- **Emulsifiers.**

These are special forms of lipids, which tend to have higher melting points than triglycerides, but behave as oils to provide lubrication in the extrusion process. Certain types such as lecithin and distilled monoglyceride form complexes with the amylose fraction of starch. This interaction occurs after the starch granules have melted and before they are dispersed, thus providing a protective surface. The complex remelts at higher temperature but reforms on cooling, so that the amylose complexes in the extrudate during cutting and handling. This serves to reduce surface stickiness in the warm extrudate.

2.1.4. Nucleation for gas bubble formation.

These are finely powdered food grade materials, which remain insoluble during processing, and provide surfaces at which bubbles may form during the release of water vapour. Such materials include the normal types of baking powder made up of sparingly soluble salts of phosphoric acid calcium or sodium salts. Also acid salts such as dicalcium phosphate increase bubbles even without sodium bicarbonate. According to Sopade and LeGrys,(1991), other particulate materials such as chalk and magnesium carbonates would also increase the fineness of the texture of extrudates.

2.1.5. Flavouring materials (Salt and sugar)

Salt is added to formulation for flavouring at levels of 1 to 1.5% of product weight. It dissolves in the water during the cooking process and has little effect on the process variables.

Sugar (Sucrose) may be added to formulation at low levels up to 10% w/w in extruded products without causing significant changes to the processing variables (Guy and Horne, 1988; Sopade and LeGrys, 1991). Its flavour becomes perceptible at levels greater than 5% but in order to produce a sweet product, levels of 10 to 15% are required. Sucrose may be added as either in a powdered form such as caster sugar or icing sugar; or as syrup. In processes with high sugar levels, there may be large effects on the main dependent process variables due to the sugar addition. Under severe processing conditions, some hydrolysis of sucrose may occur resulting in the release of glucose and fructose (reducing sugars). These reducing sugars may combine with amino groups of proteins and peptides to form colours and flavours in Maillard browning reactions.

2.2. RICE .

Rice (*Oryza sativa*) is cultivated in swampy fields in many tropical countries including Ghana, where it is used mainly for human food. It is produced in all the ten regions of Ghana, covering all the major ecological climatic zones. These include interior savanna zone, the high rainforest zones, the semi-deciduous rain forest zones, and the coastal savanna zone.().. Ghana has experienced a rapid dietary shift to rice particularly in the urban centers, during the early post-independence period (Starting, 1957). This trend has been attributed to increase income, favourable government pricing and policy, good storability of rice and the ease of cooking (Nyanteng, 1987). The cultivation of the traditional local varieties under *Oryza glaberrima* continues to dominate most of the agro-ecological zones, although having poor yield. These include; *Abrewabesi, Akromah, Agya Amoah, Bakoran* or *Bagulan,* and *Saka*.

The rice grain consists of an endosperm, the main starchy portion, and the embryo or germ, which are separated by the scutellum. This is all contained within a hull or husk, which comprises of an outer pericarp, testa and aluerone layer. The starch granules themselves are tightly bound to the endosperm protein. However the protein does not contain sufficient amount of certain amino acids to provide for the human requirement.

The chemical composition of rice grain varies considerably depending upon the genetic factors of plant variety, environmental influences such as location and season in which grown, degree of milling, and conditions of storage. The starch as in most cereals is a mixture of amylose and amylopectin. The degree of these two starches has much to do with the cooking and eating qualities of rice. The larger the proportion of amylose, the drier and more separated the grain after cooking. True glutinous rice, on the other hand are essentially 100% amylopectin.

Although the protein content of polished rice is somewhat lower than that of wheat, maize, and sorghum, the quality of the protein is considerably higher. Lysine, the most important limiting amino acid constitutes about 4% protein, twice the level in wheat flour or dehulled maize. Nonetheless, rice protein does not contain enough lysine, threonine, or methionine. Like other cereals, rice is lacking in vitamins A, D and C, but does contain small amounts of thiamine, riboflavin, and niacin. The levels of these vitamins are considerably higher in brown rice than in polished rice, because the B-complex vitamins are concentrated largely in the bran and germ, which are removed by milling. Rice is usually cooked by boiling in water or by steaming, and eaten with pulses, vegetables, fish, and meat. It's also used in the form of parched rice, rice flakes, puffed rice, and rice pudding. Rice wine, which may contain 10-15% alcohol, can be made from glutinous rice (Onwueme and Sinha, 1991).

2.3. SORGHUM.

Sorghum, guinea corn or great millet (*Sorghum bicolor*) is the fifth most important world cereal, following wheat rice maize and barley. It's a staple food and the chief grain in much of tropical Africa, India, China, and South America (Onwueme and Sinha, 1991; Ngoddy, 1985). Sorghum belongs to the family *Gramineae,* tribe *Andropogoneae,* and sub-tribe *Sorghastrae.* The plant is often an annual plant with a staple stem varying in height from 1 - 5m. When fully grown, some cultivars have tillers coming out of grown buds giving rise to these tillers. First of all, a single main root is produced from which a large number of much branched lateral roots are produced. Coming out of from the lowest nodes of the stem are adventitious fibrous roots.

The stem is usually erect dry insipid, grooved and nearly oval with the peduncle (top internode) not grooved. The saw-tooth margins of the sorghum leaves, distinguish the young plant from maize. A well-developed panicle may contain as many as 2000 seeds. The seeds are Roundish ovoid to flat, which can be white, pink-red, yellow or dark brown, depending on the phenolic pigments present. Anthocyanogens have been detected in yellow milo and red kafir type, but not in the white waxy or yellow endosperm varieties. The white or yellow seed grain types are generally preferred for food. Nutritionally, sorghum protein, as other cereal, is limited in the amino acids; lysine, threonine, tryptophan and methionine, although its chemical composition is similar to maize in many respects.

2.4. GROUNDNUT.

The groundnut (*Arachis hypogaea*) also called peanut, monkey-nut, and earthnut, is grown as an oil-seed and grain legume crop. They are a major cash crop and widely grown in practically all the tropical and subtropical regions of the world for direct use as food, oil, and for the high protein meal produced after oil extraction (Onwueme and Sinha, 1991). The utilization of groundnut is further limited due to the lack of postharvest technologies in storage and inventory management (Singh, 1985,1986). However, groundnuts are rich in calcium, phosphorus, iron, and above all constitute an excellent source of the vitamins such as; thiamin, riboflavin and niacin, but not vitamin A or C.

The groundnut protein resembles most other grains in being rich in lysine and tryptophan but deficient in methionine and cystine. Groundnut protein therefore serves as an excellent supplement to cereals and other starch crops that are comparatively high in methionine and cystine, but low in lysine and tryptophan. It is utilized in various forms including groundnut oil, roasted groundnuts, boiled or raw groundnut and ground or paste (Singh, 1992).

In most parts of Africa, surveys conducted indicated roasted groundnut followed by groundnut paste, oil, boiled and raw groundnut as the most commonly utilized forms (Singh, 1985). In Ghana, and other countries such as Nigeria, Senegal and Burkina Faso, roasted groundnuts are the preferred product (Singh, 1992). The oil produced from it is high in quality, non-drying and used in the preparation of hydrogenated cooking fats and frying oils; Whist the fraction that settles out during the manufacturing process is used for making soaps.

2.5. COWPEA.

Cowpea (***Vigna unguiculata***) is a cheap and nutritious food because of its source of protein, minerals and vitamins, for the millions of relatively poor people in less developed countries of the tropics (Kordylas, 1991). It is also known as black-eyed pea and an important crop in some areas of the tropics. Cowpea is mainly produced in the savannah and some margins of the semi-deciduous forest zones (Kordylas, 1991; Rachie, 1985).

The production level has generally been low and reasons being advanced for this being high susceptibility to diseases and pest attack, as well as storage problems. The major post-harvest loss affecting its utilization is the poor storage technique. The otherwise thought ideal traditional storage techniques are not so, as, insects, rodents and moulds do easily attack the cowpeas. Techniques used for its processing are mainly traditional involving: soaking, dehulling, grinding into paste (to fry), steaming and boiling in water.

Cowpeas are known to be of high nutritional value because of its high protein content and amino acid profile, which is complementary to that of other staples such as cereals. However, it has a reasonably balanced amino acid composition with a good source of lysine although deficient in methionine. In addition to this, cowpeas are an excellent source of water-soluble vitamins and also supply the essential minerals including calcium, iron, zinc, and potassium. They are also high in carbohydrates, low in fat, good source of dietary fibre, and no cholesterol (Uzogara and Ofuya, 1992).

Cowpeas are consumed in various forms – green pods, tender green leaves, green seeds and dry seeds (Rachie, 1985). The processing of cowpeas for consumption involves mainly traditional methods such as, soaking, dehulling, steaming, and cooking by boiling in excess water (Amegatse,1995).

In Ghana its major preparation includes as a major dish or mixed with staples such as cereals (rice, maize) and tubers (yam); boiled beans and gari; used in soups; and the preparation of " *akara, dawadawa, moin-moin and adayi* ".(Ngoddy,1985).

Table 2, is a summary of comparable chemical composition of rice, cowpea, groundnut, and sorghum.

Table 2. **Selected Nutrient Composition of Rice, Cowpea, Sorghum and Groundnuts**

	Rice	Cowpea	Sorghum	Groundnut
Moisture (%)	11	14-15	11- 12	5.4
Protein (%)	7.2	23.4-26.74	10- 15	30.4
Carbohydrate (%)	80	48.98-56.8	68- 80	11.7
Fat (%)	2	1.3-2.1	3	47.7
Crude fibre (%)	0.2	3.81- 4.64	2	2.5
Ash (%)	0.5	3.32- 4.14	2	2.3
Energy (kcal).	398	340	394	548
Calcium.(g)	0.04	110	26	58
Iron (mg).	0.0027	6.2	10.2	2.2

Sources: Osei A. K. (1996) ; Onwueme and Sinha (1991).

2.6. CEREAL-LEGUME COMPLEMENTATION.

Cereals and legumes are very important commodities in developing countries /semi-arid tropical countries from which a variety of staple foods are processed using simple indigenous techniques. These crops are both cheap and available, and above all complement each other's deficiencies (Kordylas, 1991) Cereal grains tend to be low in protein and have poor biological value; the essential amino acid being the limiting factor in cereals (Harper, 1981).

It's a well-established fact that legumes are valuable complements to cereals. This is because the legume proteins are good sources of lysine, which is deficient in cereals. On the other hand, cereal proteins are reasonably good sources of Sulphur-containing amino acids, which are limiting in legumes. Work done on cereal-legume complementation has shown a marked increase in protein quality of legume fortified cereal gruels (Osei, 1994; Akpapunam and Sefa-Dedeh, 1995)

Cowpea is sufficient in lysine and tryptophan which are deficient in cereals like rice, maize and sorghum, but deficient in Sulphur amino acids of cysteine and methionine (Amegatse, 1995). He reported of high levels of isoleucine, lysine and tryptophan in Cowpea – fortified maize dough, signifying the benefits of mixing protein of various origins in order to increase their (cereal) nutritive value.

Partially defatted flour was used to improve the nutritional quality of various cereal-based product such as "gonfa", millet-based product, and "epo-ogi", a corn-based gruel. "Gari", a commonly used cassava-based Nigerian (and Ghanaian) food can be prepared with 15% defatted groundnut flour. In this product there was a four-fold increase in the amount of protein at that level of fortification as well as a remarkable increase in the concentration of all the amino acids observed (Singh, 1992).

In the Sudan, 30% defatted groundnut flour is added to 70% sorghum flour to produce “Kisra”. There was a 73% increase in the amount of protein and 102% increase in the lysine content at that level of fortification (Singh, 1992). According to Phillips and Bressani (1993), the optimal ratio of cereals to legume blend of about 70:30, provides about 50% protein from each source.

Remarkable progress has been made in the utilization of new protein sources such as oilseed, cereals, leguminous seeds, leaf and single cell proteins (Saxena and Thakur, 2000). In producing nutritious products, cereals are usually fortified with lysine or pulse proteins. This idea had been expressed by Chanvan and Salunkhe(1986). Although most legumes do not provide enough viscosity, causing problems of binding and retention of texture and shape especially for low moisture shelf-stable foods, the well-established functional properties of polysaccharides as binders and viscosity enhancers, forms the basis for the incorporation of rice and sorghum in cereal-legume blends.

2.7. CEREAL AND LEGUME PROCESSING.

The processing of legumes and cereals are on:

- Local technology
- Imported technology (Stanley, 1986; Sefa-Dedeh, 1989)

2.7.1. TRADITIONAL TECHNOLOGY.

The technology involved is simple and may been have developed through experience to produce products of desirable quality. The most used of these processes are roasting, fermentation, boiling and frying. A wide variety of the cereals and legumes produced in Ghana are processed using these technologies. Roasting is a much popular process used in developing cooked instant flour especially from millet, sorghum, and groundnut-maize blends.

According to Kordylas (1990), these roasted grains are milled into composite flours, which can be reconstituted into porridge and other products. Fermentation on the other hand, is applied mostly to cereals in order to:

- Modify texture,
- Develop flavour and taste,
- Preserve the food and at the same time to increase its microbial safety (Kordylas, 1990)

Meanwhile the high moisture nature of the process has become a major advantage as it limits its shelf stability to few days. Frying and boiling are also thought to be very expensive as compared to the fermentation, and they even require special treatment afterwards before it could be preserved for a few days.

Some of the unit operations may be time consuming, laborious and inefficient resulting in the product's quality varying. According to Sefa-Dedeh (1989), most of these traditional cereal and legume processes involve very little quality control with respect to raw material requirements and process conditions. They are known to serve as tools or vehicles for national food delivery and nutrition and provide employment and income to these technology users. Among the enumerated characteristics of these traditional foods technologies are:

- Small scale.
- Uses simple technology.
- Low labour productivity.
- Main source of income.
- Uses local raw material.
- Products have local demands. (Sefa-Dedeh, 1989).

2.7.2. IMPORTED TECHNOLOGY -EXTRUSION TECHNOLOGY.

Extrusion is continuous high temperature process, which physically modifies a food material through the unique combination of high temperature, pressure, and shear forces resulting in the reduction of microbial contamination and enzyme inactivation (Stanley, 1986).

The process combines several unit operations including mixing, cooking, kneading, shearing, shaping, and forming. These unique operations causes large numbers of complex changes to the food including; hydration of starches and proteins, homogenization, gelation, shearing, melting of fats, denaturation or re-orientation of proteins, plastification and expansion of the food structure (Frame, 1994).

The principle of operation is similar in all types: raw material is fed into the extruder barrel and the screw then conveys the food along it. Down the barrel, smaller flights are known to restrict the volume and increase the resistance to movement of the food. As a result, of this the spaces between the screw and flights are filled and the food material becomes compressed.

As the food moves along the barrel, the screw kneads the food material into a semi-solid, plasticised mass. Inside the barrel, frictional heat and other additional heat causes the temperature of the material to rise rapidly. The food is then passed to the section of the barrel having the smallest flights, where pressure and shearing is further increased. Finally, the food is forced through the die (discharge end of the barrel), and as the food emerges out from the die under pressure, it expands to the final shape and cools rapidly as moisture flashes off as steam.

Extrusion equipments provide many design advantages that minimizes time, energy, and cost whiles introducing versality and flexibility not previously available (Huber and Rokey, 1990).

Some of the reasons include:

- ***Versality***: a wide variety of products are possible by changing the ingredient, the operation conditions, and shape of die.
- ***Reduced cost***: This process has lower processing costs and higher productivity than other cooking or forming processes. Some traditional processes including the manufacture of cornflakes are more efficient and cheaper when replaced by extrusion.
- ***Product quality***: The process involves high temperature applied for short time and limited heat treatment therefore retaining many heat sensitive components.

- ***No process effluent***: Extrusion is a low-moisture process that does not produce process effluents. This eliminates water treatment cost and does not create problems of environmental pollution.

2.7.2.1. EXTRUDERS.

The emergence of cooking extruders in cereal manufacturing has enabled food processors to perform several unit operations continuously in one piece of equipment. These equipments come in a variety of sizes, shapes, and mode of operation; and may be classified as:

- Single screw,
- Twin-screw extruders.

The twin-screw could also be further divided into:

- Intermeshing, counter rotating or co rotating, self-wiping; and
- Non-intermeshing.

Apart from this broad classification, extruders can further be classified on the basis of the amount of mechanical energy generated. Thus,

- **Low-shear** - This minimizes much of the energy to prevent the cooking of the dough, and is mostly used for making pretzels, pasta, and some types of snacks and breakfast cereals.
- **High-shear-** imparting high level of mechanical energy to convert heat to cook the dough, and also for the manufacture of pet foods, puffed snack foods and breakfast cereals.

However, Rossen and Miller (1973), classified extruders thermodynamically into three groups:

1. **Autogenous (nearly adiabatic) extruders:** They depend only on viscous dissipation of heat to modify the food material.
2. **Isothermal extruders**: this operates with either cooling to remove the heat generated by conversion of mechanical energy, or heating to maintain the temperature of the product within the barrel.
3. **Polytropic extruders:** These are the intermediates between the autogenous and isothermal types. Most practical food extruders are known to fall into this category.

The geometry of extruders, together with the process conditions and the food composition are reported to interplay in bringing about the various physical, chemical, and nutritional modifications of the food constituent (Cheftel, 1986).

2.8. EXTRUSION PROCESS PARAMETERS.

The extrusion process is known to be influenced by some process variables such as: barrel temperature, feed moisture, feed rate, screw speed and feed composition (Davidson et.al.,1984; Colonna et.al,1984; Owusu-Ansah et.al.,1983).

Other researchers have indicated the screw configuration as another important variable affecting product transformation such as expansion (Barres et.al., 1990; Gogoi, 1994 ; Sokhey et al., 1994), degree of fill and energy input to the material (Yam et.al.,1994). According to Phillips (1988), the influences of the raw materials include the chemical composition, particle size, prior thermal history and moisture level. Hauck (1981) identified the moisture content and the extrusion temperature as the most important influencing variables for the material's modification.

Owusu-Ansah et. al., (1983), demonstrated the importance of variables controlling the mechanical history and residence time of the material as being feed rate, die geometry, and screw speed. Also the dimensions and geometry of barrel, screw compression ratio, and position of elements on the modular screws are additional variables affecting shear and pressure within the extruder.

The interaction of all or some of these parameters causes modifications in the macromolecules of the food material during extrusion. These transformations are further reflected in the changes in the physical and functional properties of the resulting product such as expansion index, texture, viscosity, water absorption index, and bulk density (Alvarez-Martinez, 1988; Harper and Tribelhorn, 1992; Ilo et. al., 1998)).

2.9. EFFECT OF EXTRUSION ON PRODUCT CHARACTERISTICS.

Many unit operations especially those that involve heat have little or no effect on the nutritional quality of the food product. Heat processing is a major cause of the changes to nutritional properties of foods.

2.9.1. PROTEINS.

During the process of extrusion, there is denaturation of the protein that results in the improved digestibility of the protein. According to Cheftel (1986), the extrusion of legumes and oil seeds have provided some examples of improved digestible and the bioavailabilty of sulphur containing amino acids by the unfolding of their globulins and inactivation of trypsin inhibitors and other growth retarding factors such as lecitin through thermal treatment (Cheftel, 1986).

Extensive lysine loss and nutritional damage could take place when cereal flours or cereal/legume blends are extruded into biscuits, cookies, breakfast cereals or instant flours under severe conditions of temperature (180°) or shear forces, (rpm>100), low moisture content (15%) in the presence of reducing sugars (3% glucose, fructose, maltose and lactose) (Noguchi et. al., 1982; Pharm and delRosario,1984). On the hand, higher feed moisture is known to significantly improve lysine retention.

2.9.2. FAT / LIPIDS.

The extrusion process may affect the nutritional value of lipids as a result of oxidation, hydrogenation, isomerisation or polymerization (Cheftel, 1986). Several researchers have reported the reduction of the fat content of extruded products. The free fatty acids and monoglycerides form complexes with the amylose content of the starch during extrusion, and therefore maybe difficult to extract.

Others suggest of a decrease in fat the content being because of steam distillation or thermal degradation (Maga, 1978). Eichner(1975), suggested that heating full fat soy at low moisture should provide better stability to oxidation during storage due to the formation of anti-oxidative maillard compounds. However, fat tends to oxidize particularly when fatty blends are extruded at high temperatures of 190°C or above. The oxidized fat can or may interact with starch molecules, thereby affecting viscosity, consistency, water solubility and shelf-life of the product.

2.9.3. STARCH.

The process of extrusion is widely used to restructure starch- and protinaceous materials. Upon heating and working during extrusion, macromolecule in food ingredients such as starch loose their native organized tertiary structure and forms continuous viscous dough. The native starch undergoes substantial changes leading to greater molecular disorganization.

In the case of finished product texture, the starch loses its native crystallinity, undergoes molecular degradation, and often complexes with lipids in the feed mixture. The role of shear, temperature, moisture, and feed composition are significant in the transformation of starch by extrusion (Harper, 1986). Increasing the extrusion temperature and the feed moisture results in a high degree of gelatinisation.

The conversion of the raw starch material to a cooked and digestible material through the application of moisture and heat is known as gelatinization. The gelatinized starch affects the food's texture by absorbing water to form gels and thus increasing viscosity. The proportion of raw gelatinized starch in ready to serve or eat starchy products may be critical in determining acceptability (Guraya and Toledo, 1993).

Lower moisture content is reported to cause increase viscosity and more mechanical damage. Amylopectin cannot align itself effectively in the streamlines of flow in the screw and die because of the bulkiness of the molecule resulting in its greater mechanical damage and reduced molecular size (Davidson et. al., 1984).

These damaged starches are characteristically less cohesive than gelatinized undamaged starch. Consequently, they expand less, predominantly in the longitudinal direction, creating product with smaller pores, softer textures, greater solubility and a sticky character when eaten. (Launay and Lisch, 1983).

On the other hand, higher moisture extrudates have larger pore sizes and thicker cell walls. This is the characteristic of extruded RTE cereal products, which allows it to hydrate more slowly than snack foods, thereby retaining its desired crispness longer when consumed with milk. When extrudate is very moist, it expands significantly right after the die but collapses before it can cool, and thus solidifying to present a very hard and undesirable texture.

2.9.4. TEXTURE.

The texture of extruded products is greatly influenced by the composition of the feed to the extruder. Protein and starch are the major components of the textured food mixtures. According to Areas (1992), addition of proteins to high starch flours could change the bahaviour of transformation into a "protein-type" extrudate and subsequently, the product becoming harder and more resistant to water dispersion.

The conversion of the raw starch material to a cooked and digestible material through the application of moisture and heat is known as gelatinization. The gelatinized starch affects the food's texture by absorbing water to form gels and thus increasing viscosity. The proportion of raw gelatinized starch in ready to serve or eat starchy products may be critical in determining acceptability (Guraya and Toledo, 1993).

Owusu-Ansah et.al., (1983) found the screw speed and feed moisture as having significant effects on the breaking strength of cornstarch extrudates. Ilo et. al.,(1999) reported that increased amaranth content in extrusion cooking of rice flour and amaranth blends decreased product texture for lower amaranth levels and increased product texture for higher amaranth levels. Extrudate of rice flour and amaranth had more plasticity at higher process temperature, where low-density products with small cells and thin cell wall were observed (Ilo et.al.,1999).

A large number of different methods have been used to evaluate the texture of extrudates like all rheological measurements by:

- Texture profiling by sensory methods using taste panels (Bourne, 1982).
- Quantitative descriptive analysis (Q.D.A.) (Clarke, 1990).

In extrusion, the modification of the macromolecules affects the texture and hence the sensory attributes that relates to its mechanical properties such as crunchiness, chewiness, and hardness.

2.9.5. EXPANSION RATIO AND BULK DENSITY.

The expansion ratio and bulk density of extrudates describe the degree of puffing as it exits the die nozzle. Therefore one might expect both expansion and bulk density to be interrelated. Researchers like Phillips et. al.,(1984), and Phillips and Falcone (1988) have shown that, this was not always the case.

Expansion ratio is considered only in the perpendicular direction to the extrudate flow, whereas bulk density is considered in all directions. Elastic and moisture forces acting on the product (Padmanabhan and Bhattacharya, 1989) affect the expansion of extrudates. Feed moisture, barrel temperature, feed composition and shear rate influence the expansion and bulk density. Sefa-Dedeh and Saalia (1997), and Falcone and Phillips (1988), have found the expansion ratio of extrudates to decrease with increase feed moisture.

According to Harper (1981), the decrease is as a result of the extrudates expanding immediately after exit at die, then collapses and solidifies before cooling to develop the hard and dense texture. It has been observed that adding protein to a starch extrusion system may interfere with expansion (Falcone and Phillips, 1988). Sefa-Dedeh and Saalia (1997) have obtained similar results.

2.10. APPLICATIONS OF EXTRUSION TECHNOLOGY.

A number of recent applications asides those listed in the table below include the use of extruders as enzymatic reactors with thermostable α-amylase to produce modified starches. Caseinates are also subjected to partial hydrolysis in an extruder with selected protease and the products have been reported to have very good bacteriological quality, improved colour, flavour and water absorption properties (Jones, 1990).

Extruders are being used to decontaminate spices; and for the sterilization of cocoa nibs prior to roasting for chocolate manufacturing. In addition it is been reported that, extrusion cooking results in a 1000-fold reduction in micro-organisms and the removal of off-flavors that eliminates the need for a time consuming and expensive couching stage (Fellows, 2001).

Table.3. Some possible applications of extrusion technology.

Types of products.	Examples.
Protein-based products.	Texturised Vegetable protein (TVP); Processed cheese. Caseinates; Semi-moist & expanded pet foods, animal feed, Protein supplement; Sausage products, hot dogs, frankfurters.
Starch-based products.	Ready-to-eat (RTE), and Puffed breakfast cereals; Weaning foods; Expanded snack foods. Pre-gelatinized and modified starches and dextrin.
Sugar-based products.	Chewing gum; Fruit gum; Toffee, Liquorice.

Sources: Best, 1994; Jones, 1990; Heldman and Hartel, 1997.

These interesting developments have led to the modification of a komet oil expeller into an inexpensive short-barrel single screw extruder with some structural changes by Sefa-Dedeh and Saalia (1995).

Slots on the expeller barrel (as oil passage ways) were sealed off with galvanized steel plate to prevent material loss and to sustain a steady in-built pressure during the operation. Preliminary studies and standardization of the equipment and process parameters using corn grits established a working temperature of 130°C – 200°C

However a more detailed study of the extrusion of maize-cowpea blend and dehydrated fermented maize dough-cowpea systems established a temperature range of 165°C – 170°C as optimal for producing expanded extrudates. The fermented maize product was acceptable to both "*Hausa koko*" and regular customers as a convenient substitute. Saalia (1995) therefore recommended this condition and technology as an alternative to the addition of malt to reduce the viscosity of cereal gruels and porridge for infant feeding.

In 1996, Cornelius evaluated the production of pre-cooked foods from root crops using this same modified equipment. Again, she succeeded in producing pre-gelatinized expanded products from root crops such as cassava, yam and cocoyam at a temperature of 120°C.

Tetteh (1998), extruded fermented maize blended with amylase and cowpea. The result was the production of a low viscous high-energy protein food, which could be used for infant feeding.

In another study, Ackom(1998) studied the extrusion of millet and millet-cowpea blend. He concluded that an acceptable expanded ready-to-eat cereal product could be produced from both systems using the modified short-barrel single screw extruder.

Breakfast cereals are a growing market everywhere and simple extrusion cooking technology can easily be used (Benadi, 1998). Cereals and legumes are the main stay of the economies of developing countries and for that matter, Ghana. Therefore, properly designed convenience foods are expected to contribute to this society where social changes are altering traditional patterns of food preparation.

The extrusion of rice-cowpea-groundnut and sorghum-cowpea-groundnut blends is expected to yield a product of increased nutritional, better textural and other functional properties as well as consumer appeal. It is also expected to increase effectively and efficiently the usage of cereals and legumes. However a large number of process and ingredient variables generally influence these attributes. This therefore requires insight into how the variables interact to give the desired product characteristics through the use of appropriate statistical design.

3.0. MATERIALS AND METHODS.

3.1. MATERIALS.

Rice specie (TOX-189) was obtained from the rice farms at Ashiaman. Sorghum and Groundnut samples were purchased from the Madina market. The black-eyed Cowpea (*Vigna unguiculata* walp) specifically pambora was used.

3.2. METHODS.

3.2.1. RAW MATERIAL PREPARATION.

- **Legume preparation.**

The Cowpea and groundnut were processed as shown below:

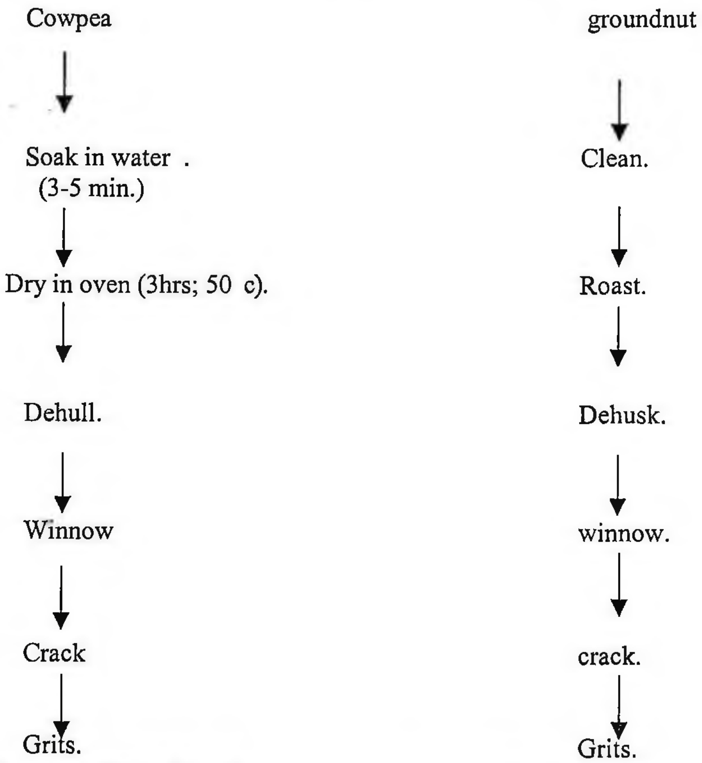


Fig. 1. **Flow chart for the preparation of grits from Cowpea and groundnut.**

- **Cereal preparation**

The Rice and Sorghum were washed, cleaned, dried and cracked or milled into grits using the Hammer mill.

3.2.2. EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS.

Response surface methodology was used to investigate the effect of extrusion process conditions (moisture, Cowpea levels and groundnut levels) on the product characteristics. Results from Sefa-Dedeh and Saalia (1997) were used to select a temperature range of between 160°C – 165°C and this helped in reducing the number of variables in the experimental design.

The independent variables considered were:

- Cowpea level.(X_1)
- Groundnut level (X_2).
- Feed moisture or level (X_3).

A Central Composite Rotatable design for $k = 3$ for the three independent variables was adopted. Coded levels for the independent variables are shown in Table 3a. and 3b.

Table 4. **Process variable and their levels to be used in the Central Composite Rotatable Design for k=3.**

A. for Sorghum

	Code	Variable level codes				
		-1.682	**-1**	**0**	**1**	**1.682**
Cowpea level (%)	X_1	0	4.06	10.01	15.96	20.02
Groundnut level (%)	X_2	0	1.47	5.01	7.89	10.01
Moisture level (%)	X_3	12.0	18.51	28.04	37.56	44.06

B. for Rice.

	Code	Variable level codes				
		-1.682	**-1**	**0**	**1**	**1.682**
Cowpea level (%)	X_1	0	4.06	10.01	15.96	20.02
Groundnut level (%)	X_2	0	1.47	5.01	7.89	10.01
Moisture level (%)	X_3	14.0	20.90	31.10	41.12	48.01

The levels were used to generate the combinations are summarized in the Table 5. The twenty sample combinations generated are shown.

Table 5. Design matrix and variable code combinations in experimental runs.

Run.	Coded Variables.			Actual Values			
	X_1	X_2	X_3	Cowpea level. X_1	Groundnut level X_2	Moisture level for rice X_3	Moisture level for sorghum X_3
1	-1	-1	-1	4.06	1.47	20.90	18.51
2	-1	1	1	4.06	7.89	41.12	37.56
3	1	-1	1	15.96	1.47	41.12	37.56
4	1	1	-1	15.96	7.89	20.90	18.51
5	0	0	0	10.01	5.01	31.1	28.04
6	0	0	0	10.01	5.01	31.1	28.04
7	-1	-1	1	4.06	1.47	41.12	37.56
8	-1	1	-1	4.06	7.89	20.90	18.51
9	1	-1	-1	15.96	1.47	20.90	18.51
10	1	1	1	15.96	7.89	41.12	37.56
11	0	0	0	10.01	5.01	31.1	28.04
12	0	0	0	10.01	5.01	31.1	28.04
13	1.682	0	0	20.02	5.01	31.1	28.04
14	-1.682	0	0	0	5.01	31.1	28.04
15	0	1.682	0	10.01	10.01	31.1	28.04
16	0	-1.682	0	10.01	0	31.1	28.04
17	0	0	1.682	10.01	5.01	48.01	44.06
18	0	0	-1.682	10.01	5.01	14.0	12.02
19	0	0	0	10.01	5.01	31.1	28.04
20	0	0	0	10.01	5.01	31.1	28.04

3.2.3. SAMPLE PRE-TREATMENT.

The various cowpea and groundnut blends were mixed together with the rice, sorghum and millet grits and the moisture level brought up to the desired final moisture by the addition a pre-determined amount of the water. The mixing was done in a Hobart mixer (model C-100, Hobart manufacturing Co., Tory OH) at a low speed for 20 minutes. The samples were packaged in polythene bags and allowed to equilibrate for 12 hours at 26°C before extruding.

3.2.4. EXTRUSION PROCESS.

The modified Komet screw oil expeller (DD 85, 1BG Monforts and Reiners, Moncerglabach, Germany) equipped with cylindrical die of 1.01cm i.d. and a screw of 1:1compression ratio with a constant pitch was used. The zone nearest the die was heated with an electric resistance sleeve and the barrel temperature monitored with a temperature sensor, which is fastened to the barrel. The extruder was choke fed, and run at a constant low speed of 29rpm for all treatments. Extrudates were collected upon attainment of steady extrusion rates. The equilibrated composite flours were extruded after which the extrudates were oven dried for a period of 5 – 7 hours at 70°C. These were then packaged in polyethylene for storage.

3.2.5. PROCESS EVALUATION.

Dried extrudates from each extrusion possible run were ground in a hammer mill (Christy and Norris) into a fine particle size powder to pass through a 40-mesh screen, and sealed in a plastic or polyethylene bag for analysis.

3.2.5.1. PROXIMATE ANALYSIS.

Crude protein (N x 6.25), Moisture, fat, crude fibre and Ash content of extrudates were determined by standard procedures in the Association of official Analytical Chemist's approved methods 920.05, 925.10, 920.85, 963.09 and 923.03 respectively (A.O.A.C., 1990).

3.2.5.2. MINERALS ANALYSIS.

The first step involved the elimination of the inorganic materials through the procedure of wet ashing. However the procedure of A.O.A.C. (1980) was slightly modified. 0.3g of ground extrudate each sample with 25ml concentrated nitric acid, followed by the addition of 70% perchloric acid. The resulting digests were then made up to 100ml solution and stored for the various analyses of the mineral components.

Calcium and iron contents were determined using the Perkin Elmer Atomic Absorption Spectrophotometer (AAS) (model: 3110, USA), at the Ecological laboratory (Ecolab) of the Department of Geography and Resource Development, University of Ghana. The instrument used had specific conditions, which needed to be set for reading each element's concentration. The values read on the AAS were in ppm (parts per million), which is equivalent to ug/ml or mg/l. The total volume of digest was 100ml; and total weight of element in digest is equal to (ppm x 100) = 100ug. 0.2g and 0.3g of sorghum and rice flours were used for the determinations. Thus, weight of elements (calcium and iron) of sample is given as: ppm x 100/ 0.2 and ppm x 100/ 0.3 for rice and sorghum respectively.

The phosphorus content was determined by the colorimetric or spectrophotometric method. Exactly 2ml of the digest was reacted with 5.0ml molybdic acid. (The molybdic acid is prepared by dissolving 25ml of ammonium molybdate in 300ml distilled water; with 75ml of concentrated sulphuric acid in 125ml of water to get 0.5litre of molybdic acid.). One ml each of 1% Hydroquinone and 20% Sodium sulphite was added in that sequence, and the solution is made up to 100ml and allowed to stand for 30mins in order to allow the colour to stabilize after which the absorbency is determined at 680nm.

A standard curve of colorimetric readings verses concentration of phosphorus using portions of standard phosphate solution (1ml, 2ml, 3ml) subjected to reactions with molybdic acid, hydroquinone and sodium sulphate solutions. All readings were corrected by the reading of a "blank" to eliminate the effect of any colour produced by the reagents.

3.2.5.3. PHYSICAL CHARACTERISTICS.

Expansion Ratio.

This was measured as the ratio of the cross-sectional area of the dried cylindrical extrudate to that of the die. The diameter of the extrudate would be the average of 10 random measurements. The vernier caliper measures within ±0.01mm. The ER is given by:

$$ER = \frac{D^2}{d^2}$$

Where; D = diameter of extrudate (mm); d = diameter of the die hole (mm).

Bulk Density.

The bulk density of extrudates was estimated using the method of Barett and Peleg (1992). A 5cm long cylindrical section of extrudate was weighed and the diameter measured using a caliper. Bulk density was then calculated as the ratio of the weight of extrudate to the volume of extrudate. The volume on the other hand was determined by placing the weighed piece of extrudate in a 100ml-graduated measuring cylinder. The cylinder was filled to the mark with dry millet grains, and tapped gently 10 times at the sides to ensure uniform packing of the grains. The decrease in the volume of grains in the cylinder after the piece of extrudate is removed is noted as the volume of the piece of extrudate.

Colour Measurement.

The colour of extrudates was determined on the flour of all possible experimental runs. The colour space parameters L*, a* and b* of the flours were measured with a Minolta CR-310 tristimulus colorimeter (Minolta camera Co. Ltd, Osaka, Japan) in triplicates. The L* value represents lightness (with 100 = perfect / brightness to 0 = darkness / blackness); a* represented the extent of green colour (in the range from negative = green to positive = redness); b* quantifies blue in the range from (negative = blue to positive = yellow). The total colour change was then calculated as;

$$\Delta E = \sqrt{(\Delta L^2 + \Delta a^2 + \Delta b^2)}.$$

Where:

$\Delta L = L^* - L^*_0$

$\Delta a = a^* - a^*_0$

$\Delta b = b^* - b^*_0$

Thus these were the absolute differences in values between reference tile (white porcelain) and sample values obtained. The standard values obtained were as follows: $L^*_0 = 104.63$; $a^*_0 = 0.31$ and $b^*_0 = 4.63$.

3.2.5.4. FUNCTIONAL CHARACTERISRICS

Water Absorption Capacity

This was carried out by the procedure of Fleming et.al., (1974). Five grams of sample (extrudate flour) was weighed into a centrifuge tube together with 30g of water, and thoroughly mixed. This was allowed to stand for 30 minutes, and then centrifuged at

3000g for 15 minutes. The sample was weighed after decanting the supernatant, with the amount of water retained in the sample taken as water absorbed. This procedure was carried out both at room temperature (27 C) and at 70 C for each sample.

Swelling Capacity

Five (5g) of extrudate flour was weighed into a 100ml-graduated measuring cylinder. The volume occupied was noted. 100ml distilled water was then added to the sample and mixed well. The volume of sample was measured after 1, 5, 10, 15, 25, 30, 45 and 60 minutes.

3.2.6. STATISTICAL ANALYSIS.

ANOVA was used to compare differences among the samples. Regression models were then developed for each product index and the influence of each independent variable assessed. The combinations of process conditions to yield optimal product indices were estimated.

4.0. RESULTS AND DISCUSSION.

4.1 Extrusion of Rice and Sorghum.

Based on conditions established by Sefa-Dedeh and Saalia (1997), preliminary investigations were carried on extruded cereals alone (rice and sorghum) and the following results obtained. Samples were extruded at 13.62% and 11.36% feed moisture levels for rice and sorghum respectively and at a constant temperature of 165°C.

Table 6. **Chemical and Physical characteristics of Rice and Sorghum extrudates**

	Rice Extrudate.	Sorghum Extrudate.
Product moisture (%).	7.48±0.05	7.05±0.13
Protein (%).	7.28±0.04	10.10±0.16
Ash (%).	0.59±0.03	1.21±0.04
Fat (%).	0.65±0.04	1.28±0.04
Crude fibre (%).	0.42±0.05	1.32±0.05
Expansion ratio.	3.426±0.202	2.369±0.189
Bulk density.(g/ml)	0.154±0.001	0.539±0.009
Swelling capacity(ml)	51	48
Water Absorption capacity (%dmb):		
a. 27°C.	302.62.	246.36
b. 70°C	359.90	312.99

Results in Table 6 show that, Expansion ratios or rice and sorghum extrudates (Table 6) were higher compared to that of the cereal-legume blended extrudates. Similar findings were observed on the cereals such as maize (Sefa-Dedeh and Saalia, 1997) and millet (Sefa-Dedeh and Ackom, 1998). Both the expansion ratio and bulk density are used to describe the degree of puffing of extrudates. It is therefore expected that under similar conditions as the expansion index increases, the bulk density would automatically decrease. The development was also observed in the study as was also observed by Sefa-Dedeh and Saalia (1997).

Various other researchers have established the importance of process variables such as the feed moisture, barrel temperature, die diameter and ingredient composition among others as affecting both the expansion ratios and bulk densities (Sefa-Dedeh and Saalia, 1997; Owusu-Ansah et.al., 1984).

The moisture contents in both products were low and ranged between 7.48% and 7.05% for rice and sorghum extrudates respectively. What this means is that, the product would have extended shelf-life. Other indices determined such as the chemical indices were as expected when compared to literature values. Differences could be attributed to variety and experimental differences.

Functional properties such as water absorption capacity (at 27°C and 70°C) and swelling capacities were high. This property is an important characteristic in the development of ready-to-eat (RTE) foods from cereals. This can be explained as a result of the low feed moisture operating condition. Under such a condition and relatively high constant temperature (165°C), there would be enough transformation, modification and biopolymer interactions during extrusion to give the observed high water absorption capacity and consequent low bulk density.

Generally, the modified oil-expeller used in this experiment as a single screw extruder produced some expanded extrudates of widely different physical structure as a result of the various blends. The samples with low feed moisture in both systems had high porosity and fragility and spongy structures (Figs. 3 – 12). These changes in product characteristics are because of the modification of starch and protein components under the high temperature and pressure. On emerging from the extruder barrel, moisture flashes off and the extrudate expands under reduced pressure, thereby resulting in the modification. Average residence time of 2.02 minutes was recorded for low moisture feed samples and 1.35 minutes for high feed moisture samples.

During extrusion, it was observed that samples with high feed moisture content had less puffing ability and shorter residence time. Some particular blends were difficult to extrude and caused irregular extrusion and die head blockage. Over-feeding or over-filling in the feed section (of screw flights) resulted in "flow back" of feed, over heating of feed and subsequent die blockage.

4.2. Extrusion of Cereal-legume blends.

4.2.1. Physical Characteristics.

The design of the experiment involved the use of Response Surface Methodology, and the data obtained from the measured product's characteristics or indices was analyzed using stepwise multiple regression procedure. Models were developed to relate extrusion process parameters (viz. feed moisture, cowpea and groundnut levels) to extrudate indices or characteristics.

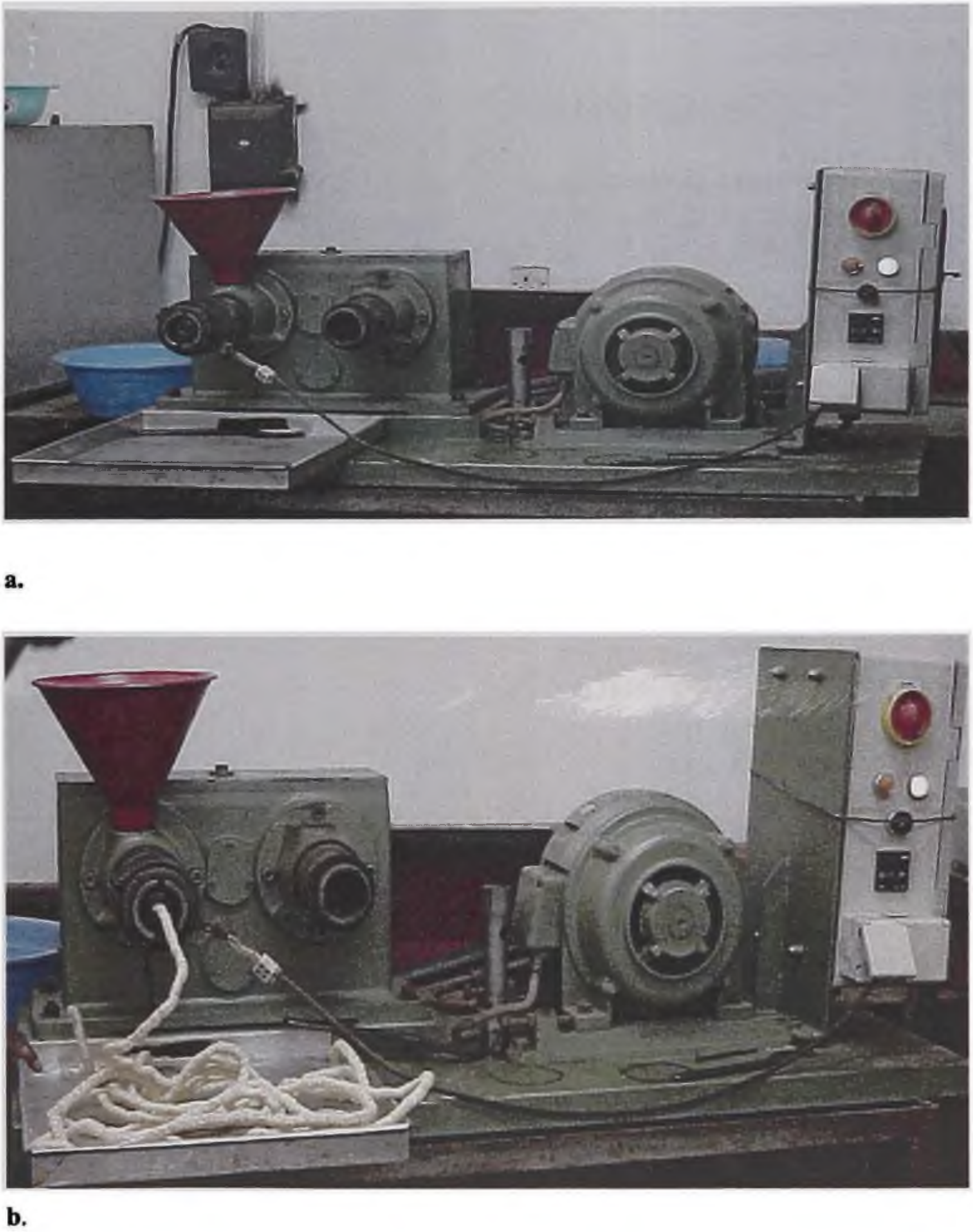


Figure 2. The modified Komet oil expeller used as the single screw extruder (**a**) not in use (**b**) showing extrudates coming out

15.96% Cowpea

1.47% Groundnut
20.90% Feed Moisture

Fig. 3

10.01% Cowpea
5.01% Groundnut
14.00% Feed Moisture

Fig. 4

4.06% Cowpea
7.89% Groundnut
20.09% Feed Moisture

Fig. 5

4.06% Cowpea
1.47% Groundnut
20.90% Feed Moisture

Fig.6

15.96% Cowpea
7.89% Groundnut
20.90% Feed Moisture

Fig.7

15.96% Cowpea
1.47% Groundnut
18.51% Feed Moisture

Fig. 8

10.01% Cowpea
5.01% Groundnut
12.02% Feed Moisture

Fig. 9

4.06% Cowpea
7.89% Groundnut
18.51% Feed Moisture

Fig. 10

4.06% Cowpea
1.47% Groundnut
18.51% Feed Moisture

Fig.11

15.96% Cowpea
7.89% Groundnut
18.51% Feed Moisture

Fig. 12

The adequacies of the fitted models were evaluated using the test of lack of fit, F-value and R^2 values. According to Joglekar and May (1987), a good fitted model's R^2 value should be at least 80%. However, this 80% may appear excessive for a preliminary study and therefore an R^2 value of 60% is acceptable (Malcolmson et.al, 1993). Based on this criterion models were adequately fitted for product's indices, which were near 60%, or more than 60% for both the rice-blend and sorghum blend systems. Their coefficients and R^2 values determined for each of the products indices are summarised in the Tables below.

4.2.1.1. Product moisture.

The moisture content of the rice-blend and sorghum-blend systems ranged between 8.43% 13.67% and 7.90% 10.64% respectively. This index is presumed as one of the most important determinants of the shelf-stability of a product.

High moisture products usually have shorter shelf-stability compared to lower moisture products (Ashworth and Draper, 1992), and all cases should require further processing or drying so as to allow for extended storage time. This is because the former has high water activity, which enhances microbial activity. Therefore there is the need for this further cost operation to bring down the levels of moisture to allow for easy handling, storage and improved general acceptability.

When compared to the data on extruded cereals alone, the cereal blends had higher moisture values. The incorporation of the legumes could be the reason for the observed higher values in both systems. Sefa-Dedeh and Saalia (1997) and Tetteh (1998) reported similar findings. Cowpea proteins are known to have water-binding effects hence its significant influence in the models. This explanation can also be extended to the influence of groundnut proteins.

Models developed in predicting this index in both systems could explain 67.17% and 76.15% of variations and a non-significant F-value of 2.99 and 3.08 (as lack-of-fit) (Table 10) in moisture contents for the rice and sorghum systems respectively Table 7 and 8. ANOVA test for the rice system revealed the significant effect of feed moisture at $p < 0.001$ as influencing this index in Table 9. Other significant process variables were the level of cowpea addition and the quadratic effect of groundnut addition to this index (both at $P < 0.05$ and $p < 0.01$)

In the sorghum-blend system, cowpea addition was the most significant process variable ($p < 0.001$). Feed moisture, linear interaction term of groundnut and feed moisture, as well as the quadratic terms of cowpea and groundnut also influenced the product's moisture content at $p < 0.05$ (Table 11).

The response surface plot based on the model (Fig.12) showed that the moisture content of the rice extrudates increased with increasing levels in feed moisture and cowpea at 10% groundnut. In the sorghum system the response surface plot (Fig.13) showed that, increasing levels of both the feed moisture and cowpea gave the increase in the product's moisture content. In both systems the plots were carried out at the 10% level of groundnut, and the results were similar. . This affirms the statement that cowpea proteins have water-binding effect. Groundnut proteins do not exhibit the same effect.

Figure 13. Response surface plot for Moisture content of Rice extrudate at 10% groundnut level

Model:

$$\mathbf{Z = 4.173917 - 0.009712\, X_1 + 0.884627\, X_2 + 0.234459\, X_3 + 0.004551 X_1 X_3 - 0.111733 X^2_2 - 0.00273\, X^2_3}$$

$R^2 = 0.6717$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).

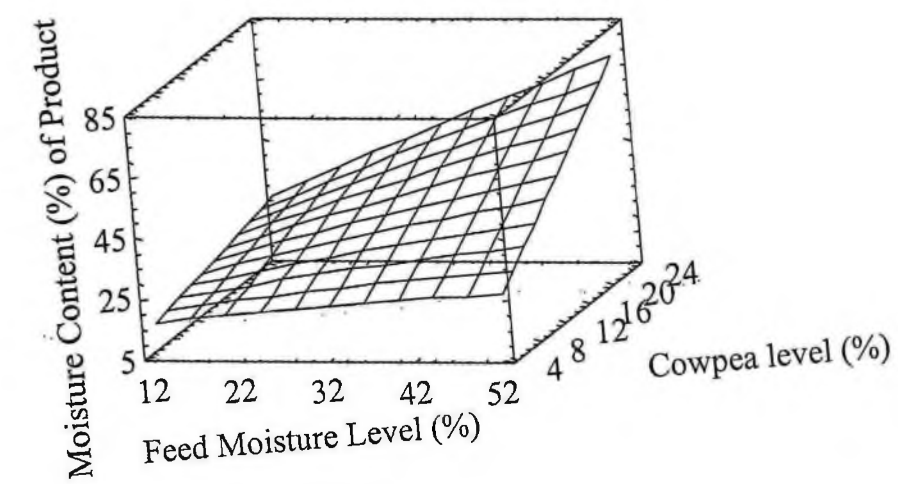

Moisture Content (%) of Product
85
65
45
25
5
12
22
32
42
52
Feed Moisture Level (%)
4
8
12
16
20
24
Cowpea level (%)

Figure 14. Response surface plot for Moisture content of Sorghum extrudates at 10% groundnut level

Model:

$$\mathbf{Z = 6.687262 - 0.085184.\,X_1 - 0.200547\,X_2. + 0.136298\,X_3 + 0.001348.X_1X_2. - 0.010384\,X_2X_3 + 0.006534\,X^2{}_1 + 0.059474\,X^2{}_2 - 0.001267\,X^2{}_3}$$

$R^2 = 0.7615$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).

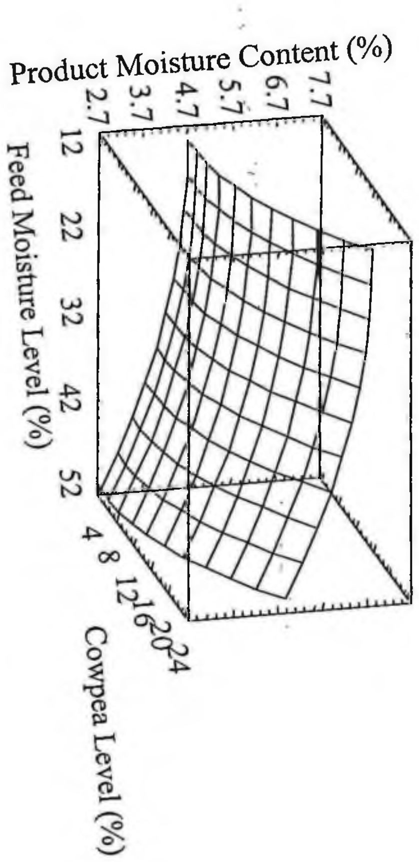

Product Moisture Content (%)
2.7
3.7
4.7
5.7
6.7
7.7
12
22
32
42
52
Feed Moisture Level (%)
4
8
12
16
20
24
Cowpea Level (%)

Table 7. **Regression coefficients and adjusted R^2 values in the models of Moisture content, Expansion ratio and Bulk density of Rice-Cowpea-Groundnut system**

Variables.	Product Moisture.	Expansion ratio.	Bulk density.
Constant.	4.173917	5.283179	-0.799574
X_1	-0.009712	-0.015223	-0.000063
X_2	0.884627	0.251131	-0.057223
X_3	0.234459	-0.239094	0.081602
X_1X_2	-		0.004902
X_1X_3	0.004551		-0.000918
X_2X_3	-		-0.005246
$X_1X_2X_3$	-		
X^2_1	-	-	
X^2_2	-0.111733	-0.028614	0.015681
X^2_3	-0.00273	0.002999	-0.000365
R^2	**0.6717**	**0.6191**	**0.8649**

4.2.1.2. Expansion Ratio.

This index describes the degree of puffing undergone by the sample as it exits the extruder. Expansion phenomena are dependent on the viscous and elastic properties of melted dough. According to Baladran-Quintana et. al., (1998), expansion is an important characteristics of extruded products being developed as a snack and RTE by food industries.

From the experiment the expansion ratios measured for all the extruded samples ranged from 0.601 – 3.262 and 0.931 – 2.145 for the rice-blend and sorghum-blend systems respectively.

Table 8. Regression coefficients and adjusted R^2 values in the models of Moisture content, Expansion ratio and Bulk density of Sorghum-Cowpea-Groundnut system

Variables.	Product Moisture.	Expansion ratio.	Bulk density.
Constant.	6.687262	2.936245	0.642331
X_1	-0.085184	0.009692	-0.02377
X_2	-0.200547	-0.028339	0.035077
X_3	0.136298	-0.085797	0.01908
X_1X_2	-	-	-0.001846
X_1X_3	0.001348		0.001361
X_2X_3	-0.10384		
$X_1X_2X_3$	-		
X^2_1	0.006534		-0.001111
X^2_2	0.059474	-	-
X^2_3	-0.001267	0.00101	-0.000722
R^2	**0.7615**	**0.4243**	**0.7994**

The regression models developed to predict the expansion ratios could explain 61.91% and 42.43% of the variations and a non-significant F-value of 6.44 and 1.64 (as lack-of-fit) (Table 10) in the rice-blend and sorghum-blend system respectively (Tables 7 and 8). In both systems, ANOVA showed the feed moisture to be the most important or significant variable. Other variables, which showed significant effect in the rice-blend system was the quadratic effects of the feed moisture (at $p < 0.05$) (Table 9). However, in the sorghum extrudate, only the linear effect of feed moisture proved significant (at $p < 0.001$) (Table11) although this effect was negative (Table 8).

Response surface plot for the rice system (Fig.15) showed the expansion of the extrudates decreased sharply with increasing feed moisture. The addition of cowpea had a slight increasing effect on the expansion of the rice-blend extrudates. This was observed at 10% of groundnut addition.

Figure 16, response surface plot for the sorghum showed the expansion of the extrudates to decrease with increasing feed moisture though increasing as cowpea levels increased. The extent of decrease with increasing feed moisture was gradual at the 10%groundnut level. Therefore for the sorghum extrudates, cowpea and the increasing groundnut addition did not interfere with expansion. However, Sefa-Dedeh and Saalia (1997) observed that adding protein to a starch system might interfere with expansion especially when cowpea was added to maize

Several researchers have observed that expansion ratio decreased with increasing feed moisture. This is because increasing feed moisture results in lower degree of starch gelatinization for different products (Falcone and Phillips, 1988; Kokini et.al., 1992; Sefa-Dedeh and Saalia, 1997). The increase in initial feed moisture would decrease the dough temperature, because moisture would reduce friction between the dough and the screw/ barrel, and have a negative impact on the starch gelatinization thereby reducing the product's expansion.

Table 9. **F-values from ANOVA for the Moisture content, Expansion ratio and Bulk density of Rice- blend extrudates.**

Variables.	Product moisture.	Expansion ratio.	Bulk density.
X_1	10.12**	0.70	1.01
X_2	0.55	0.19	13.97***
X_3	20.73***	24.44***	71.77***
X_1X_2		-	6.03*
X_1X_3	0.73		2.09
X_2X_3			19.95**
$X_1X_2X_3$		-	
$X^2{}_1$	-	-	
$X^2{}_2$	11.38**	2.18	13.10***
$X^2{}_3$	1.36	8.38*	1.71

*, **, *** = Significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$.

Result shown in Table 10, support the tentative models at adequately describing the data obtained. The lacks of fit results for indices studied were not significant.

Table 10. **Analysis of Variance for the full regression of the models showing lack of fit**

	Source of variation.	Product moisture.	Expansion ratio.	Bulk density.	Protein.	Fat.	Swelling capacity.
Rice extrudate.	Model.	7.47855***	7.17578***	16.2040***	4.94226***	12.1927***	5.91805**
	Lack of fit.	2.99	6.44	3.45	1.42	11.88	4.26
Sorghum extrudate	Model.	8.5849***	4.5013**	11.8151***	9.05839***	16.2343***	11.6321***
	Lack of fit.	3.08	1.64	3.80	2.88	5.85	6.70

	Source of variation.	Water absorption capacity @27C.	Water absorption capacity @ 70C.	Total colour change.	L – Value (Lightness)	a – Value (redness).	b – Value (yellowness).
Rice extrudate	Model.	4.10788*	4.43409**	3.4031*	3.71212	4.07516*	3.64759*
	Lack of fit.	3.29	3.74	6.69	0.46	3.94	1.49
Sorghum extrudate	Model.	5.31042**	5.56151**	8.76238***	9.58799***	10.605***	8.3703***
	Lack of fit.	2.38	3.49	5.32	1.43	1.53	0.52

Figure 15. Response surface plot for Expansion ratio of Rice extrudates at 10% groundnut level

Model:

$$Z = 5.283179 - 0.01522 X_1 + 0.251131 X_2 - 0.239094 X_3 - 0.028614 X^2_2 + 0.002999 X^2_3$$

$R^2 = 0.6191$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).

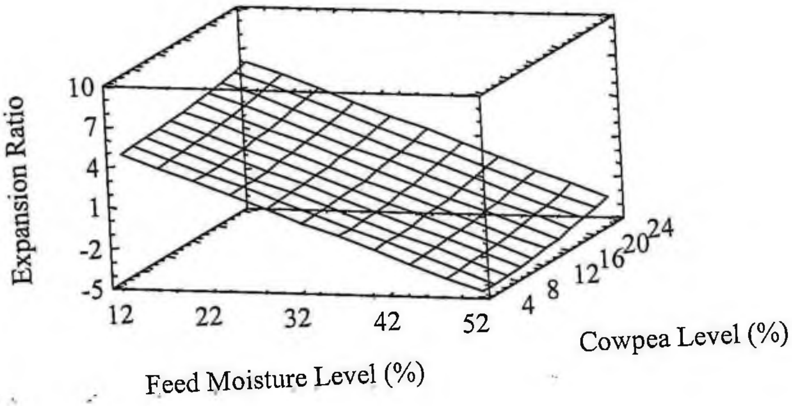

Expansion Ratio
10
7
4
1
-2
-5
12
22
32
42
52
Feed Moisture Level (%)
4
8
12
16
20
24
Cowpea Level (%)

Figure 16. Response surface plot for Expansion ratio of Sorghum extrudates at 10% groundnut level

Model:

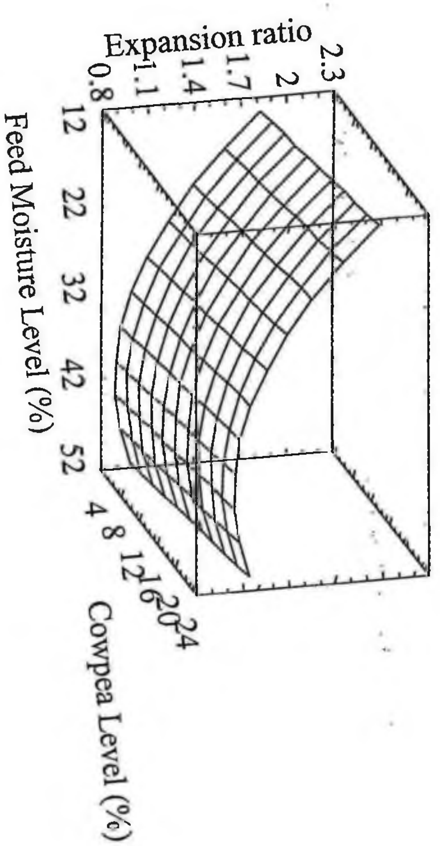
$$\mathbf{Z = 2.936245 + 0.009692\, X_1 - 0.028339\, X_2 - 0.085797\, X_3 + 0.00101\, X^2_3}$$

$R^2 = 0.4243.$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).


Expansion ratio
0.8
1.1
1.4
1.7
2
2.3
Feed Moisture Level (%)
12
22
32
42
52
Cowpea Level (%)
4
8
12
16
20
24

4.2.1.3. Bulk density.

Bulk density has been linked with the expansion ratio in describing the degree of puffing in extrudates. At high moisture levels, bulk density is also high. This is because the extrusion cooking is not enough to cause vapourisation of the moisture leading to retention of moisture and hence the reduced puffing of the product. As a result a denser product is obtained. This was what was observed with product from runs that had high feed moisture levels. However, the formation of expanded products is associated with high pressure and temperature. The rapid release of pressure as the food emerges from the die causes instantaneous expansion of steam and gas in the material to form low-density products (Fellows, 2001).

The effect of the process variables on the bulk density of the products is as shown in Tables 7 and 8. The bulk density ranged from 0.295g/ml – 1.541g/ml and 0.375g/ml – 0.969g/ml for the rice blend and sorghum blend system respectively.

The model to predict this index could explain 86.49% and 79.94% of the variations and a non-significant F-value of 3.45 and 3.80 (as lack-of-fit) (Table 10) in the rice and sorghum systems respectively (Tables 7 and 8). Feed moisture, linear interaction term between cowpea and groundnut, as well as the quadratic effect of cowpea were found to significantly influence this index in the rice blend system at $p<0.001$, $p<0.001$ and $p<0.05$ respectively (Table 9). Other variables such as the linear interaction term between groundnut and feed moisture and the quadratic effect of groundnut also influenced the bulk density at $p<0.001$.

In the sorghum blend system, the linear effects of cowpea, feed moisture, and the linear interaction term between cowpea and feed moisture were found significant at $p<0.001$. Another important variable of influence was the quadratic effect of the feed moisture at $p<0.05$ (Table 11).

The response surface graph (Fig.17) for the rice system showed increase in the bulk density of the product with increasing feed moisture and cowpea levels to the system. Groundnut level showed no effect. Figure 18 is the response plot for the sorghum system. The graph indicates that, increasing addition of moisture resulted in decreased bulk density as it increased but increased with increasing cowpea addition.

Table 11. F-values from ANOVA for the Moisture content, Expansion ratio and Bulk density of Sorghum - blend extrudates.

Variables.	Product moisture.	Expansion ratio.	Bulk density.
X_1	25.92***	0.63	30.53***
X_2	0.15	1.00	4.67*
X_3	7.86*	14.66**	16.93***
X_1X_2		-	2.25
X_1X_3	0.36	-	10.72***
X_2X_3	6.24*	-	
$X_1X_2X_3$	-	-	
X^2_1	9.91**	-	3.61
X^2_2	16.80**		
X^2_3	1.44	1.71	14.00***

*, **, *** = Significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$.

Figure 17. Response surface plot for Bulk Density of Rice extrudates at 10% groundnut level

Model:

$$\mathbf{Z = -0.799574 - 0.000063\,X_1 - 0.057223\,X_2 + 0.081602\,X_3 + 0.004902\,X_1X_2 - 0.000918\,X_1X_3 - 0.005246\,X_2X_3 + 0.015681\,X^2_2 - 0.000365\,X^2_3}$$

$R^2 = 0.8649$.

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).

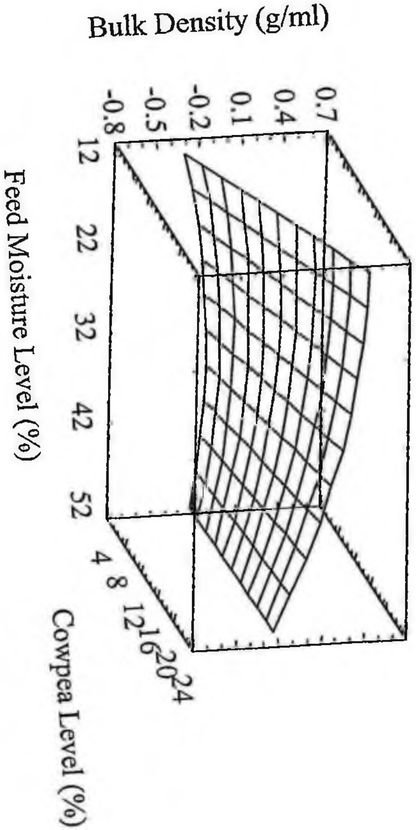

Bulk Density (g/ml)
-0.8
-0.5
-0.2
0.1
0.4
0.7
Feed Moisture Level (%)
12
22
32
42
52
Cowpea Level (%)
4
8
12
16
20
24

Figure 18. Response surface plot for Bulk Density of Sorghum extrudates at 10 % groundnut level

Model:

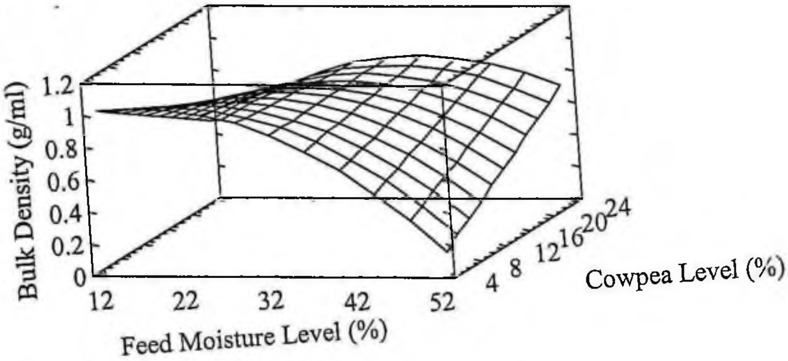
$$\mathbf{Z = 0.642331 - 0.02377\,X_1 + 0.035077\,X_2 + 0.01908\,X_3 - 0.001846\,X_1X_2 + 0.001361\,X_1X_3 - 0.001111\,X^2_2 - 0.000722\,X^2_3}$$

$R^2 = 0.7994$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).


Bulk Density (g/ml)
1.2
1
0.8
0.6
0.4
0.2
0
12
22
32
42
52
Feed Moisture Level (%)
4
8
12
16
20
24
Cowpea Level (%)

4.2.2. Chemical Characteristics.

4.2.2.1. Protein Content.

Cereal grains are known to be low in protein (both in quantity and quality) and hence the need for complementation with legumes. This combination would help make complete proteins because the legume would provide lysine and other limiting amino acids.

The protein content measured for all possible runs of extrudates ranged from 15.76% - 19.54% and 16.18% - 21.24% for rice-blend and sorghum-blend systems respectively. These values when compared to the preliminary results showed a remarkable increase of between 53.81% - 62.74% and 37.58% - 52.45% in protein content for the rice-blend and sorghum-blend systems respectively.

These results of approximately 60% and 50% protein increase in extrudate content are very significant and encouraging. With this increase, it can be suggested that combined legume (cowpea–20% and groundnut-10% effects) supplementation could optimally yield 50% protein fortification for enhanced nutrition in human diet.

It is important to note that protein derived from the balance of these cereals with the legumes can supply essential amino acids needed for growth and maintenance. With these significant protein increases, the consumption of this ready-to-eat cereal would contribute protein to a person's diet especially in our part of the world.

Models developed for each system could explain 50.92% and 67.96% of the variations and a non-significant F-value of 1.42 and 2.88 (as lack-of-fit) (Table 10) in the protein contents for the rice and sorghum systems respectively (Table 12). ANOVA for the rice extrudates revealed the significant effect ($p < 0.05$) of the linear terms of cowpea and groundnut addition to this index. However, the quadratic term of cowpea was the most significant to the system ($p < 0.001$) (Table 13). For the sorghum system, cowpea and groundnut additions were the significant process variables affecting this index at $p < 0.05$ (Table 13).

The response surface plot for rice extrudates (Fig.19) also revealed the additions of cowpea and groundnut as increasing the protein content the extrudates. The level of moisture added showed no effect. Figure 20, also shows that both increasing levels of cowpea and groundnut resulted in the overall increase in the protein content of sorghum extrudates. Feed moisture levels had no effect.

Table 12 **Regression coefficients and the adjusted R^2 values for Rice-cowpea-groundnut and Sorghum-cowpea-groundnut systems in the models of Protein and fat contents**

Variables.	**Protein**		**Fat**	
	Rice.	**Sorghum**	**Rice**	**Sorghum**
Constant.	17.848572	15.466592	-1.648024	-2.328619
X_1	-0.364436	0.171613	0.354482	0.607867
X_2	-0.014486	0.460717	0.433595	0.692341
X_3	-0.007115	-0.026786	0.0344	0.150586
X_1X_2	-	-0.021105	-	-0.015252
X_1X_3			-0004073	-0.007829
X_2X_3	-	-	-	0.008694
$X_1X_2X_3$	-	-	-	
X^2_1	0.022878	0.006518	-0.0093	-0.012607
X^2_2	0.023437	-	-	-0.051116
X^2_3			-	-0.00202
R^2	**0.5092**	**0.6796**	**0.7465**	**0.8783**

Figure 19. Response surface plot on Protein content of Rice extrudates at maximum feed moisture (48.01%).

Model:

$$\mathbf{Z = 17.84857 - 0.364436\, X_1 - 0.04486\, X_2 - 0.007115\, X_3 + 0.022878\, X^2_1 + 0.023437\, X^2_2}$$

$R^2 = 0.5092$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).

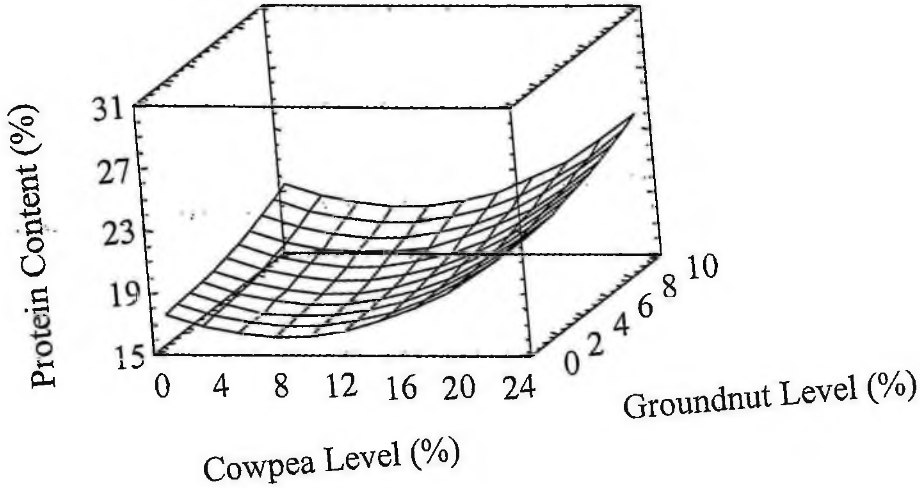

Protein Content (%)
31
27
23
19
15
0
4
8
12
16
20
24
Cowpea Level (%)
0
2
4
6
8
10
Groundnut Level (%)

Figure 20. Response surface plot on Protein content of Sorghum extrudates at maximum feed moisture (44.06%).

Model:

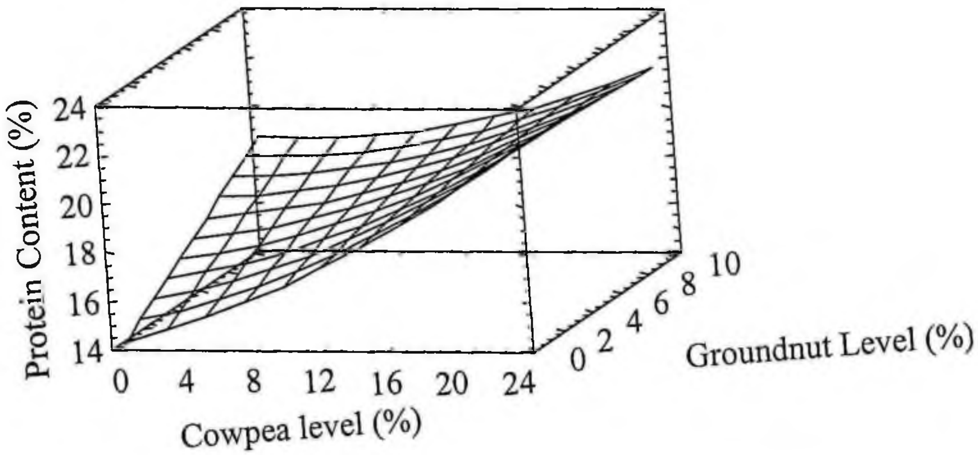
$$\mathbf{Z = 15.466592 + 0.171613\, X_1 + 0.460717\, X_2 - 0.026786\, X_3 - 0.021105\, X_1X_2 + 0.006518\, X^2_1}$$

$R^2 = 0.6796$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).


Protein Content (%)
24
22
20
18
16
14
0
4
8
12
16
20
24
Cowpea level (%)
0
2
4
6
8
10
Groundnut Level (%)

4.2.2.2. Fat content.

Fat provides lubrication effect in the compressed polymer mix as well as modifies the eating quality of extrudates (Guy, 1994). The addition of groundnut is supposed to add some characteristic flavour to the product, thereby enhancing the flavour profile of the product. The fat content of the extrudates ranged from 0.76% - 4.52% and 2.22% - 5.97% for all extrudates of the rice-blend and sorghum-blend systems respectively.

The germ and bran of cereals contain some lipids; nevertheless, cereals are naturally low-fat foods. It is expected that relatively high fats contents are obtained in the cereal-legume blends as compared to results from the study involving only the cereals. The addition of the groundnut caused the considerable increase in the fat content in both systems. This is because groundnut is known to contain considerably high amounts of fat.

The regression models developed to predict the fat content explained 74.65% and 87.83% of the variations and a non-significant F-value of 11.88 and 5.85 (as lack-of-fit) (Table 10) in the rice-blends and sorghum-blends respectively (Table 12).

In the rice-blend system, the only significant process variable was the addition of groundnut at $p < 0.001$(Table 13). With the sorghum system, the quadratic effect of cowpea was of significance; aside the level of groundnut addition ($p < 0.001$), the linear term of cowpea and the interaction term of cowpea and feed moisture ($p < 0.001$) all being significant (Table 13).

Analysis of variance (ANOVA) results showed that the level of groundnut addition was the most significant variable in both systems. These findings suggest that a 5% – 10% level of groundnut addition to any cereal system would considerably raise the overall fat content of the system.

From Figure.21, the response surface plot for the fat content in rice extrudates showed significant increase as the level of cowpea and groundnuts increased. In the sorghum plot in Figure.22, fat content attained its maximum value with about 6% groundnut addition and saw a gradual decline with further additions. However, maximum fat content was observed at 12%

addition of cowpea to the system. After this, further additions of the cowpea resulted in decreasing level of the fat content in the sorghum extrudates.

Table 13. **F-values from ANOVA for the Protein and Fat contents of both Rice- blend and Sorghum-blend systems**

Variables.	Protein		Fat.	
	Rice.	Sorghum.	Rice.	Sorghum
X_1	5.47*	30.07***	2.35	12.28**
X_2	5.63*	10.62**	52.75***	77.59***
X_3	0.09	1.38	0.16	0.01
X_1X_2		2.02	1.33	4.43
X_1X_3		-	-	10.24**
X_2X_3	-	-	-	3.69
$X_1X_2X_3$	-	-	-	-
X^2_1	13.05***	1.21		21.51***
X^2_2	0.48		4.38	13.27**
X^2_3		-	-	3.09

*, **, *** = Significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$.

Figure 21. Response surface plot on Fat content of Rice extrudates at maximum feed moisture (48.01%).

Model:

$$\mathbf{Z = -1.648024 + 0.354482\, X_1 + 0.433595\, X_2 + 0.0344\, X_3 - 0.004073\, X_1X_3 - 0.0093\, X^2_1}$$

$R^2 = 0.7465$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).

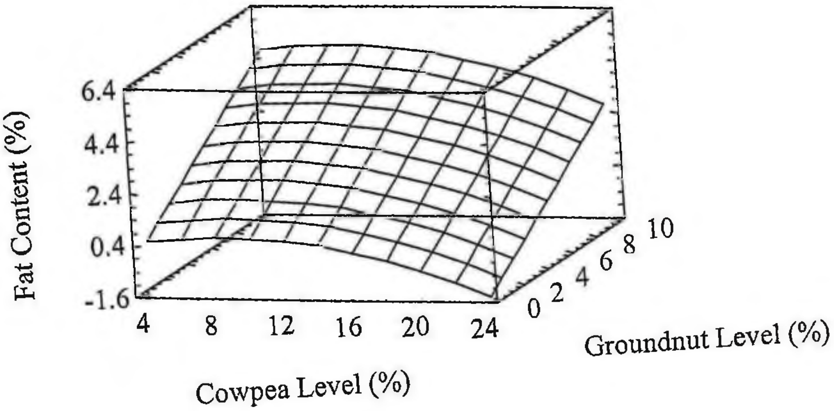

Fat Content (%)
6.4
4.4
2.4
0.4
-1.6
4
8
12
16
20
24
Cowpea Level (%)
0
2
4
6
8
10
Groundnut Level (%)

Figure 22. Response surface plot on Fat content of Sorghum extrudates at maximum feed moisture (44.06%).

Model:

$$\mathbf{Z = -2.328619 + 0.607867\,X_1 + 0.692341\,X_2 + 0.150586\,X_3 - 0.015252\,X_1X_2}$$

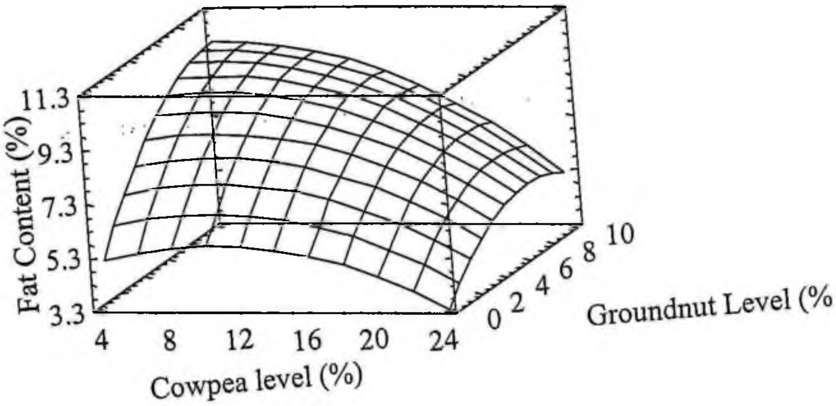
$$\mathbf{- 0.007829\,X_1X_3 + 0.008694\,X_2X_3 - 0.02607\,X^2_1 - 0.051116\,X^2_2 - 0.00202\,X^2_3}$$

$R^2 = 0.8783$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).


Fat Content (%)
11.3
9.3
7.3
5.3
3.3
4
8
12
16
20
24
Cowpea level (%)
0
2
4
6
8
10
Groundnut Level (%

4.2.2.3. Ash Content (Minerals)

Crude ash content gives an indication of inorganic elements that are present in a food as minerals. From the preliminary results, (Table 6), the original ash content of rice and sorghum are 0.59% and 1.21% respectively. After the fortification, the ash content determined ranged from 0.83% - 1.30% and 2.03 – 3.66% for rice-blend and sorghum-blend systems respectively.

The differences between the experimentally determined values and that of the preliminary study could be attributed to the addition of cowpea and groundnut to both systems. Literature and research has shown that legumes such as cowpeas and groundnuts contain significant quantities of ash (Tables 2). Therefore is it not surprising to realise significant increases in the rice and sorghum blend extrudates as compared to the no added legume cereal extrudates (Table 6) as a result of the fortification.

Naturally essential minerals such as calcium, iron, and phosphorus are low in cereals and are thus recognised among the major minerals. They form components of body tissues and play specific roles for the proper functioning of the body. Since the increase in ash content was significant, these essential minerals (calcium, phosphorus and iron) were determined in the extrudates of both systems.

Calcium is found in blood and body fluids as calcium ions or in combination with proteins. It also helps in muscle contraction. Phosphorus is essential for energy storage and cell transfer, cell division and reproduction. Iron is also an essential component of haemoglobin of blood cells.

Experimental results of ash contents revealed increase in the contents of the rice-legume blend and sorghum-legume blend systems as compared to the cereal extrudates as a result of the fortification. This increase in these essential minerals is expected as groundnuts and cowpeas contain substantial amounts of them.

Multiple range test for calcium in both rice and sorghum blends showed that there were no differences in the increase observed between the various possible combinations. The same trend was observed in the iron content of sorghum sample.

However, the effect of feed moisture influenced the level of iron in rice extrudate (appendix V). Multiple range tests showed a significant difference in iron content of rice sample with the lowest feed moisture (14.0%) and the rest of the moisture levels.

4.2.2.4. Crude Fibre.

A highly expanded cereal product is usually difficult to achieve due to the high fibre and fat content (Gordon et. al., 1986). Fibre particles usually decrease a product's expansion by rupturing the cell walls before the gas bubbles could expand to its full potential (Jin et. al., 1994). Consequently, extruded products with a high fibre content are usually compact, tough, not crisp, and with undesirable texture (Lue et. al., 1991). This cannot be said of the rice-legume blend and sorghum-legume blend extrudates as they were spongy and crispy (Figure 3 – 12).

From the experiment, crude fibre content determined ranged from 0.694% - 1.570% and 2.264% - 3.568% for rice-blend and sorghum blend systems respectively. These values showed increase over the preliminary determined values (Table 6.). These differences are because of the effects of the levels of fortification.

Generally, cereal fibre is known to positively impact a diet. Nutritionists and medical personnel have shown its physiological role as very important. Jenkins et. .al, (1993), found that a very high cereal fibre intake reduced blood lipids. With these improved fibre contents of extrudates

4.2.3. Functional Characteristics.

4.2.3.1. Water Absorption Capacity.

This index describes the weight of water that is bound to one gram of dry sample. According to Gomez and Aguilera (1983), water absorption capacity depends on the availability of the hydrophilic groups to bind water molecules and the gel forming ability of the macromolecules. Indications are that the damaged starch granules absorb considerable amounts of the water at room temperature and swells resulting in increased viscosity (Colonna *et. al.*, 1989).

Results from all the possible runs showed a much lower values when compared to the preliminary results. These ranged from 193.5% – 486.11% (%dmb) at 27°C and 160.81% – 375.11% (%dmb) at 70°C for the rice blend extrudates. The sorghum blend extrudates recorded 165.39% – 296.89% (%dmb) at 27°C and 181.43% – 322.17% (%dmb) at 70°C.

The model for predicting this index for rice-blend systems explained 56.68% and 52.03% of the variations observed and a non-significant F-values of 3.29 and 3.74 (for lack-of-fit) (Table 10) for this index at 27°C and 70°C respectively (Table14). Though the R^2 values were slightly lower than the 60% recommended by Malcolmson et. al.,(1993), the models were adopted.

ANOVA test showed the linear effect of feed moisture as well as the linear interaction term between cowpea, groundnut and feed moisture significantly influencing this index at 27°C (at $p < 0.05$) (Table 16). When the temperature was raised to 70°C, the linear and quadratic effects of the feed moisture were significant at $p < 0.05$ and $p < 0.01$ respectively (Table 16).

The R^2 value from the models developed in predicting this index in the sorghum-blend systems explained 61.36% and 59.02% and a non-significant F-values of 2.38 and 3.49 (for lack-of-fit) (Table 10) of the variations at 27°C and 70°C respectively (Table 15). These were very close to the recommendation of at least 60% and over (Malcolmson et. al., 1993). In cases (at 27°C and 70°C), the linear and quadratic effects of the feed moisture as well as the addition of groundnut were significant at $p \angle 0.05$ (Table 17).

The response surface plot for the rice extrudates at 27°C (Fig.23) showed the water absorption capacity decreasing with increasing feed moisture and cowpea. Meanwhile at 70°C (Fig. 24), water absorption decreased with increasing feed moisture content up to 34% and started increasing beyond that. Initial low cowpea levels saw a gradual decrease in water absorption by the rice extrudates. As cowpea additions increased, the water absorption also began to rise.

Response surface plot for the sorghum extrudates at 27°C (Fig.25) showed increasing feed moisture caused the water absorption to decrease whilst addition of cowpea increased this index. A similar trend was observed at 70°C (Fig.26) for the sorghum extrudates. Here too the extent of water absorption decreased with increasing feed moisture levels.

Generally, water absorption depends on the ability of the macromolecules to gel, as damaged starch molecules are able to absorb substantial amounts of water. One expects the high temperature (165°C) in the extruder coupled with the shear generated by the screw during the process to cause starch degradation and therefore solubilization of the starch with lees absorption rate.

However, as feed moisture increases there is a resultant lower degree of starch gelatinization for different products (Falcone and Phillips, 1988; Sefa-Dedeh and Saalia, 1997). This increase would decrease the dough temperature; reduce friction between the dough and the screw/ barrel and hence negatively influence starch degradation. The overall increase in water absorption could be attributed again to the water binding effect of the cowpea proteins.

Table 14. Regression coefficients and adjusted R^2 values in the models of Water Absorption and Swelling Capacities for Rice-cowpea-groundnut system

Variables.	Water absorption capacity @ 27°C	Water absorption capacity @ 70°C	Swelling capacity.
Constant.	331.003261	917.681892	110.329162
X_1	35.488807	-24.483284	-0.15053
X_2	42.365479	0.6399	-0.053046
X_3	-7.918833	-34.0088	-3.957273
X_1X_2	-6.879273	-	-
X_1X_3	-0.952177	0.344488	
X_2X_3	-1.201767	-	
$X_1X_2X_3$	0.194994	-	
X^2_1		0.525286	
X^2_2	-	-	
X^2_3	0.13981	0.45212	0.048853
R^2	**0.5668**	**0.5203**	**0.5470**

Table 15. **Regression coefficients and adjusted R^2 values in the models of Water Absorption and Swelling Capacities for Sorghum-cowpea-groundnut system**

Variables.	**Water absorption capacity @ 27C**	**Water absorption capacity @ 70C**	**Swelling capacity.**
Constant.	527.3736	501.949358	111.57526
X_1	0.014071	5.691796	-0.146479
X_2	-16.462395	-18.020466	0.327018
X_3	-18.162688	-16.442945	-4.850809
X_1X_2	-		-
X_1X_3	0.157267		-
X_2X_3		-	
$X_1X_2X_3$	-	-	
X^2_1	-0.215333	-0.262556	
X^2_2	1.7833	1.922754	
X^2_3	0.261596	0.258875	0.070435
R^2	**0.6136**	**0.5902**	**0.6912**

Figure 23. Response surface plot for Water Absorption capacity at 27°C of Rice extrudates at 10% groundnut

Model:

$$\mathbf{Z = 331.00326 + 35.488807\,X_1 + 42.365479\,X_2 - 7.918833\,X_3 - 6.879273\,X_1X_2}$$
$$\mathbf{-0.952177\,X_1X_3 - 1.201767\,X_2X_3 + 0.194994\,X_1X_2X_3 + 0.13981\,X^2_3.}$$

$R^2 = 0.5668$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).

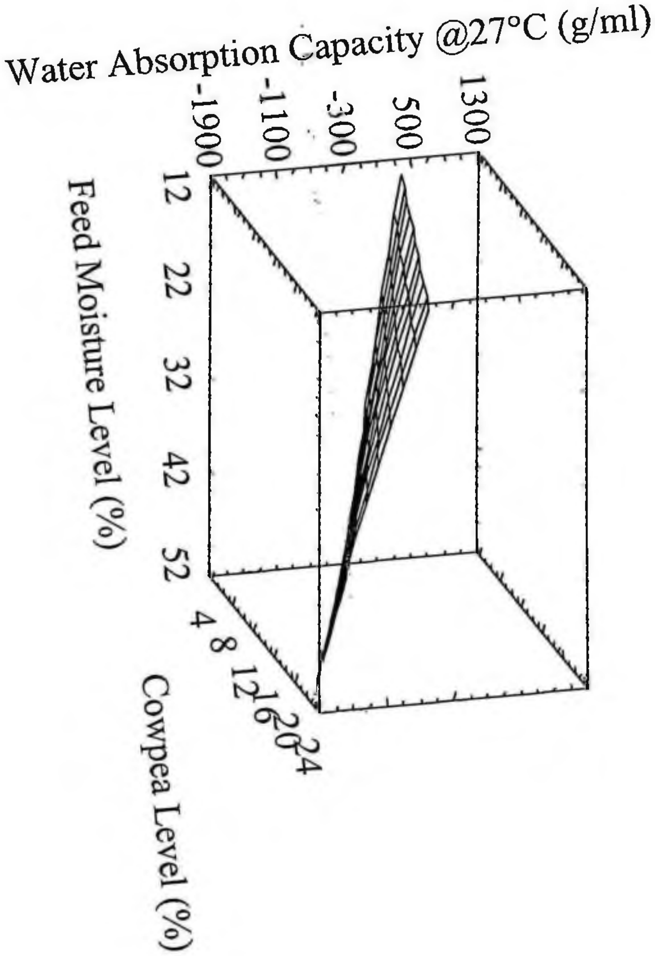

Water Absorption Capacity @27°C (g/ml)
-1900
-1100
-300
500
1300
Feed Moisture Level (%)
12
22
32
42
52
Cowpea Level (%)
4
8
12
16
20
24

Figure 24. Response surface plot for Water Absorption capacity at 70°C of Rice extrudates at 10% groundnut

Model:

$$\mathbf{Z = 917.681892 - 24.483284\,X_1 + 0.63991\,X_2 - 34.0088\,X_3 + 0.344488\,X_1X_3 + 0.525286\,X^2{}_1 + 0.45212.X^2{}_3.}$$

$R^2 = 0.5401$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).

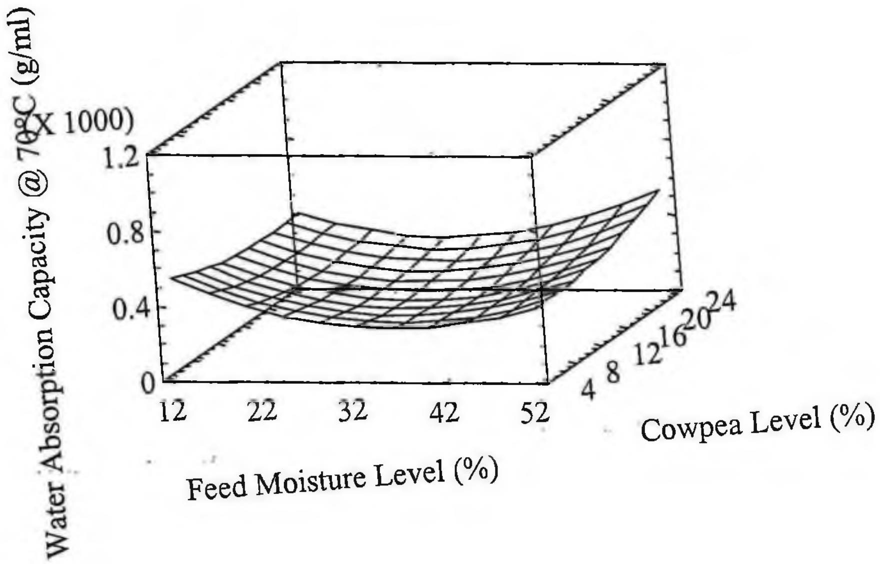

Water Absorption Capacity @ 70°C (g/ml)
(X 1000)
1.2
0.8
0.4
0
12
22
32
42
52
Feed Moisture Level (%)
4
8
12
16
20
24
Cowpea Level (%)

Figure 25. Response surface plot for Water Absorption capacity at 27°C of Sorghum extrudates at 10% groundnut

Model:

$$\mathbf{Z = 5273736 + 0.014071\ X_1 - 16.462395\ X_2 - 18.162688\ X_3 + 0.157267\ X_1X_3}$$

$$\mathbf{-0.215333\ X^2{}_1. + 1.7833\ X^2{}_2 + 0.261596\ X^2{}_3}$$

$R^2 = 0.6163$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).

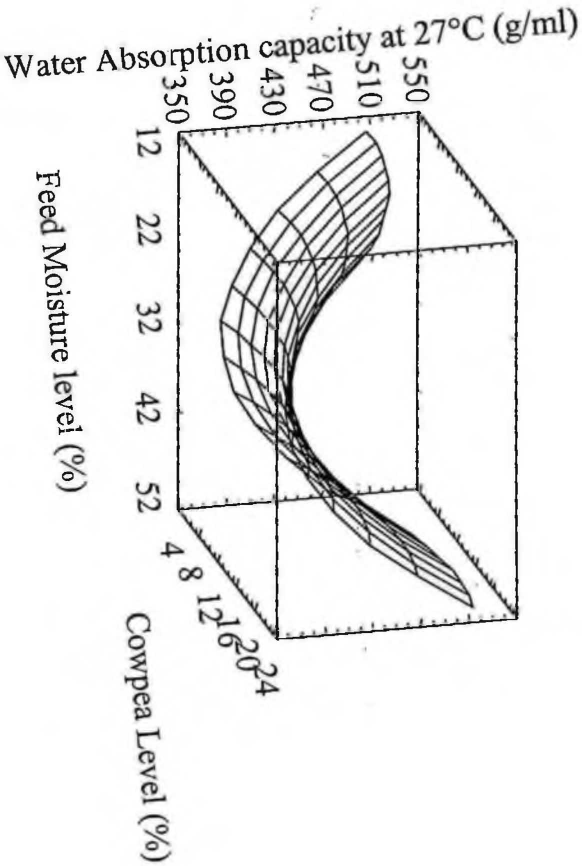

Water Absorption capacity at 27°C (g/ml)
350
390
430
470
510
550
Feed Moisture level (%)
12
22
32
42
52
Cowpea Level (%)
4
8
12
16
20
24

Figure 26. Response surface plot for Water Absorption capacity at 70°C of Sorghum extrudates at 10% groundnut

Model:

$$\mathbf{Z = 501.949358 + 5.691796\, X_1 - 18.020466\, X_2 - 16.442945\, X_3 - 0.262556\, X^2_1 + 1.922754\, X^2_2 + 0.258875\, X^2_3.}$$

$R^2 = 0.5203$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).

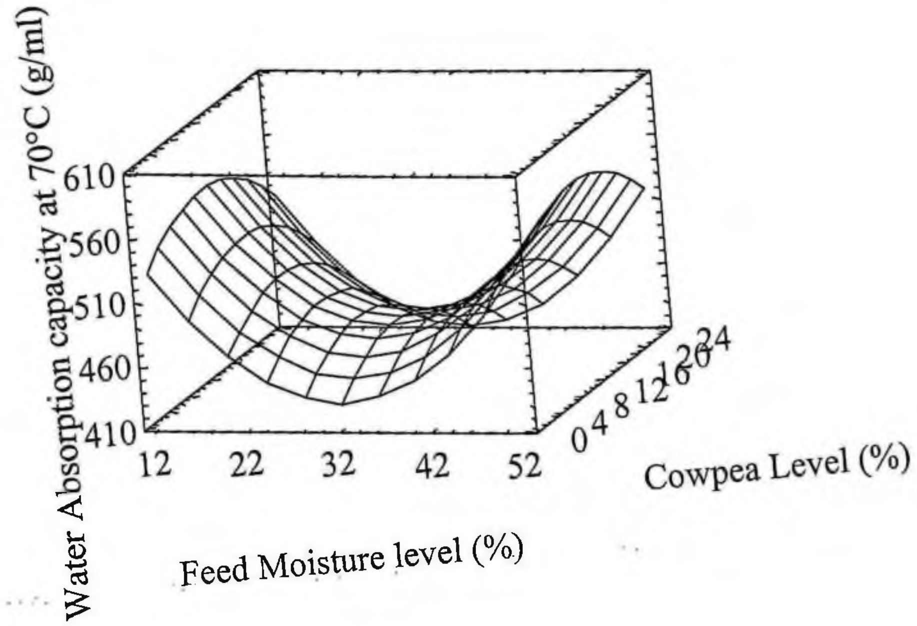

Water Absorption capacity at 70°C (g/ml)
610
560
510
460
410
12
22
32
42
52
Feed Moisture level (%)
0
4
8
12
16
20
24
Cowpea Level (%)

Table 16. **F-values for Water absorption (at 27°C and 70°C) and Swelling capacities from ANOVA for Rice - blend extrudates**

Variables.	Water absorption capacity @27°C	Water absorption capacity @70°C	Swelling capacity.
X_1	0.99	2.67	0.19
X_2	0.47	0.27	0.0
X_3	20.03***	4.55*	20.52***
X_1X_2	1.09	1.76	
X_1X_3	0.02	-	
X_2X_3	2.56		-
$X_1X_2X_3$	6.09*		-
$X^2{}_1$	-	1.51	-
$X^2{}_2$	-	-	-
$X^2{}_3$	1.60	15.84***	6.22*

*, **, *** = Significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$.

Table 17. **F-values for Water absorption (at 27°C and 70°C) and Swelling capacities from ANOVA for Sorghum - blend extrudates.**

Variables.	Water absorption capacity @ 27°C	Water absorption capacity @ 70°C	Swelling capacity.
X_1	0.01	0.17	0.29
X_2	0.22	0.40	0.70
X_3	9.52**	8.48*	28.59***
X_1X_2			
X_1X_3	1.32		-
X_2X_3		-	
$X_1X_2X_3$	-		
X^2_1	2.08	2.58	
X^2_2	7.40*	7.34*	
X^2_3	16.62**	14.40**	16.95***

*, **, *** = Significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$.

4.2.3.2. Swelling Capacity.

Swelling is the expansion of cells (starch granules) upon the imbibition of water. The water molecules enter the cell granules causing solvation of the molecules, occupying capillary and intramolecular spaces of the molecules. The flour of extrudates upon reconstitution in water would swell and provide viscosity to the slurry. This characteristic is obtained as a result of the presence of starches and proteins.

Results from all the possible runs showed a slight increase over that of the preliminary study. Maximum swell volumes after a one-hour period yielded 61ml and 56ml for the rice-blend and sorghum-blend systems respectively. These high values can be attributed to the presence of water binding proteins most especially from the addition of the cowpea and possibly the addition of groundnut too as well as the relatively high extrusion temperature. Extrusion cooking is associated with high temperature and pressure. These results in protein denaturation, starch gelatinisation hence increased water intake.

The regression models developed to fit the data could explain 50.87% and 69.12% of the variations in swelling capacity (Tables 14 and 15), and a non-significant F-values of 4.26 and 6.70 (for lack-of-fit) (Table 10) for rice-blend and sorghum-blend systems respectively. In both systems the linear and quadratic terms of feed moisture was significant (Tables 16 and 17).

Response surface plot for rice extrudates (Fig.27) and sorghum extrudates (Fig.28), all showed the decrease of swelling capacity with increasing feed moisture. The denaturation of proteins and gelatinization of starch is believed to influence this index. However, it is shown by the graph that the addition of the legumes had no effect on the swelling capacities of the extrudates.

Figure 27. Response surface plot on swelling capacity of Rice extrudates at 10% groundnut.

Model:

$$\mathbf{Z = 110.329162 - 0.150531\,X_1 - 0.053046\,X_2 - 3.957273\,X_3 + 0.048853\,X^2_3.}$$

$R^2 = 0.5470$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).

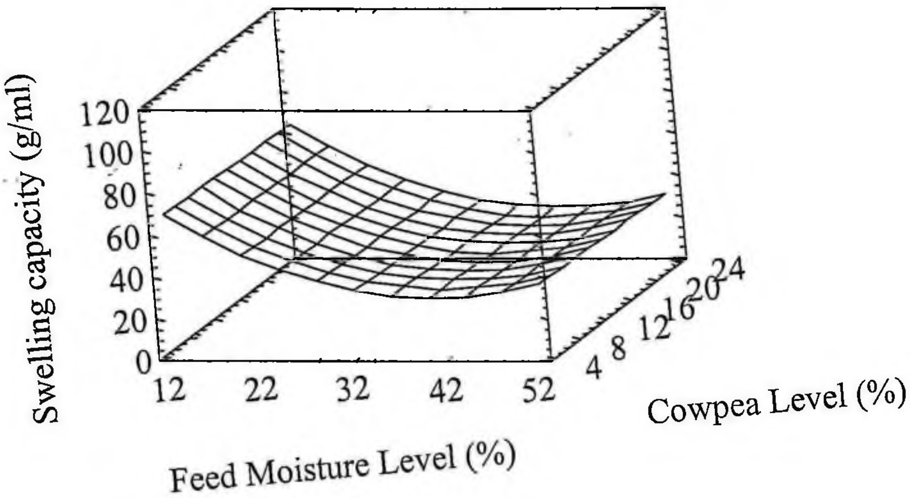

Swelling capacity (g/ml)
120
100
80
60
40
20
0
12
22
32
42
52
Feed Moisture Level (%)
4
8
12
16
20
24
Cowpea Level (%)

Figure 28. Response surface plot on swelling capacity of Sorghum extrudates at 10% groundnut

Model:

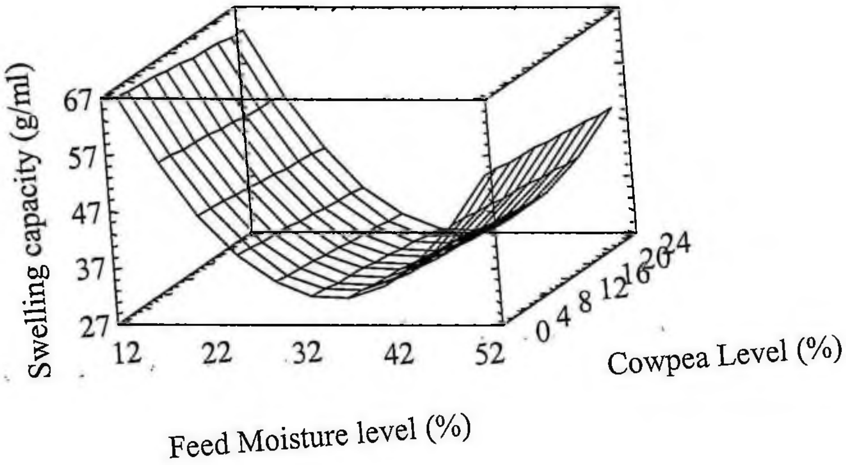
$$\mathbf{Z = 111.57526 - 0.146479\, X_1 + 0.327018\, X_2 - 4.850809\, X_3 + 0.070435\, X^2_3}$$

$R^2 = 0.6912$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).


Swelling capacity (g/ml)
67
57
47
37
27
12
22
32
42
52
0 4 8 12 16 20 24
Cowpea Level (%)
Feed Moisture level (%)

4.2.3. Total Colour Change.

Colour is an important characteristic of extruded foods. Colour changes are known to occur during extrusion process and can provide information about the degree of thermal treatment (Chen *et.al.*, 1991). These colour changes could be as result of reactions such as non-enzymatic browning and pigment degradation that takes place.

The rice-blend extrudates had colour values of the range: L from 79.07 – 91.21; a from 0.66 – 2.97 and b from 15.20 – 20.79. Sorghum blends had ranges between L from-62.23 – 70.61; a from: 7.40–11.08and b from:-16.01–22.72.

Visual comparison of the data between both systems, revealed enhanced redness (a-values) in the sorghum extrudates than in the rice-blend system. This was possibly due to the original grain colour. Therefore, it was surprising that the rice extrudates maintained higher levels of brightness (L values). On the other hand, the extent of yellowness were quite close (b values)(Appendix V). Tables 18 and 19 shows regression coefficients and the adjusted R^2 values, with Table 10 showing the F-value for the lack-of-fit in the two systems.

The levels of cowpea addition ($p < 0.001$ and $p < 0.05$) and feed moisture ($p < 0.001$) as well as the linear interaction term between cowpea groundnut and feed moisture significantly influenced the lightness (L-value) of sorghum extrudates (Table 21). The model developed for the lightness of rice extrudate could not be adopted as the observed R^2 values was low (Table 18).

Table 18. Regression Coefficient and the adjusted R^2 values of L, a, b values and Total colour change in the model for the Rice-cowpea-groundnut system.

Variables.	Total colour change.	L – Values (Lightness)	a – Values (redness).	b – Values (yellowness).
Constant.	25.235418	81.416137	-9.294078	2.658683
X_1	-0.501703	0.613445	1.209255	0.70934
X_2	0.699531	-0.355093	1.81902	1.955619
X_3	-0.290745	0.290389	0.409212	0.577188
X_1X_2		-	-0.234239	-0.151752
X_1X_3	0.033518	-0.029258	-0.029145	-0.008186
X_2X_3	-	-	-0.037263	-0.044403
$X_1X_2X_3$	-0.001101	-	0.006227	0.003392
X^2_1	-	-	-	
X^2_2	-			-
X^2_3		-	-0.004715	-0.007396
R^2	**0.3875**	**0.3631**	**0.5642**	**0.5271**

The ANOVA test for redness (a-value) of rice extrudate was enhanced with the linear terms of groundnut and interaction term between cowpea, groundnut and feed moisture all at $p<0.05$ (Table 20). In the sorghum system, the feed moisture at $p<0.001$ established a significant effect (Table 21).

ANOVA test for the yellow colour (b-value) in rice extrudates showed the addition of cowpea and the quadratic term of feed moisture as significantly affecting this index at $p<0.01$ and $p<0.05$ respectively (Table 20).

Table 19. Regression Coefficient and the adjusted R^2 values for L, a, b values and Total colour change in the model for the Sorghum-cowpea-groundnut system.

Variables.	Total colour change.	L – Values (Lightness).	a – Values (redness).	b – Value (yellowness).
Constant.	28.060356	78.271571	7.590461	15.485268
X_1	0.282407	-0.241846	-0.054736	0.25112
X_2	1.647469	-1.510974	0.009556	-0.003489
X_3	0.548263	-0.497362	0.029701	-0.010973
X_1X_2	-0.10373	0.089621	-	-
X_1X_3	-0.022002	0.019993	-	-
X_2X_3	-0.07011	0.06542	-	
$X_1X_2X_3$	0.005153	-0.004267	-	0.001147
X^2_1	-	-		-0.015373
X^2_2		-	-	-
X^2_3			0.001387	0.001419
R^2	**0.7409**	**0.7598**	**0.6704**	**0.6995**

On the other hand, linear terms of cowpea, feed moisture and groundnut additions as well as the interaction term between cowpea groundnut and feed moisture showed significant influence at $p < 0.05$ for the sorghum extrudates (Table21).

Total colour changes between all possible runs for the rice-blend and sorghum-blend systems varied widely between 17.46 - 30.18 and 36.73 – 45.94 respectively. This suggests that there was much colour change in the sorghum-blend system.

Analysis of variance indicated a significant linear effect of feed moisture at $p < 0.001$ and cowpea addition at $p < 0.05$ (Tables 21) for the sorghum system. Another significant effect was from the interaction term between cowpea, groundnut and feed moisture ($p < 0.05$). In the rice system, the only significant variable of influence was cowpea addition (at $p < 0.05$). Unlike the sorghum system that had an R^2 value of 74.09%, only 38.75% of the variation could be explained for in the rice system. Therefore the model for the rice system as considered inadequate (Malcolmson et. al.., 1993).

Table 20. **F-values for Total colour change, L, a, b values from ANOVA for the Rice-blend extrudates.**

Variables.	Total colour change.	L – Value (Lightness).	a – Value (redness).	b– Value (yellowness)
X_1	10.51***	7.76*	4.44*	15.77***
X_2	2.11	2.47	4.83	0.57
X_3	0.02	0.00	3.26	0.16
X_1X_2	-	-	3.94	3.22
X_1X_3	3.63	4.60*	0.00	3.88
X_2X_3	-		4.23	1.04
$X_1X_2X_3$	0.75		9.20*	0.56
X^2_1			-	2.09
X^2_2	-		2.70	
X^2_3			13.94**	5.10*

*, **, *** = Significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$.

Table 21. F-value for Total colour change, L, a, b values from ANOVA for the Sorghum- blend extrudates

Variables.	Total colour change.	L – Value (Lightness).	a – Value (redness).	b – Value (yellowness)
X_1	5.94*	14.11***	3.68	5.38*
X_2	0.55	0.05	0.04	11.55**
X_3	45.46***	42.06***	38.12***	21.92***
X_1X_2	3.13	2.54		
X_1X_3	0.07	0.00	-	-
X_2X_3	1.66	3.73	-	-
$X_1X_2X_3$	4.52*	4.64*	-	5.89*
X^2_1				5.22*
X^2_2	-	-	-	
X^2_3	-	-	0.62	0.28*

*, **, *** = Significant at p 0.05, p 0.01 and p 0.001.

Response surface plot for the redness in rice extrudates (Fig.29), showed a gradual increase in redness with increasing additions of groundnut and decreasing with increasing addition of cowpea. The effects of the legumes were the same at both higher and lower feed moistures. In Figure.30, the plot for sorghum extrudates saw the redness to decrease with increasing additions of cowpea and groundnut and the maximum feed moisture. Here too, lower feed moisture extrudates behaved the same as the high feed moisture extrudates.

The yellow colour in rice extrudate saw a sharp decreased as groundnut levels increased, however the increasing addition of the cowpea remained the same with little or no effect both lower and higher feed moisture (Fig. 31). Increasing cowpea addition caused an initial increased in the yellow colour of sorghum extrudates up to 12% mark (of the cowpea addition), and started to decreasing with further additions of the cowpea (Fig. 32). The final decrease was dependent on the feed moisture level. Lower feed moisture levels recorded the lowest yellow colour in the sorghum extrudates.

The brightness (lightness) of the sorghum extrudates decreased as the groundnut level kept increasing. It rather increased with increasing levels of cowpea (Fig.33). The level of feed moisture showed no effect. The model for rice could be adopted because of it low R^2 value.

The effects of the cowpea and groundnut additions saw an overall colour change in the sorghum extrudates. The response surfaces plot (Fig.34) for the total colour change in sorghum extrudates was not dependent on the level of feed moisture.

Figure 29. Response surface plot for a-Value (redness) of Rice extrudates at maximum feed moisture of 48.01%

Model:

$$\mathbf{Z = -9.294078 + 1.209255\, X_1 + 1.81902\, X_2 + 0.409212\, X_3. - 0.234239\, X_1X_{2.} - 0.029145\, X_1X_3 - 0.037263\, X_2X_3 + 0.006227\, X_1X_2X_2 - 0.000136\, X^2_3}$$

$R^2 = 0.5642$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).

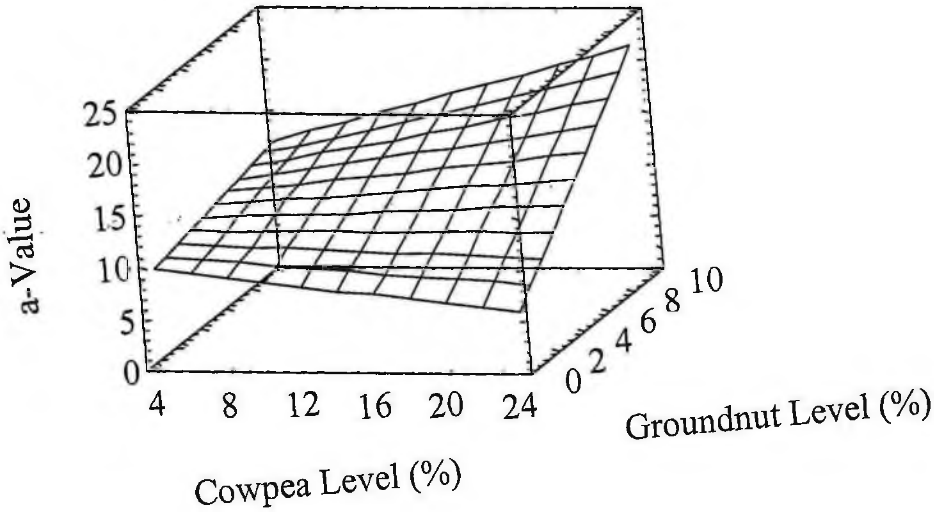

a-Value
0
5
10
15
20
25
4
8
12
16
20
24
Cowpea Level (%)
0
2
4
6
8
10
Groundnut Level (%)

Figure 30. Response surface plot for a – Value (redness) of Sorghum extrudates at maximum feed moisture of 44.06%.

Model:

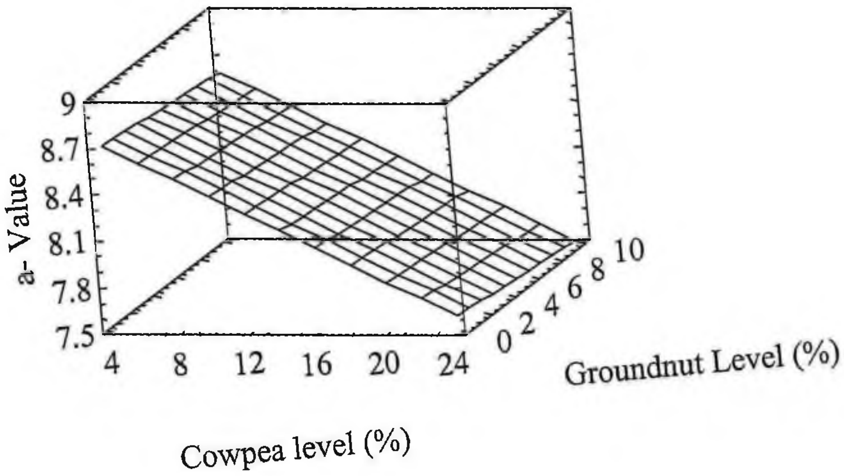
$Z = 7.590461 - 0.054736X_1 -0.009556 X_2 \; 0.029701X_3 + 0.001387 X^2_3$

$R^2 = 0.6704$.

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).



9
8.7
8.4
8.1
7.8
7.5
a- Value
4
8
12
16
20
24
Cowpea level (%)
0
2
4
6
8
10
Groundnut Level (%)

Figure 31 Response surface plot for b- Value (yellowness) of Rice extrudates at maximum feed moisture of 48.01%

Model:

$$\mathbf{Z = 2.658683 + 0.70934\,X_1 + 1.955619X_2 + 0.577188\,X_3 - 0.151752\,X_1X_2 - 0.008186X_1X_3 - 0.44403\,X_2X_3 + 0.003392\,X_1X_2\,X_3}$$

$R^2 = 0.5430$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).

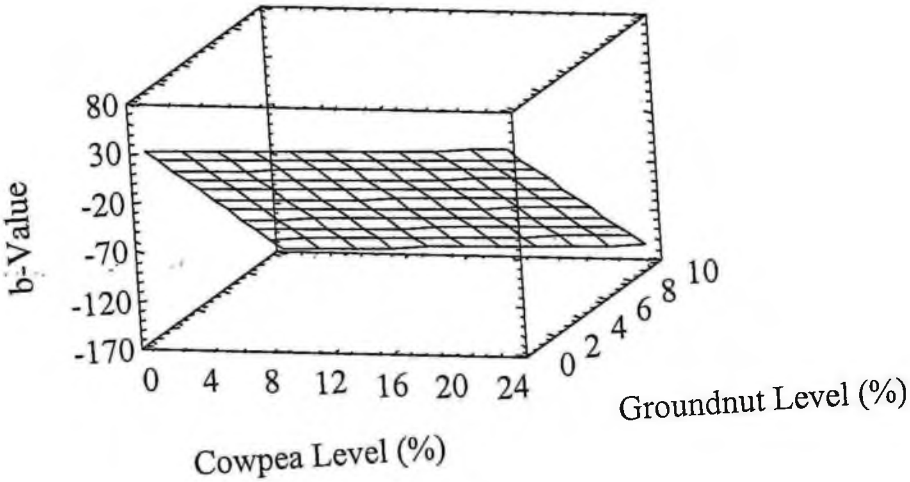

80
30
-20
-70
-120
-170
b-Value
0
4
8
12
16
20
24
Cowpea Level (%)
0
2
4
6
8
10
Groundnut Level (%)

Figure 32. Response surface plot for b–Value (yellowness) of Sorghum extrudates at maximum feed moisture of 44.06% .

Model:

$$\mathbf{Z = 15.485268 + 0.2511\ X_1 - 0.003489\ X_2 - 0.010973\ X_1X_2 + 0.001147\ X^2{}_1 - 0.015373\ X^2{}_1 + 0.001419\ X^2{}_3.}$$

$R^2 = 0.6995$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).

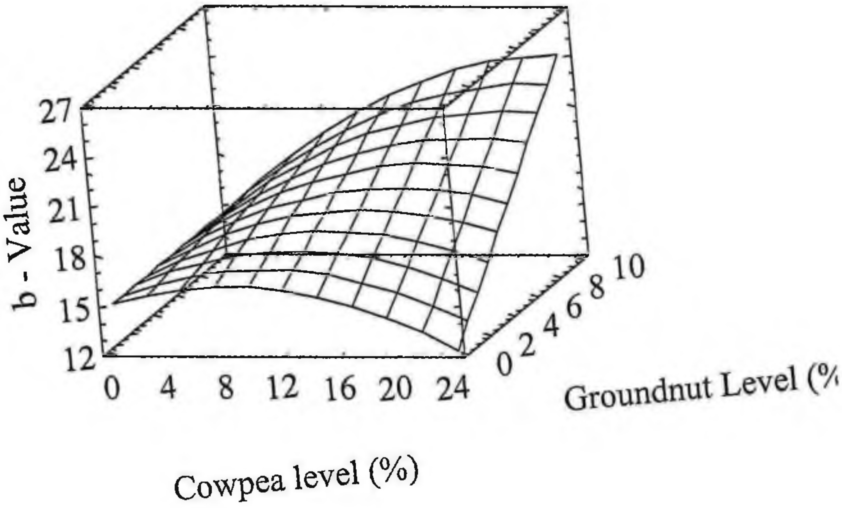

b - Value
27
24
21
18
15
12
0
4
8
12
16
20
24
Cowpea level (%)
0
2
4
6
8
10
Groundnut Level (%

Figure 33. Response surface plot for L –Value (Brightness or Lightness) of Sorghum extrudates at maximum feed moisture of 44.06%.

Model:

$$\mathbf{Z = 78.271571 - 0.241846\, X_1 - 1.510974\, X_2 - 0.497362\, X_3 + 0.089621\, X_1X_2 + 0.019993\, X_1X_3 + 0.06542\, X_2X_3 - 0.004267\, X_1X_2\, X_3}$$

$R^2 = 0.7409$.

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).

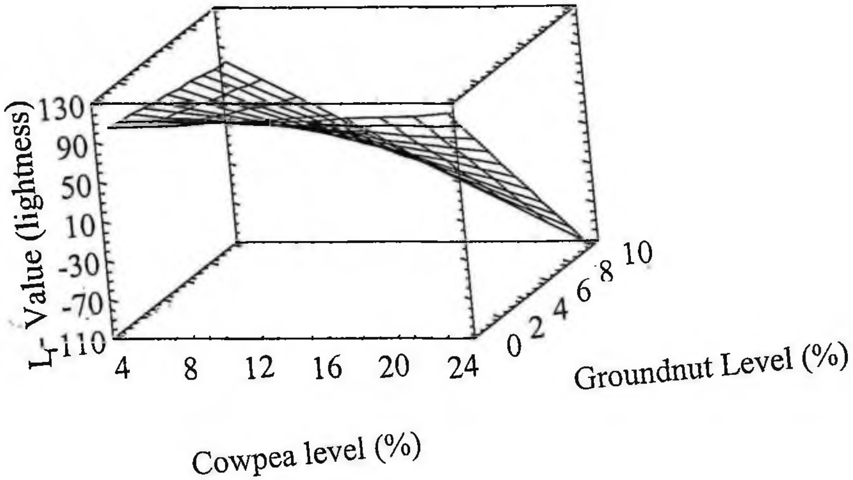

L- Value (lightness)
130
90
50
10
-30
-70
-110
4
8
12
16
20
24
Cowpea level (%)
0
2
4
6
8
10
Groundnut Level (%)

Figure 34. Response surface plot for Total colour change of Sorghum extrudates at maximum feed moisture of 44.06%.

Model:

$$\mathbf{Z = 28.060356 + 0.282407\,X_1 + 1.647469\,X_2 + 0.548263\,X_3 - 0.010373\,X_1X_2}$$

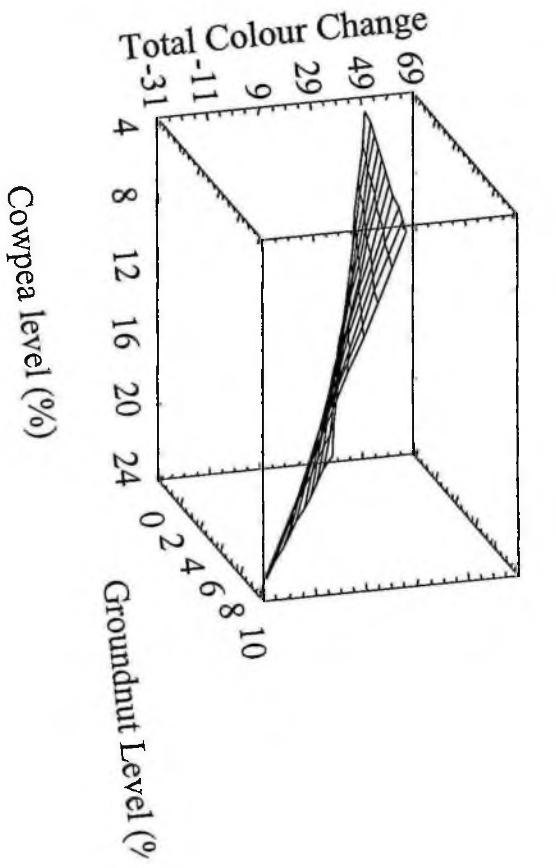
$$\mathbf{-0.022002\,X_1X_3 - 0.07011\,X_2X_3 + 0.005153\,X_1X_2X_3}$$

$R^2 = 0.7409$

X_1 = Cowpea level (%)

X_2 = Groundnut level (%).

X_3 = Feed moisture level (%).


Total Colour Change
-31
-11
9
29
49
69
4
8
12
16
20
24
Cowpea level (%)
0
2
4
6
8
10
Groundnut Level (%

5.0. CONCLUSION.

Using a modified oil expeller as single screw extruder, it was possible to produce direct expanded products with spongy structures from both the rice-based and sorghum-based blends.

5.1. Extrusion of Rice and Sorghum.

Extrudates form the cereals alone had enhanced expansion ratios resulting in low bulk densities in both cases. The product moisture content was low meaning they could store longer. The other chemical indices such protein, fat, crude fibre and ash contents were comparable to literature values. The water absorption and swelling capacities of flours from the extrudate were high. This means their flours would absorb more water and form more viscous slurry.

5.2. Extrusion of cereal – legume blends.

The parameters studied under the process: cowpea levels, groundnut levels and feed moisture levels are important or significant process variables and interrelated in affecting the physical, chemical, functional and the quality parameter (colour) of the products.

Physical indices such as moisture content, expansion ratio, and bulk density were significantly affected by the addition of cowpea and feed moisture. Low feed moisture and cowpea level resulted in good expansion, less bulk density, and low product moisture contents of both types of blend.

Increasing the feed moisture decreased both the water absorption capacity and swelling capacity of rice and sorghum extrudate blends. However increasing cowpea level resulted in increasing water absorption capacity but decreased the swelling capacity slightly. Addition of groundnut did not have any effect on these parameters.

High cowpea and legume additions reflected in the increases in protein, fat crude fibre, and ash (minerals – calcium, iron, and phosphorus) contents of rice and sorghum blend extrudates. For instance there was a remarkable increase in protein content by as much as 53.81% - 62.74% and 37.58% - 52.45% in rice and sorghum extrudates respectively

The increasing addition of cowpea increased the brightness or lightness of sorghum blend extrudates, resulted in the total colour change, but decreased both the redness and yellowness of sorghum bend extrudates. However, increasing groundnut addition increased the redness and decreased the yellowness in rice blend extrudates.

In the end the models developed, showed that extrusion condition optimal to produce puffed or direct expanded extrudates with spongy structure should be at low feed moisture. Therefore the combination of low feed moisture with cowpea levels up to 20% and groundnut level of up to 10% are likely to produce ready-to-eat puffed snack with enhanced nutrition from rice-cowpea-groundnut and sorghum-cowpea-groundnut blend extrudates (as shown in Figs. 2 - 11).

5.3. Further studies.

From the research, the following areas of further work are suggested:

1. To repeat the suggested optimal condition for the production of the rice blend and sorghum blend with the incorporation of flavours such as salt and or sugar so as to;

a) Detailed consumer studies and marketing potential on our markets.

b) Storage studies to ascertain the shelf-life of products.

2. Study the application of extrusion in the production of malted cereal beverage – *"Nmeda* and *Pito*"

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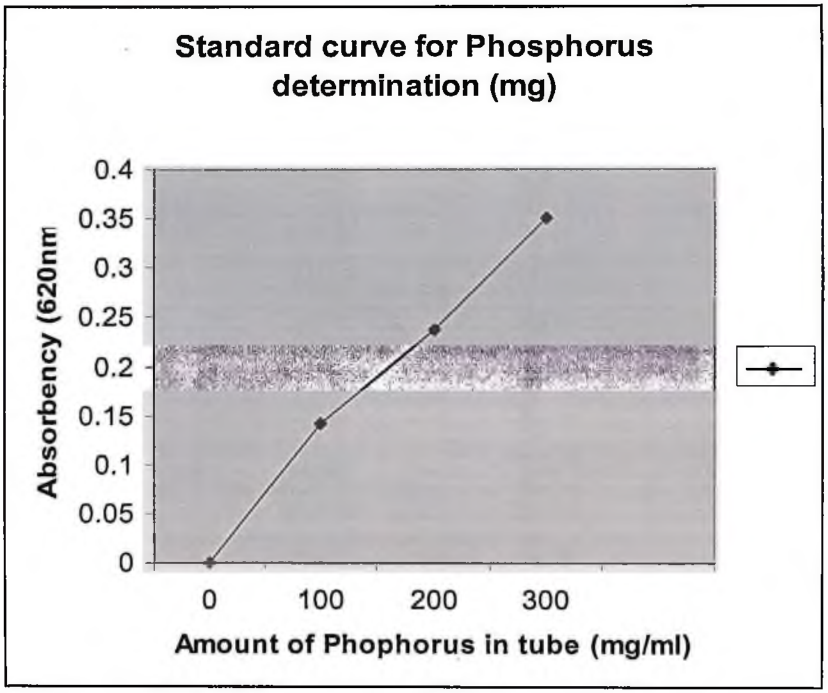
APPENDICIES

Appendix I. Phosphorus.

Data and results used for the calibration curve for standard phosphorus solution containing 10mg phosphorus/ml.

Tube no.	Volume of phosphorus in Tube (ml).	Amount of phosphorus in Tube (mg).	ABSORBANCE (620nm)		
			1	2	Mean.
1	0.1	0.0	0.000	0.000	0.000
2	1.0	100	0.188	0.120	0.189
3	2.0	200	0.237	0.238	0.238
4	3.0	300	0.350	0.351	0.351

from the standard curve, the following absorbances were extrapolated and phosphorus concentration as follows:



Using 2ml of digest, run 1 for rice extrudate, absorbency of 0.065 gave 0.48mg phosphorus (by extrapolation from graph); thus, 1ml = 0.48/2 = 0.24mg phosphorus.

$$\text{Mg phosphorus / 100g sample} = \frac{n \times 100 \times 100 \times 100}{W \times 2 \times 1000}$$

Where n = g of phosphorus in 1ml; W = wt of sample used.

$$\text{Therefore run1 : mg Phosphorus} = \frac{0.24 \times 100 \times 100 \times 100}{0.3 \times 2 \times 1000} = \text{400mg P per 100 g sample}$$

from the standard curve, concentrations extrapolated and calculated phosphorus concentrations are presented as follows:

Run	**Rice Extrudates**		**Sorghum Extrudates**	
	µg P in 1ml	**mg / 100g sample**	**µg P in 1ml**	**mg / 100g sample**
1	0.24	400	0.185	462.5
2	0.08	133.33	0.185	462.5
3	0.12	200	0.1775	443.75
4	0.08	133.33	0.2	500
5	0.25	416.67	0.155	387.5
6	0.25	416.67	0.155	387.5
7	0.05	83.33	0.215	537.5
8	0.08	133.33	0.115	287.5
9	0.05	83.33	0.1625	406.25
10	0.25	416.67	0.175	437.5
11	0.45	750	0.15	375
12	0.45	750	0.15	375
13	0.25	416.67	0.165	412.5
14	0.40	666.67	0.135	337.5
15	0.05	83.33	0.19	475
16	0.08	133.33	0.175	437.5
17	0.14	233.33	0.165	412.5
18	0.125	208.33	0.2	500
19	0.05	83.33	0.21	525
20	0.05	83.33	0.21	525

Appendix II. Colour measurements

Run	Rice Extrudates				Sorghum Extrudates			
	L -value	a-value	b-value	Total colour change	L-value	a-value	b-value	Total colour change
1	87.11	1.14	15.20	20.48	69.26	8.18	16.01	37.98
2	87.99	1.77	15.55	19.96	66.87	9.97	18.97	41.53
3	79.12	1.25	20.73	30.18	66.69	10.21	17.99	41.42
4	82.99	2.62	18.39	25.75	70.20	7.63	18.0	37.65
5	85.72	2.49	20.06	24.50	68.62	8.21	17.26	38.97
6	85.72	2.49	20.06	24.50	68.62	8.21	17.26	38.97
7	88.61	0.66	15.91	19.60	62.23	11.08	18.66	45.94
8	84.69	2.43	18.84	24.58	68.12	8.43	17.16	39.45
9	84.48	2.97	20.79	25.97	70.61	7.40	16.53	36.73
10	79.07	2.48	19.57	29.69	65.85	10.36	22.72	43.96
11	87.46	2.16	17.49	21.53	66.33	9.56	18.89	41.90
12	87.46	2.16	17.49	21.53	66.33	9.56	18.89	41.90
13	87.24	2.13	19.37	22.87	69.75	8.29	18.50	38.38
14	87.92	2.03	16.51	20.57	65.42	9.71	16.39	42.00
15	85.44	2.54	19.36	24.29	66.18	10.25	20.39	42.73
16	91.21	0.75	15.79	17.46	68.66	8.49	16.98	38.90
17	87.64	1.50	18.81	20.37	65.87	10.53	20.98	43.29
18	85.14	1.50	16.07	22.63	70.56	8.15	17.72	37.33
19	85.57	2.02	18.60	23.69	68.14	8.85	19.92	40.48
20	85.57	2.02	18.60	23.69	68.14	8.85	19.92	40.48

APPENDIX III. Data and sample calculation for **Calcium** and **Iron** determinations from the AAS.

The values read on the AAS were in ppm (parts per million), which is equivalent to ug/ml or mg/l. The total volume of digest was 100ml therefore, total weight of element in digest is equal to (ppm x 100) = 100ug. ; 0.2g and 0.3g of sorghum and rice flours were used for the determinations.

Thus, weight of elements (calcium and iron) of sample is:

i. Sorghum sample = ppm x 100/ 0.2 = **ppm x 500**

Thus, run 1 with concentration of 0.43 would be 0.43 x 500 = 215ug/ g sample.

OR:

Total weight of element in digest = ppm x 100 = 0.43 x 100 = 43ug.

Now, 0.2g gives 43ug; therefore, 1g = $\frac{43 \text{ x } 1}{0.2}$ = 215ug/g sample.

ii. Rice sample = ppm x 100/ 0.3 = **ppm x 333.33** (conversion factor). This sample procedure could be followed for calculating the weight of elements in the rice sample.

Below is a table showing calculated concentrations of each element in the extrudates.

Run.	Rice extrudates.		Sorghum extrudates.	
	Calcium(ug/g)	**Iron(ug/g)**	**Calcium (ug/g)**	**Iron (ug/g)**
1	153.33	93.33	215	75
2	163.33	66.67	270	220
3	163.33	66.67	200	225
4	260	70	235	260
5	243.33	93.33	210	285
6	243.33	93.33	210	285
7	193.33	66.67	185	190
8	196.67	76.67	320	60
9	246.67	76.67	170	195
10	260	93.33	275	155
11	63.33	83.33	250	140
12	63.33	83.33	250	140
13	246.67	183.33	355	165
14	180	83.33	195	155
15	226.67	83.33	310	210
16	220	60	200	165
17	163.33	80	170	200
18	223.33	223.33	255	190
19	203.33	83.33	200	285
20	203.33	83.33	200	285