

PHYSICOCHEMICAL PROPERTIES OF
HYDROTHERMALLY TREATED
COWPEAS SEEDS.

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BY

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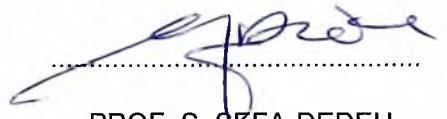


DECLARATION

This research was conducted by me under supervision of Prof. S. Sefa-Dedeh of the Department of Nutrition and Food Science, University of Ghana, Legon.



NICOLE SHARON KOMEY



PROF. S. SEFA-DEDEH



DEDICATION

To my mother, Naa Awula

who nursed my pains and cheered my gains



ABSTRACT

Cowpeas are a relatively inexpensive source of proteins and vitamin B. Unfortunately, the problem of insect infestation is one of the main constraints to the efficient and widespread utilisation of cowpeas. The hydrothermal treatment which involves the exposure of cowpeas to steam followed by drying has been used effectively in protecting cowpeas against the insect infestations. This study set out to assess the functional, chemical and textural changes associated with the hydrothermal treatment.

An alternative steaming system was designed and compared to the current steaming system used in the process. Changes in physical, functional and chemical properties of two (2) cowpea varieties - blackeye and asontem, following steaming for 0, 2, 5, 10 and 15 min were investigated. Indices measured were germinating capacity, water absorption capacity, soaked seed hardness, protein solubility, least gelation capacity and trypsin inhibitor activity. Steaming had a significant effect on all the indices. A complete loss of viability following steaming was observed in all the seeds. There were also significant decreases in the water absorption capacity and protein solubility of steam treated cowpea seeds. The steam treatment was effective in inactivating trypsin inhibitors, with complete inactivation being attained after 10 min steaming. Steaming also resulted in increases in leached solids during soaking and the concentration required to form a stable gel.

The effect of steaming on textural characteristics was monitored over a 6 month storage period at either room temperature (~28°C) or cold room temperature (6°C). Two test cells - the Kramer Shear and the Warner-Bratzler blade were used for the

analysis. The steam treatment resulted in an immediate and pronounced increase in cooked bean hardness, such that peak force values increased from less than 20 kg to greater than 25 kg after 2 hours cooking. Storage however, had different effects on the steamed and unsteamed cowpeas. The typical increase in hardness of stored legumes was observed in the unsteamed seeds, whilst the steamed seeds (especially the 10 min sample) showed a decrease in cooked bean hardness after the 6 months of storage.

A three factor-three level Box-Behnken experimental design was used to follow the effect of steaming time (2, 6, 10 min), drying temperature (35, 45, 55°C) and drying humidity (0.01, 0.02, 0.03 g water/kg air) on some characteristics of blackeye peas. Indices measured were moisture content, 1000 seed weight, water absorption, dehulling efficiency and cooked bean hardness. Increasing steaming time resulted in increased moisture content whilst the most efficient drying occurred under conditions of high drying temperature and humidity. Steaming did not have a significant effect on the density of the cowpea seeds. The variables (steaming time, drying temperature and drying humidity) influenced the regression models developed to predict product characteristics. A reduction in water absorption capacity probably due to seed hardness was observed in all the steamed seeds. At high drying humidity, increasing drying temperature increased water absorption capacity. The treatments improved the dehulling efficiency with the effect of drying condition, especially temperature, being more significant. The hardening of the steamed seeds as evidenced by the reduced water absorption capacity was also reflected in the cooking characteristics of the seeds. In general, increasing drying temperature resulted in a decrease in cooked bean hardness.

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1.0 INTRODUCTION

1.1 NUTRITIONAL CONTRIBUTION OF LEGUMES

The relative importance of cereals as a dietary component for the people of many countries can not be overemphasised (FAO, 1971). In Ghana, maize forms the base material for various kinds of main dishes, snacks and beverages. According to Plahar and Leung (1982), maize contributes about 90-95% of the total calories in the diet of the population along the coastal plains. A survey of traditional Ghanaian foods identified almost 60 products made basically from maize (Sefa-Dedeh, 1989). These products include *kenkey*, *akple*, *oblayo*, *koko*, *ashikoo* and *aliha* (Sefa-Dedeh, 1989).

On the average, the protein content of cereal grains ranges between 7-13% (dmb). Thus the nutritional value of cereals, especially when they constitute the major part of the diet, depends to a considerable extent on their protein quantity. Another problem with cereal protein is its quality. Bressani (1972a) concluded that common corn is deficient in the essential amino acids, lysine and tryptophan and has a poor essential amino acid pattern.

These facts show that heavy dependence on cereals as staple foods can lead to malnutrition. In Ghana and other developing countries, the high prevalence of protein-energy malnutrition has been attributed to the high consumption of cereals

in the diet, among other reasons (Amegatse, 1995). An increase in meat prices during recent years and also the need for protein-rich foods to supplement the low protein staple diets has necessitated the heavy reliance on legumes in most developing countries (Uzogara and Ofuya, 1992).

Legumes or pulses contain overall higher protein (16-35%) than staples such as cassava (2-3%); maize (9-10%); and millet (9-10%) (Ihekoronye and Ngoddy, 1985). Also their proteins contain more than adequate proportions of lysine and the other essential amino acids except the sulphur amino acids and tryptophan.

Cowpeas (*Vigna unguiculata*) are the most important legume in West Africa and contribute a significant amount of protein and water-soluble vitamins to the diet (Phillips and McWatters, 1991; Bressani, 1985). This was further emphasized by results from a survey on household consumption of cowpeas in Nigeria which revealed that cowpeas contribute greater than 50% of all legumes consumed in Nigeria (King *et al.*, 1985). Nnayelugo *et al.* (1985) also noted that legumes contribute 31% of the protein intake of Nigerian pre-school children, 24% of iron, 35% of thiamin and 21% of niacin.

Cowpeas like the other legumes are of high nutritional value because of their high protein content and amino acid profile which is complementary to that of staples such as cereals. In addition to this, cowpeas are an excellent source of the water-soluble vitamins and also supply the essential minerals including calcium, iron, zinc and

potassium. They are also high in carbohydrate, low in fat and contain no cholesterol. Cowpeas are also a good source of dietary fibre. They however contain anti-nutritional factors such as oligosaccharides which are indigestible and cause flatulence after consumption (Uzogara and Ofuya, 1992).

1.2 CONSTRAINTS TO UTILISATION - INSECT INFESTATION AND CONTROL MEASURES

Cowpeas are generally cheap, easily available and very versatile in food preparation and are therefore highly acceptable and popular (Uzogara and Ofuya, 1992). However, they are highly prone to insect infestation leading to both quantitative and qualitative losses in storage. Baboule and Murdock (1990) reported that storage pests are the main constraints to the availability of cowpeas as food in developing countries and when unprotected during storage, cowpeas can become inedible and worthless. Amegatse (1995) reported that 66.7% of cowpea farmers interviewed in a survey conducted in Ghana, indicated that insect (weevil) infestation was the major problem associated with cowpea storage. The cowpea beetle, *Callosobruchus maculatus* Walp has been identified as the principal storage pest of cowpea grains in sub-Saharan Africa (Singh and Rachie, 1985).

Low resource farmers tend to sell their produce immediately after harvest, when prices are low, partly because of the anticipated storage losses due to inadequate preservation methods of grains after harvest. Efficient storage of farm produce is therefore needed for two main reasons - to enhance the income of producers and to ensure household food availability during the lean season.



The reduction of post-harvest losses through the control of insect infestation would not only enhance the quality of the available grain but would also ensure increased cowpea supply in sub-Saharan Africa. Many pest management options are available to subsistence farmers. Resistant cowpea varieties have been developed as a control measure against the weevil. Other protective measures include the use of wood ash, edible oils (groundnut, coconut, soya), kerosene, paraffin, triple plastic bagging and chemicals (actellic, primiphos-methyl). The application of chemical insecticides though effective is usually limited in developing countries by environmental, social, financial and safety considerations. Elimination of the use of synthetic chemicals in preservation could have both economic and health benefits for the consumer and also the environment (Egwuatu, 1987). Currently the idea of Integrated Pest Management (IPM) is being promoted widely. IPM has been described in part as an approach leading to a 'chemical-free' agricultural practice, whilst others view it as a system which promotes the most efficient use of chemical pesticides (Yudelman *et al.*, 1998). However, it is generally accepted that IPM involves a greater reliance on non-chemical approaches to pest management (Vander Mey *et al.*, 1996; Yudelman *et al.*, 1998). According to Jackai *et al.* (1985) there are no reported IPM techniques for cowpeas.

Whilst progress has been made, the problem of stored cowpea grains free from pests is far from being solved. Thus new technologies that improve upon or add to the existing methods are needed.

1.3 THE HYDROTHERMAL TREATMENT

The hydrothermal treatment is a simple, inexpensive and safe physical modification process which does not require the use of sophisticated equipment or trained personnel. It involves the exposure of whole cowpea seeds to steam followed by drying to acceptable storage moisture content. Preliminary work by Sefa-Dedeh *et al.* (1994) showed that 5 and 10 min steamed cowpeas were resistant to the weevil. Subsequently studies were conducted to determine the effect of the steaming process on the seeds. Results have shown that though the number of eggs laid was not affected by the treatment, there was no emergence of adult insects in the steamed cowpeas. Microscopic examination by Egyir-Yawson (1999) also showed that hatched eggs initiated feeding but somehow were unable to complete development and died at an early instar. He also observed significant differences in the protection afforded by solar dried samples as compared to oven dried samples after steaming. The latter samples were not resistant to the attack, that is, there was emergence of adult insects. Field studies have been conducted at both the farm and market level and generally, the process is efficient at 10 and 15 min steaming (Sefa-Dedeh and Saalia, 1997).

Studies have been conducted to monitor the effects of the treatment on the seeds. Results have shown significant differences in all the indices measured for the untreated and steam treated seeds (Osei, 1993; Sefa-Dedeh and Demuyakor, 1994; Saalia, 1995). A reduction in anti-nutritional factors (phytic and tannic acids) have also been reported (Obeng, 1996).

A review of literature showed little information on the effects of the different preservation methods such as the application of actellic, wood ash or edible oils, on the treated seeds. It is however necessary that in addition to documenting the obvious advantages provided by a preservation method, the effects of the treatment on the chemical, structural and functional properties of the seeds must be investigated. This is because these properties have a direct and great bearing on the final utilisation of the seeds. Any changes in properties could affect the functionality/utilisation of the seeds.

1.4 OBJECTIVES

The main objective of the study is to assess functional, chemical and textural changes occurring in cowpea seeds as a result of the hydrothermal process as a means of providing practical information for evaluating the process.

1.4.1 Specific Objectives

1. To develop and evaluate an alternate simple steaming system as compared to the laboratory steam exhaust box.
2. To study the physical, chemical and functional changes associated with the steaming process.
3. To monitor textural changes in steamed whole cowpea seeds with storage.
4. To investigate the effect of drying temperature and humidity on some physical and functional characteristics of steamed whole cowpea seeds.

2.0 LITERATURE REVIEW

2.1 COWPEA - PRODUCTION, COMPOSITION AND UTILISATION

Cowpeas, (*Vigna unguiculata* L. Walp) also known as blackeyed peas, is one of the most commonly utilized legumes in Africa. It is an important crop in some areas of the tropics where it provides more than half the plant protein in human diets (Rachie, 1985). It is produced mainly in the savannah areas and also in the margins of the semi-deciduous forest.

Cowpeas constitute about 2 per cent of the total world output of grain legumes. The world's production of cowpea for the period 1970 - 1974 averaged 1.1 million tonnes compared to 898,000 tonnes for the period 1965 -1969, an increase of almost 23 per cent. Cowpeas are cultivated widely in the tropics, the major producing countries being Nigeria, Burkina Faso, U.S.A, Ghana and Uganda (Kay, 1979), of which Nigeria and Niger together produce almost half of the world crop (Rachie, 1985) (Table 1).

The production level and land under cultivation in Ghana, has generally been low though over the last few years there has been some slight increases (GSS, 1992). The low production levels are thought to be due to low farm mechanisation, marginal crop management, high susceptibility to disease and pest attack, and storage problems.

Table 1: Cowpea Production in Some Selected Countries

COUNTRY	PRODUCTION (TONNES)
Nigeria	850,000
Brazil	600,000
Niger	271,000
Burkina Faso	95,000
USA	60,000
Ghana	57,000
Kenya	48,000
Uganda	42,000
Malawi	42,000

Source: Rachie (1985)

Cowpeas are consumed in various forms - green pods, tender green leaves, green seeds and dry seeds (Rachie, 1985). Usually, the processing of cowpeas for consumption involves mainly traditional methods including soaking, dehulling, steaming and cooking by boiling in excess water (Amegatse, 1995). In Ghana, cowpeas are prepared in a variety of ways - as a major dish; mixed with staples such as cereals or tubers; or used in soups. Examples of popular cowpea dishes include *waakye*, *akara* and *tubani* (Dovlo *et al.*, 1976).

A distinguishing feature of cowpeas like other legumes, is their high protein content. Osei *et al.* (1996) quoted a range of 24-27% for 4 varieties of cowpeas available in Ghana. Cowpeas have a reasonably balanced amino acid composition and are generally a good source of lysine though deficient in methionine. They usually tend

to be low in fat (2-5%) but high in carbohydrate (55-60%) with starch forming a large proportion of this fraction (Wolf, 1977). They are also a good source of iron, zinc, B vitamins and both soluble and insoluble dietary fibre. The proximate composition of some cowpea varieties is shown in Table 2 below.



Table 2: Chemical Composition of Selected Cowpea Varieties

Cowpea Variety	Moisture (%)	Protein (%)	Carbohydrate (%)	Fat (%)	Ash (%)	Fibre (%)
Asontem	14.16	24.11	51.34	1.61	4.14	4.64
Ayiyi	14.29	26.74	48.98	2.1	3.92	3.97
Bengpla	14.62	24.62	51.11	1.79	3.75	4.11
Soronko	15.2	25.47	50.2	2	3.32	3.81
Blackeye ^a	-	23.4	56.8	1.3	-	3.9

Source: Osei *et al.* (1996); ^a - Kay, 1979

2.2 LIMITATIONS TO USE

In spite of their overall high nutritional quality and relative low cost, cowpeas are not regularly selected as food due to various factors (Uzogara and Ofuya, 1992).

2.2.1 Hard-to-cook Defect

The amount of time required to adequately soften the legume seed during cooking has been reported to range from 24 min to 4 hours (Bressani, 1993) with an average of 60 – 95 min. Longe (1983) studying the relation between chemical characteristics and cooking quality of different varieties of cowpeas, recorded an average cooking time of 74.5 min for all the 13 varieties. Due to this the preparation of legumes for consumption usually involves soaking of seeds in water prior to cooking.

This problem of prolonged cooking time may be either species-related e.g. soybeans or storage-induced e.g. cowpeas (Liu and McWatters, 1994). Various workers (Molina *et al.*, 1976; Sefa-Dedeh *et al.*, 1979; Jackson and Varriano-Marston, 1981) have established that unfavourable conditions of storage (high temperature and humidity) results in the development of the hard-to-cook defect. The defect is characterised texturally by the restricted softening of the cotyledon upon cooking. It has been suggested that this results from a lack of cell wall separation due to changes in the lamella-cell wall complex (Rockland and Jones, 1974). As a result, the cookability of the seeds is reduced. Cookability is the condition in which the dry legume seeds achieve a degree of tenderness acceptable to the consumer during cooking (Garruti and Bourne, 1985).

This phenomenon is of both nutritional and economic importance in the tropics and sub-tropics since legumes provide a large portion of the dietary protein of the population and also because of the loss of an important functional property of the bean (Garruti and Bourne, 1985). There are also losses in methionine and lysine as a result of the prolonged cooking times (Antunes and Sgabieri, 1980). It is also an energy problem especially in areas where fuel is expensive due to the long cooking hours required (Garruti and Bourne, 1985). The high fuel requirement of beans due to the development of the hard-to-cook defect affects its utilisation.

Various theories have been proposed to explain this phenomenon including:

1. The breakdown of phytic acid by phytase inhibiting the chelation of divalent

cations rendering pectates in the middle lamella unsusceptible to softening (Muller, 1967; Moscoso *et al.*, 1984).

2. Lignification of cell wall material through polymerisation of lignin precursors from amino acid pools and the mediation of peroxidase (Varriano-Marston and Jackson, 1981; Haard, 1985; Hincks and Stanley, 1987).
3. Oxidation of polyphenols under the action of polyphenol oxidase followed by polymerisation and complexing of reaction products with proteins (Elias, 1982).

It thus appears that the hardening is enzyme-controlled though non-enzymatic reactions including auto-oxidation and browning could also play a part (Aguilera and Ballivan, 1987).

Some disadvantages of the hard-to-cook defect include a lowering of nutritional quality of the seeds. Tuan and Phillips (1992) reported that though protein digestibility was significantly reduced by high temperature and high humidity storage, starch digestibility was not significantly affected. Subjecting dry beans to conditions that induced hard-to-cook phenomenon (37°C, 76% RH), lowered protein quality and availability of essential amino acids (Antunes and Sgarbieri, 1979).

2.2.2 **Anti-nutritional Factors**

Anti-nutritional factors which are known to interfere with protein digestibility and the biological utilisation of nutrients have been found in some common legumes (Evans

and Bandermer, 1976; Liener, 1983). These include trypsin inhibitors, tannins and phytic acid. Tannins which have been implicated in the etiology of anaemia and PEM in children (Restrec Newsletter, 1993) have been assayed in the darker varieties of cowpeas (Chang *et al.*, 1994).

Tannins are naturally-occurring polyphenolic compounds of molecular weight between 500 and 3000, containing sufficiently large number of phenolic hydroxyl or other suitable groups which allow effective formation of cross-links between proteins and other macromolecules (Swain, 1965). They include compounds such as caffeine, vanillic, gallic acids and lignin. Tannins possess an astringent taste which affects palatability. They also form non-digestible complexes with proteins and inhibit the action of digestive enzymes (Silano *et al.*, 1981).

Other important anti-nutritional factors are the protease inhibitors such as trypsin inhibitors. Most of the information on trypsin inhibitors in nutrition has come from studies on soybeans (Liener, 1972). The activity of soybean trypsin inhibitors is thought to be due to the protein, soybean-trypsin-inhibitor-A2 (Rackis *et al.*, 1962), generally known as the Kunitz inhibitor with a molecular weight of 21,500.

Although legumes are known to contain toxic or anti-nutritive constituents, they have continued to be a valuable source of proteins to man over many centuries due to the various ways of detoxifying them. Tannins for example are removed through any of the following methods;

- a. Dehulling - removes the seed coat where most of the colour and tannins are concentrated.
- b. Soaking in water containing sodium bicarbonate (1L : 1 tablespoon) for 12-15h. This removes 60% of tannins and reduces cooking time by 50%.
- c. Germination - similar to the effect of bicarbonate but also reduces phytates and flatulence factors. (Restrec Newsletter, 1993).

It has been found that trypsin inhibitors from legumes disappear from seeds upon germination but reappear in the young seeds. Although germination is known to cause an improvement in the nutritive value of legume seeds (Marero *et al.*, 1988), the content of protease inhibitors in soybeans and other legumes like kidney beans remain constant or actually increases during germination (Pusztai, 1972; Kakade *et al.*, 1973).

It has been found that the effect of heat treatment on trypsin inhibitors is a function of temperature, time duration, particle size and moisture conditions (Liener, 1972). Generally, autoclaving in steam at 15lb/in² for 10-15 min almost completely inactivates the enzyme. Soaking overnight before steaming at atmospheric pressure and also extrusion cooking results in a product free of trypsin inhibitors (Liener, 1972).



2.2.3 Flatulence

There has been various reports on the formation of intestinal gas following the ingestion of dry mature legumes (Sosulski *et al.*, 1982). Research has shown that flatus production in humans varies with legume specie, biotype and cultivar. In terms of gas forming properties, legumes can be arranged as follows in decreasing order: field bean biotypes; chickpea; lima beans; soybean; pigeon pea; mung bean, smooth peas and lentils (Sosulski *et al.*, 1982).

Galactose containing oligosaccharides such as raffinose, stachyose and verbascose have been reported as the principal components in legumes seeds responsible for flatulence (Sathe *et al.*, 1984). Flatulence results from a lack of intestinal α -galactosidase to hydrolyse the oligosaccharides into low molecular weight sugars which can then be absorbed in the small intestine. These non-digestible oligosaccharides are consequently exposed to bacteria in the colon, which are able to ferment them, producing hydrogen and methane gases. This may be a possible explanation for the abdominal distension and discomfort associated with legume consumption (Rackis, 1975; Wagner *et al.*, 1977). The indigestion and gastric discomfort experienced after ingestion of cowpeas discourages the incorporation of cowpeas into the diet of infants.

The oligosaccharide content of legumes varies; raffinose ranges between 0.2 to 2% whilst stachyose is between 1-8%. (Smith and Circle, 1972; Olson *et al.*, 1975; Murphy, 1975; Rao and Belavady, 1978). Onigbinde and Akinyele (1983) observed

that the concentration of stachyose was the highest in 20 different varieties of cowpeas analysed for sugar content. They however reported that boiling decreased stachyose and raffinose whilst sucrose concentration almost doubled. This was attributed to a possible heat hydrolysis of the oligosaccharide to simple disaccharides.

Different treatments have been applied to legumes and their products to remove flatulence factors. These factors survive ordinary cooking (Olson *et al.*, 1975) and actually a significant increase has been observed with cooking (Rao and Belavady, 1978). This seems to suggest that a large part of the oligosaccharide in pulses is present in a form bound either to proteins or to other macro-molecules, or as a constituent of high molecular weight polysaccharides. Cooking may affect such bonds and release at least, part of the bound oligosaccharide (Rao and Belavady, 1978). Phillips and McWatters (1991) found that dehulling cowpeas resulted in a partial reduction of the flatulence problem.

2.2.4 **Objectionable Beany Flavour**

The action of lipoxygenase enzyme on the free fatty acids in the seeds results in the formation of compounds which leads to the development of the undesirable flavour responsible for the low acceptability of some legume foods (Kon *et al.*, 1970). This off-flavour has been a constraint in feeding cowpeas to children and also to the incorporation of cowpeas into other foods during product development.

Investigators have identified a range of oxidation products of linoleic acid generated by the lipoxygenase action including aldehydes, ketones and alcohols. Most of these products have undesirable odours, especially ethyl vinyl ketone which according to Mattick and Hand (1969) has a raw green bean odour. Therefore the inactivation of the enzyme in the intact legume to prevent the development of the undesirable flavours has received a lot of attention. In soymilk production for example, the processes used include hot water grinding, bleaching and grinding at low pH followed by cooking (Wang and Toledo, 1987).

Storage of cowpeas with moisture content of 10% or less would slow down this process, while heat treatment higher than 80°C will denature the lipoxygenase enzyme. Okaka and Potter (1979) reduced beany flavour of drum-dried cowpeas by acidified water soaking followed by blanching of cowpeas.

2.3.5 **Insect Infestation**

Cowpeas are seasonal and there is therefore the need to store the surplus for use during the lean season. During storage, various pests including rodents, molds and insects attack cowpeas. Amegatse (1995) reported that 66.7% of respondents in a survey in Ghana indicated that insect (weevil) infestation was the major problem associated with cowpea storage. About 80 insect species have been identified as pests of stored cowpeas in Ghana, including *C. maculatus* which is one of the nine major pests identified (Agen-Sampong, 1977). The infestation usually occurs on the field and sometimes during storage by cross-contamination. The females reproduce rapidly and therefore the population can grow exponentially within a few months.

The FAO (1989) estimates that post harvest food losses of grains in developing countries through mishandling, spoilage and pest infestation average 25% of the total food grain production. Various estimates of the magnitude of the post harvest losses (due to insect attack) have been made. The values are generally very high; an estimated 30% of stored rice is lost to insects in Sierra Leone whilst, 25-45% of stored maize is lost to insect pests in Ghana (Hill and Waller, 1988). Comparable levels of losses have been reported in East and Southern Africa and other parts of the tropical world (Boxall, 1989). In the Sahelian areas of Nigeria, weevil infestation of cowpea grain may reach 40% in markets by the early wet season, i.e. June/July (Caswell, 1981).

The loss of food material as a direct result of insect attack occurs through two main means. Insect activity either through boring into the kernels and/or surface feeding results in the removal of food materials, usually from the portions of highest nutritional value. There is also the respiring activity of the insects which results in high moisture development in the stored grains encouraging the growth of micro-organisms with their own associated problems.

A relatively insignificant weight loss in a grain sample may have far reaching effects. This is especially important if it leads to either a total rejection of the whole batch by the consumer or to a drastic price reduction. Up to 30% loss in weight may occur after six (6) months with 70% of seeds being infested and grain being almost unfit for consumption (Singh and Jackai, 1985). Insect infestation leads not only to

economic losses but also results in nutritional losses in cases where the attack is substantial. The nutritional losses occur from decreases in essential amino acids and B vitamins, and also from contamination with uric acid, a metabolite of insects (Bressani, 1983; Uzogara and Ofuya, 1992). Seed viability can also be affected (Wolfson, 1989; Lowenberg-DeBoer, 1995).



2.3 CONTROL OF STORAGE PESTS

Pest management techniques are varied and involves methods that integrate either cultural practices, biological, chemical or physical factors. The choice of the method is affected by many considerations including the availability and costs of inputs, labour intensiveness, time frame for application of the technique, the level of know-how for using the technology, the economic status of the person, cultural biases and amount of grain (Murdock *et al.*, 1997). Amegatse (1995) found that majority (56.2%) of cowpea farmers interviewed in the Ga District of the Greater Accra Region, Ghana, employed intermittent drying of bagged cowpeas whilst 27% used chemical pesticides or airtight containers. Preservation with palm kernel oil, smoke, wood ash and kerosine were other methods used.

2.3.1 Chemical Preservatives

Synthetic chemicals are and will continue to be important agents in the control of insect pests of stored grains especially in developing countries in spite of the continuing controversy surrounding their harmful side effects (Yudelman *et al.*, 1998). Even though these chemicals are generally targeted at insect pests, some of them

are broad spectrum biocides that have profound effects on non-target species in the agricultural ecosystem. There is also a problem of chemical residues after application which could exceed the recommended safety levels. For example, applying 100g of actellic super dust per 90-100kg bag of grain produces residues of 3.3mg permethrin and 17.7mg pirimiphos methyl per kg grain. This is more than the FAO/WHO recommended residual levels of 2mg and 10mg/kg respectively (Golob, 1988; Uronu, 1988).

In Africa, most subsistence farmers do not keep their produce in storage for long periods. Thus there is the danger of consuming or selling grains with high chemical residues. In fact in Tanzania, it has been reported that 1000 deaths per year could be attributed to various pesticide poisoning (Ak'habuhaya and Lodenius, 1988). Although cowpea farmers have long recognised the usefulness of insecticides, factors such as availability, information and cost have kept the technology beyond their reach (Jackai *et al.*, 1985).

2.3.2 Edible Oils and Biologic Materials

Mixing dry beans such as cowpeas thoroughly with small amounts of vegetable oils has proved to be an effective protection (Schoonhoven, 1978; Singh *et al.*, 1978). The oil covers the testa and plugs the egg micropyle (acting as an ovicide) and therefore prevents oxygen supply to the embryo. It also deters oviposition and causes death of adults. A variety of oils are suitable, e.g. palm kernel oil, cotton seed oil, groundnut oil, and sheanut oil. Reports have shown that groundnut oil was

the most effective of the edible oils, providing complete protection for up to 25 weeks after treatment (Singh *et al.* 1978; Pereira, 1983). Cockfield (1992) studying the effectiveness of groundnut oil as a control measure, found that using the oil afforded a protection similar to that of pirimiphos methyl.

The amount of oil needed for an effective preservation is usually very small, 5ml/kg (Singh *et al.*, 1978). There are however, some difficulties associated with this treatment. Thorough mixing of oil and grain becomes tedious when the sample size is large. There is also the problem of rancidity or other inherent negative properties e.g. neem oil stains the hands and has an unpleasant 'garlic' odour (Murdock *et al.*, 1997). It is also easy to pick up dust and debris.

Another method involves the use of plant parts such as leaves of various mints or pungent-smelling plant materials. Ofunya (1986) noted that onion scales and dried chili pepper conferred some degree of protection against *C. maculatus*.

2.3.3 **Sealed Container Storage**

In this method, the moisture present results in germination of some grains. The resulting respiration eliminates oxygen in the enclosure thus suppressing insect infestation. Sealed containers may be large, elaborate, underground silos or simple metal drums (Murdock *et al.*, 1997).

A practical drum storage technique has been developed in Senegal under the Bean/Cowpea Collaborative Research Support Program (CRSP). The beans are first sun dried and then the drum is filled with the dry beans. It has been recommended that the drum be sealed for a minimum of 2 months before opening. It is also important that the drum be air-tight. Its advantages include the relatively low initial cost and repeated use of the drums. However, the period within which the drum must remain sealed for the treatment to be effective is quite long. There is also the problem of weight of large drums but this is usually overcome by using racks.

Storage using triple plastic bagging is another simple and inexpensive method also developed by the CRSP project in Cameroon. The technique makes use of clear plastic bags which are widely available. The grains are put in a bag (40-50kg) and tightly sealed with twine. This is then placed completely into a second and then a third bag and sealed similarly. Tests in various Cameroonian villages has shown that the method is effective and readily accepted by small-scale farmers. Due to the transparent nature, the farmer can observe the grains periodically. However, the bags can be easily destroyed through improper handling and they are also vulnerable to rodent attack. (Murdock *et al.*, 1997)

In Ghana, the Grains Development Project has investigated the potential of storing cowpeas in hermetically sealed Kilner jars. They found that the method was effective (Osei, 1993).

2.3.4 **Co-storage with ash and other abiotic materials**

Wolfson *et al.* (1989) found that the most common traditional postharvest storage method in Northern Cameroon was the use of ash. This has also been noted in other sub-saharan African countries including Ghana (Murdock *et al.*, 1997). The ash used comes from the cooking fire and results vary with differences in mode of application and the ash:grain ratio used. The latter factor is usually more important and the method is more effective if the ratio is 3 or more parts ash to 4 parts grain. Although the ash stops the development of the bruchid population in the grain store, it does not kill them. It is therefore important to mix with the ash immediately after threshing.

2.3.5 **Biological Control**

An example of this method involves the use of resistant cultivars including bruchid resistant seeds or pods or a combination of resistant seeds and pods. Seed resistance is a valuable tool but it must be carefully controlled to avoid the rapid development of a virulent bruchid biotype. Some observations in Cameroon have suggested that the development of varieties with combined resistance to bruchid both in pods and seeds could result in an effective approach to achieving a durable and high level of bruchid resistance (Murdock *et al.*, 1997).

2.3.6 **Solar and Other Heat disinfestation Techniques**

- a. Susceptibility of insects to thermal destruction: High temperatures can be used to kill insects due to their limited physiological capability of

thermoregulation. As a result, bruchid eggs, larvae and pupae which are immobile can not escape from a hot environment and therefore are excellent targets for postharvest management using elevated temperatures. This has been used for a long time by sub-saharan African farmers who disinfest cowpeas by heating on iron plates over fire. Though this technique works, it is difficult to control the cowpea from overheating and burning (Murdock *et al.*, 1997).

- b. CRSP Plastic Solar Heater: This also exploits the thermal susceptibility of the storage pest. A simple solar heater was developed from a sheet of black polyethylene placed on the ground. The grains are spread out on the sheet and the two edges folded and secured with stones, thus enveloping the grains. When exposed to the sun rays for 2 hours, all stages of the insects were killed. The method did not change the cooking time, rate of germination or the vigor of the seedlings. The solar heater has been field-tested and introduced in North Cameroon (Murdock *et al.*, 1997).

2.3.7 Irradiation

Radiation sterilisation using gamma rays helps to reduce the fertility of the female *C. maculatus* (Ahmed *et al.*, 1979). Combinations of irradiation with other measures such as temperature has been suggested as a viable means of controlling insect infestation of stored food. However, irradiation has not been fully accepted by most consumers on safety basis (Wolf, 1992). There is also the problem of the high initial

capital requirements especially in Africa where most processors are small-scale industrialists.

2.4 REVIEW OF THE EFFECTS OF THE HYDROTHERMAL TREATMENT OF COWPEA SEEDS

The hydrothermal treatment is a simple, inexpensive and safe physical modification process which does not require the use of sophisticated equipment or trained personnel. It involves the exposure of whole cowpea seeds to steam followed by drying to acceptable storage moisture content. Sefa-Dedeh *et al.* (1994) reported that 5 and 10mins steamed cowpeas were resistant to the weevil. A detailed study was subsequently undertaken to compare the effect of steam and solar heat on some aspects of the developmental biology (oviposition, developmental period, sex-ratio, and food preference) and control of *C. maculatus* under ambient laboratory conditions (Sefa-Dedeh *et al.* 1998). It was concluded that even though the number of eggs laid was not affected by the treatment, there was no emergence of adult insects in the steamed cowpeas. This was the same even after 6 months storage whilst the seeds of the untreated and solar dried samples were completely destroyed within the period.

Egyir-Yawson (1999) obtained similar results. According to his report, microscopic examination showed that all hatched eggs had initiated feeding but somehow were unable to complete development in the steamed seeds and had died at an early instar. He suggested that death could have resulted from an inability to utilise the nutrients possibly, due to structural changes in the protein and starch molecules after

steaming. The study also revealed significant differences in the resistance shown in steamed samples dried either in the solar dryer as compared to those dried in an air oven. The latter samples were not resistant to the attack, that is, there was emergence of adult insects.

Field studies have been conducted both at the farm and market levels (Sefa-Dedeh and Saalia 1997). Results have shown that up to 10 weeks of storage, steamed seeds were still clean with no signs of insect infestation. After this period, the 5 min steamed seeds showed some signs of infestation, however the rate of damage was much lower compared with the control. The 10 min steamed seeds remained uninfested for the entire experimental period of 24 weeks. Another observation made was that infestation was stopped when infested samples were steamed and then stored. Seed viability was however completely lost following steaming and seeds could thus not be used for cropping.

Osei (1993) studied the effects of the process on some functional properties of 4 varieties of cowpeas - *Ayiyi*, *Asontem*, *Bengpla* and *Soronko*. In general, there were significant differences in all the properties studied compared to the control. There was a general increase in flour water absorption (25 and 70°C) with steaming time. Swelling capacity increased after 2min steaming but decreased after that with steaming time. Fat absorption, foam volume and foam stability all decreased with steaming time. He also found that whilst pasting temperature increased with steaming time, the other viscoamylograph indices - viscosity at 95, 95-hold, 50 and

50-hold, were all reduced with steaming. Also no peak viscosity was observed, that is, gelling was gradual.

Sefa-Dedeh and Demuyakor (1994) investigated the effects of steaming and storage on some physicochemical properties of cowpea seeds and flour. They reported that whilst the steaming resulted in an increase in water absorption of the flour samples, the steamed seeds showed reduced water absorption capacities. Storage further reduced the water absorption capacity for both seeds and flour. Steaming also increase the fat absorption capacity of the flour whilst the foaming property decreased with steaming and storage for the seeds and also the flour. They further observed characteristic differences in the viscoamylograph data following steaming, the most significant difference being a reduction in the viscosity at 95°C and 95°C-Hold which is an indication of the ease of cooking of the sample.

A decrease in seed water absorption was reported by Saalia (1995). He observed no significant differences in the surface topography of both steamed and unsteamed seeds. However, removal of the seed coat revealed marked differences in the surface topography. The usual ridges between individual cells were filled by the swelling and rounding of the cotyledon surface cells as a result of the steaming. Cross-sectional examination revealed more differences; unsteamed seeds showed a distinct layer of organised cells at the cotyledon surface which became fused with the underlying cells after steaming.

Obeng (1996) investigating the effect of steam treatment on processing and chemical characteristics of cowpea seeds and flour, recorded reduced seed viability with steaming. The effect of the steam treatment was found to be more pronounced in the *Amantin* variety compared to *Asontem*. A general reduction in both tannic and phytic acid concentration with increasing steaming time was also recorded. Leached solids of the cooked seed increased with steaming time whilst cooked seed hardness was affected significantly by cowpea variety, cooking time and steaming time. Acceptability of the cooked bean was also significantly affected by both variety and cooking time but not steaming time.



Consumer evaluation studies have also been conducted on the steamed seeds (Sefa-Dedeh and Saalia, 1996). Two procedures were used - administering questionnaires and focus group discussion. Steaming reduced the acceptability of the cowpea based on the appearance, an attribute deemed important in consumer selection of the product. A majority of the respondents (84%) reported that unsteamed seeds had higher swelling capacity than the steamed seeds. However, the soaked steamed seeds were relatively softer to touch as compared to the unsteamed. No conclusive information was obtained on the time required to cook the beans to the desired softness. The reported 'normal' cooking time ranged between 45 min to 120 min, possibly due to differences in heating systems. Steaming affected neither the flavour nor the taste of the cowpea meals prepared using the samples.

2.5 SOME SPECIFIC EFFECTS OF PROCESSING ON LEGUMES

The processing of legumes is generally essential to make them nutritious, non-toxic, palatable and acceptable (Uzogara and Ofuya, 1992). Processing invariably involves heat treatments such as boiling, steaming, frying and roasting though other techniques are also used.

The extent and consequences of thermal denaturation of proteins depends on various factors including the intensity and duration of the applied heat, water activity, nature of the protein, pH, salt content, and the kind and concentration of other reactive molecules (Cheftel *et al.*, 1985). Structural changes and limited hydrolysis of peptide bonds occur as a result of mild heat treatments. This does not usually adversely affect nutritional quality as much as it does the functional properties of the proteins (Cheftel *et al.*, 1985).

Structural changes occur as a result of the exposure of cowpeas to heat. These changes in turn affect the functional properties of the cowpeas and therefore its utilisation. This is because it has been suggested that the acceptability of proteins as food ingredients is to a large extent determined by the functional and physical properties and not its nutritional value (Johnson, 1970).

Sefa-Dedeh *et al.* (1979) found that the most significant structural change during cooking of non-oilseed legumes was the breakdown of the middle lamella resulting in easy cell separation. Other workers (Sefa-Dedeh *et al.*, 1978; Jones and Boulter,

1983; Shomer *et al.*, 1990) had reported that legume softening during cooking was associated with cell separation. Thus the breakdown of the middle lamella appears to contribute significantly to the softening of the cell during cooking. Gelatinisation of cell starch and consequent deformation of spherical granules are other changes observed.

Losses in protein solubility and minerals especially potassium and phosphorus; and leaching of soluble constituents and electrolytes also occur during moist cooking. There is also the inactivation of enzyme inhibitors e.g. trypsin and amylase inhibitors; changes in tannin and polyphenol content, and their redistribution between cooked beans and cooking water. A decrease in oligosaccharide content following soaking and cooking has also been reported (Bressani, 1993; Antunes and Sgabieri, 1980; Jaffe, 1980).

The application of heat to cereals, pulses and also macaroni and pasta causes a case hardening effect which renders them highly resistant to insect infestation. According to Majumder (1982), the case hardening causes mechanical resistance to mandibular chewing and also prevents utilisation of the gelatinised starch by gut enzymes.

Roasting has been used in the control of the development of the hard-to-cook defect in beans. Dry roasting of beans results in lower protein quality and digestibility. It is however an inefficient means of improving the nutritive value of common beans and there may also be some residual levels of trypsin inhibitor activity (Bressani, 1993).

The nutritive value and protein digestibility of grain legumes are improved by processing or cooking since these treatments destroy the heat labile antinutritional factors (Bressani, 1972b). An increase in the level of water soluble vitamins and protein digestibility and also a decrease in phytate content and cooking time with fermentation has been recorded (van Veen and Steinleraus, 1970; Tamang and Sarkar, 1988).

Reduction in cooking time and an improved *in vitro* protein digestibility (due to removal of dietary fibre and tannins in seed coat) have been reported after dehulling. Milling and air-classification of food legumes have also been used to produce high protein and carbohydrate fractions (Bressani, 1993).

Germination leads to an overall increase in vitamins and non-phytate phosphorus content and a decrease in phytic acid. This results in an improved absorption of minerals. Protein and carbohydrate digestibility are also improved through a combination of germination and cooking (Bressani, 1993). However germination does not appear to have any effect on trypsin inhibitors though it improves the nutritional quality of legumes.

Generally, exposing beans to heat treatment improves their texture, palatability and nutritive value (Tobin and Carpenter, 1978). There is also a reduction of the beany flavour during drum drying, however losses in lysine may occur (Kon *et al.*, 1970; Almas and Bender, 1980).

2.6 FACTORS AFFECTING THE COOKABILITY OF GRAIN LEGUMES

Cooking of dry beans is necessary to develop acceptable flavor and texture, to inactivate anti-nutritional factors and to make the bean protein nutritionally available. Usually, it involves overnight soaking of the dry beans in water, draining and cooking in fresh boiling water for an hour or longer. Innovative processes have included the production of quick-cooking beans by soaking in solutions of several salts (Rockland, 1972) and the production of instant bean powders by soaking, retorting and dehydration (Bakker *et al.*, 1973). Various factors are known to have a direct influence on the cookability and therefore the acceptability of legumes. These factors include storage conditions, soaking treatments and cooking method.



2.6.1 Storage Conditions

Controlled storage conditions are essential for the preservation of bean quality; the critical parameters being seed moisture content, relative humidity of air and storage temperature (Antunes and Sgarbieri, 1980). There is a rapid deterioration of cooking quality of beans with increasing storage temperature, especially at moisture contents above 10%. Burr *et al.* (1968) observed that pinto beans stored at 32°C for 7 months took 340 min to cook compared with 24 min for fresh beans. However storage at 8°C and moisture content of less than 10% did not affect cooking time even after 2 years.

Cooking time of legumes is a function of their moisture content, storage temperature, time and relative humidity (Sefa-Dedeh *et al.*, 1979). It has been reported that beans

with moisture content of greater than 13 % deteriorate significantly in flavour and texture after 6 months storage at 77°F (25°C) becoming unpalatable after 12 months (Morris and Wood, 1956). However, when stored at moisture contents below 10% the quality after 2 years at the same temperature was comparable to the control (- 10°F). Burr *et al.* (1968) recorded increases in cooking time, between 9 - 17 fold, for 3 different beans - pinto, lima and sanilacs, stored at 90°F (32°C) with moisture content above 13%.

Sefa-Dedeh *et al.* (1978) observed that the rate of softening of cowpeas cooked at 100°C followed first order kinetics. However, storing cowpea seeds at high temperature (21 or 29°C) and high relative humidity (35% or 85%) altered the behaviour of the seeds during cooking. Micro-structural evidence also showed that there was no break down of the middle lamella after cooking seeds stored at the high temperature and relative humidity. This was thought to partly account for the hardness observed in these seeds.

Jackson and Varriano-Marston (1981) reported that black beans stored for a year at room temperature had a cooking half-time (i.e. when 50% of beans were cooked) of 45 min compared to 31 mins for fresh beans. Beans stored at 41°C and 75% RH for 55 days remained hard even after 6 hours in boiling water. When the beans were decorticated, the cooking half-time for all samples was reduced; fresh decreased to 12 mins; 1 year at room temperature required 27 mins and the 55 day beans that were previously uncookable, had a cooking half-time of about 120 mins. They

concluded that the seed coat was a major barrier to bean softening during cooking and also that there could be some biophysical and/or biochemical changes in both seed coat and cotyledon during storage (Jackson and Varriano-Marston, 1981).

Moscoso *et al.* (1984) suggested that the loss of cookability in mature dry beans stored under high temperature and humidity could probably be due to a decrease in the concentration of phosphorus in phytic acid and changes in the ratio of monovalent to divalent cations in the tissue. Garruti and Bourne (1985) using Texture Profile Analysis (TPA) recorded a considerable increase in all the TPA parameters measured (hardness, fracturability, gumminess, chewiness, springiness and cohesiveness) after 6 months storage at 30°C or 40°C and 80% RH. Sensory analyses by a trained panel showed that after storage at high temperature, the texture of the cooked beans changed from a soft moist, pasty, starchy type of texture into a hard, fracturable, lumpy, non-pasty, somewhat dry texture similar to that of roasted peanuts and quite unlike the texture associated with normal beans. Changes in a total of 23 different textural parameters were recorded after the high temperature storage (Garruti and Bourne, 1985). According to Jones and Boulter (1983) the deterioration in textural quality is due to the failure of the cotyledon cells to separate during cooking.

Onayemi *et al.* (1986) studied the effects of different storage conditions and cooking methods on some characteristics of cowpeas. They found that storage under nitrogen for 6 months closely resembled the freshly harvested seed in terms of

cooking time compared to storing in hermetic containers or jute bags at room temperature.

2.6.2 Soaking Treatments

Generally, it is thought that soaking legume seeds in water improves their cookability. However, overnight soaking has little effect whilst prolonged soaking (8 days) actually rendered yellow peas uncookable (Mattson, 1946; Liu and McWatters, 1994). Thus an optimum soaking period must be considered. Liu and McWatters (1994) found that water soaking did not have any significant effect on the texture of control cowpea seeds cooked for 1 hour. However, there was a gradual increase in hardness with soaking time for aged seeds (12 months at 30°C/64% RH).

Procedures that influence cell integrity, texture, water imbibition and heat transfer have all been shown to reduce preparation time for dry beans. Research has shown that removal of gases (nitrogen, oxygen and carbon dioxide) from the interstitial tissues improved water uptake. This can be achieved by either raising water temperature or reducing the partial pressure of the gases in the surrounding medium (Kilgore and Sistrunk, 1981). Other investigators have reported the use of sodium bicarbonate in soaking as a means of greatly reducing the cooking time of dry beans.

The soaking solution employed also has a significant effect on the texture of the beans. Lu *et al.* (1984) observed that Faba beans soaked in NaHCO_3 before canning were softer than either the control or seeds soaked in Na_2EDTA . This was

attributed in part to a disruption of cell integrity as a result of an ion exchange reaction between sodium ions and the divalent ions in the intracellular cement. A reduction of the cooking time of African yam beans with increasing soaking time was recorded irrespective of the soaking medium (Njoku *et al.*, 1989). Soaking in potash or NaCl solutions for 12 hours or in tap water for 24 hours resulted in a 50% reduction of cooking time. Soaking in either NaCl or potash was preferred to water soaking since the former solutions resulted in a more rapid softening of the yam beans.

Soaking cuts down the time required to render legumes edible and thus reduces the amount of fuel needed in the preparation and therefore the loss of nutrients during cooking. It is an important part of legume preparation especially in high altitude areas where water boils at lower temperatures (Abou-Samaha *et al.*, 1985). Soaking can however be a long process, thus ways have been designed to shorten the time. These include increasing the temperature of the soak water and by increasing the rate of water imbibition through the vacuum infiltration technique (Rockland and Metzler, 1967). Though useful, soaking can result in the loss of nutrients including minerals and vitamins. Other components lost are tannins, oligosaccharides and trypsin inhibitors. The loss of nutrients can be minimised through the soaking of whole seeds.

2.6.3 Cooking Method

According to Liu and McWatters (1994), normal cooking of legumes involves either bringing seeds to boil from cold water or dropping them into boiling water. They observed that the cooked seed texture of control cowpeas (similar to freshly harvested) was not affected by the cooking method. However, cooking method had significant effects on the cookability of aged seeds showing signs of storage induced hard-to-cook defects. For the same time period of soaking, seeds cooked from cold water were firmer than those cooked initially from boiling water. This was thought to be due to the pre-heating treatment that occurs before the cold water reaches boiling point. The activation of enzymes such as phytase and pectin methylesterase; accelerated leaching of electrolyte and protein coagulation during the pre-heating period are all thought to be responsible for the firming effect (Liu and McWatters, 1994).

Addition of small amounts (0.07%) of sodium bicarbonate or baking soda has been found to reduce the cooking time of dry legumes (Perry *et al.*, 1976). Frying soaked soybeans in oil prior to boiling has also been suggested for reducing the cooking time (Onate *et al.*, 1972). In Africa, the pH of the cooking water is raised with an alkaline rocksalt called "Kanwe" or trona (Ankrah and Dovlo, 1978), in an effort to reduce the cooking time. The effect of the alkaline salt is mainly through increased water uptake and cowpea tenderisation.

3.0 MATERIALS AND METHODS

3.1 MATERIALS

Two varieties of cowpea - California No. 5 Blackeye and *Asontem* were used in the study. The cowpea seeds were obtained from Yonifah farms and the Crop Research Institute, Ghana. Another batch of freshly harvested and dried California No. 5 Blackeye was obtained from a local farmer. All the seeds were kept at cold room temperature (6°C) throughout the experimental period.

3.2 SAMPLE TREATMENTS

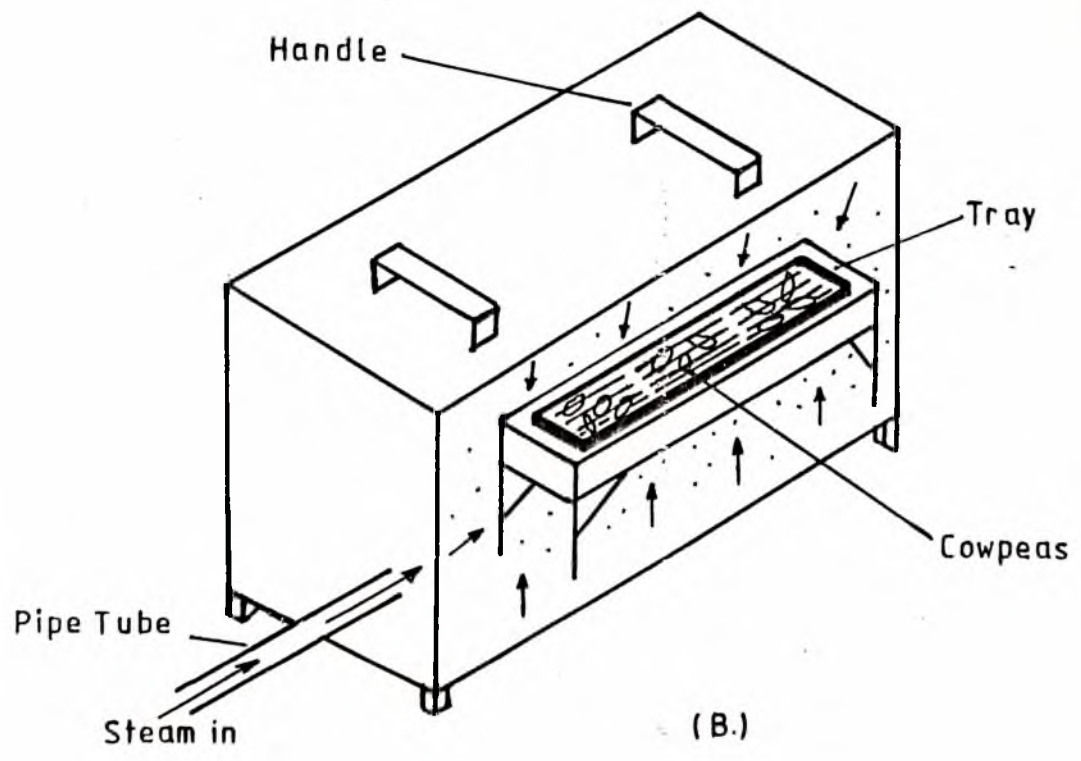
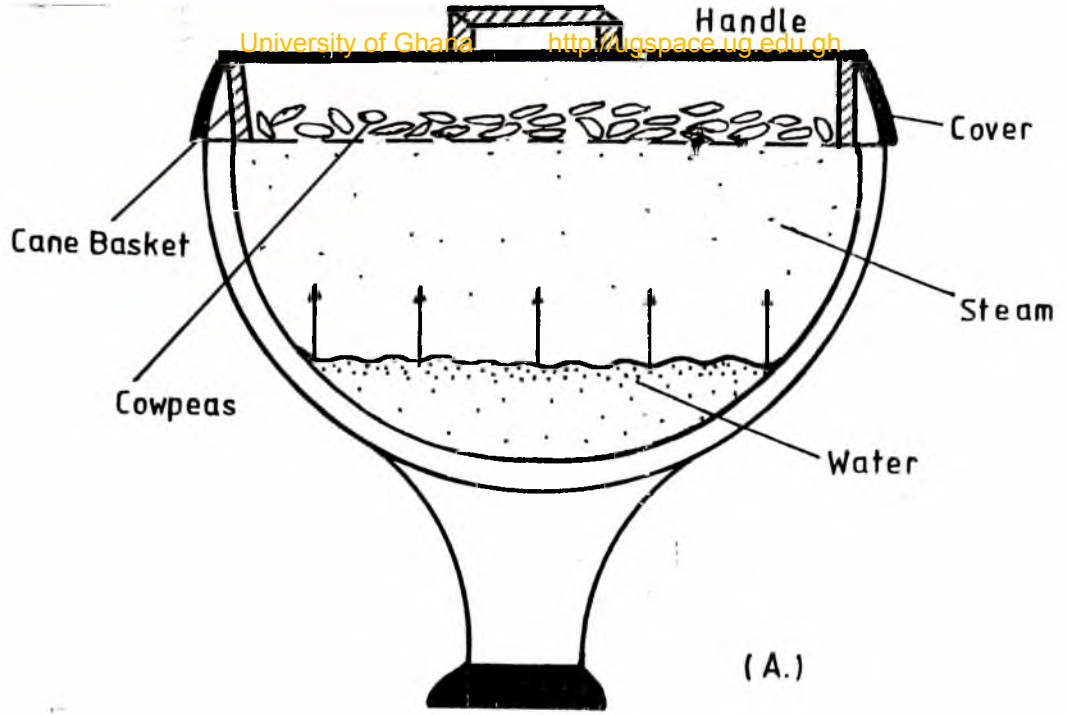
3.2.1 Hydrothermal Treatments

Cowpea seeds were removed from the cold room and allowed to equilibrate to room temperature (about 2 hours) before steaming. Two different steaming systems were employed in the study. Steam was generated in either a steam exhaust box or a jacketed steam kettle. The setup of the steaming systems used in the hydrothermal treatments is shown in Figure 1.

In the first system, 2.5kg of cowpea seeds were spread out on metal trays and exposed to steam at 50psi in a steam exhaust box for 2, 5, 10 and 15 min. The second system involved spreading 2.5kg of seeds in a cane basket lined with muslin cloth and then covered with a wooden lid. The seeds were then exposed to steam generated from boiling water in a jacketed steam kettle by placing the basket over the steam kettle. Steaming times used were 2, 5, 10 and 15 min. The samples obtained from these two systems were solar dried for a total of 27 hours.

Figure 1 Steaming systems used in hydrothermal treatment of cowpeas

A = Jacketed steam pan
B = Steam exhaust box



A summary of the hydrothermal treatments used in the study is shown in Figure 2.

The dried seeds were kept at 6°C till needed for analyses. Unsteamed cowpea seeds, 'control' were also used in all the determinations.

3.2.2 **The Effect of Drying Conditions**

A 2kg sample of freshly harvested blackeye peas was spread out in a wire basket placed in a steam retort. The steaming was done at atmospheric pressure and steam temperature of 210K. The seeds were steamed for 2, 6 or 10 min. The samples were then dried under conditions of controlled temperature and absolute humidity in an environmental growth chamber (Environmental Growth Chambers, Model NQ2, Chagrin Falls, OH) set to the desired conditions. There were three levels for each variable; temperature – 35, 45 and 55°C and absolute humidity – 0.01, 0.02 and 0.03 g water/kg of air. During the actual drying, relative humidity conditions were used to obtain the corresponding absolute humidity values. A three factor-three level Box-Behnken experimental design was selected for Response Surface Methodology (RSM). This design resulted in 15 experiments which are shown in Table 3. The loss of moisture from the samples was monitored during drying till a moisture content of about 10% was attained, at which point the drying process was stopped.

Figure 2 Summary of hydrothermal treatment of cowpea seeds

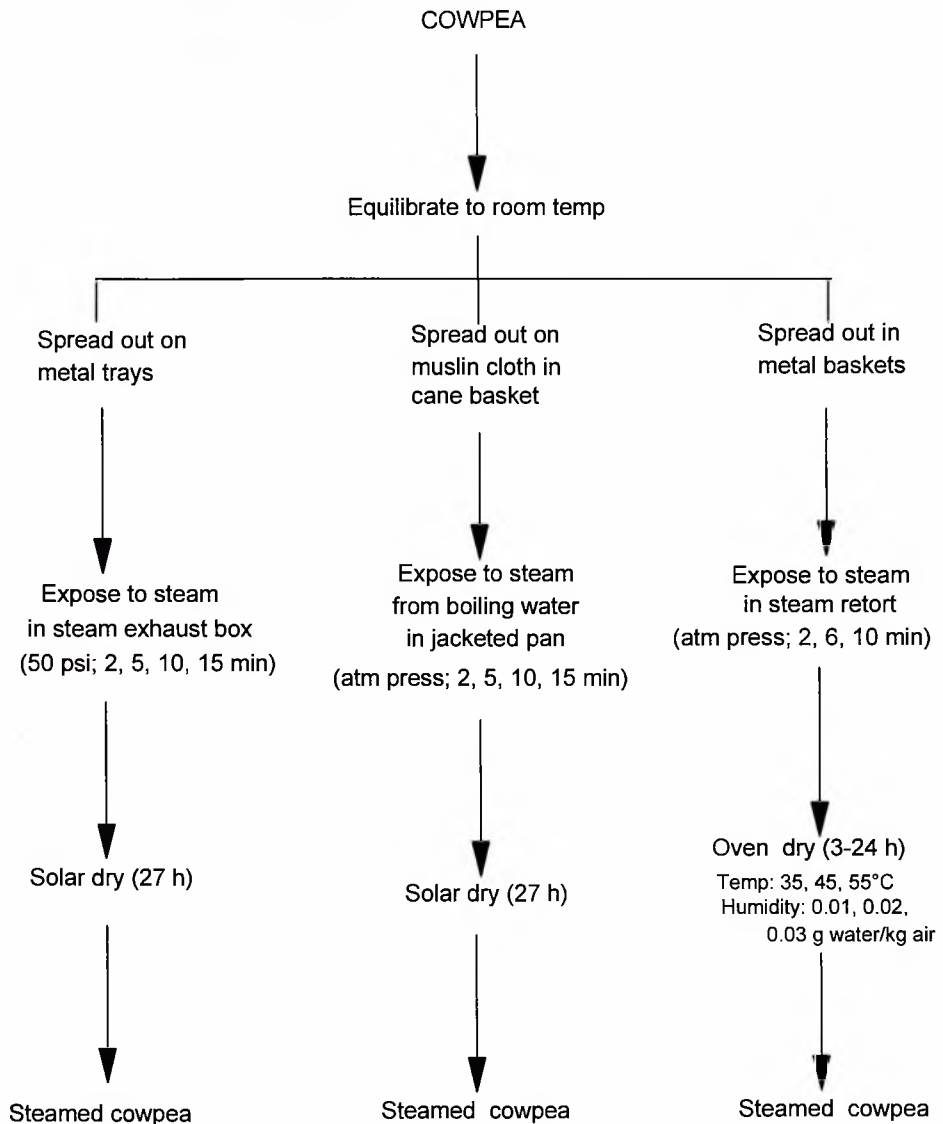


Table 3: Variable Combination from the Box-Behnken Experimental Design

Test No	Steaming Time		Drying Temperature		Absolute Humidity		Sample Code ¹
	Coded	Uncoded min	Coded	Uncoded °C	Coded	Uncoded g water/kg air	
1	-1	2	-1	35	0	0.02 (56) ²	2 min/35°C/56%
2	-1	2	0	45	-1	0.01 (16)	2 min/45°C/16%
3	-1	2	0	45	1	0.03 (48)	2 min/45°C/48%
4	-1	2	1	55	0	0.02 (20)	2 min/55°C/20%
5	0	6	-1	35	-1	0.01 (28)	6 min/35°C/28%
6	0	6	-1	35	1	0.03 (81)	6 min/35°C/81%
7	0	6	0	45	0	0.02 (33)	6 min/45°C/33%
8	0	6	0	45	0	0.02 (33)	6 min/45°C/33%
9	0	6	0	45	0	0.02 (33)	6 min/45°C/33%
10	0	6	1	55	-1	0.01 (10)	6 min/55°C/10%
11	0	6	1	55	1	0.03 (29)	6 min/55°C/29%
12	1	10	-1	35	0	0.02 (56)	10min/35°C/56%
13	1	10	0	45	-1	0.01 (16)	10min/45°C/16%
14	1	10	0	45	1	0.03 (48)	10min/45°C/48%
15	1	10	1	55	0	0.02 (20)	10min/55°C/20%

¹ - Sample Code - steaming time (min)/drying temperature (°C)/drying humidity (%)

² - (Relative Humidity %)

3.3 PHYSICAL ANALYSES

3.3.1 Moisture Content

The moisture content of the samples was determined using either the AOAC (1990) method No. 950.40 of oven drying at 105°C for 6 hours or the AACC (1983) method No. 44-15A of drying at 130°C for 1 hour in a forced air oven. The moisture content

was determined before and after steaming and also after drying. Triplicate determinations were performed and the mean value reported.



3.3.2 Germinating Capacity

About 20 seeds were soaked for 12 hours and placed in petri dishes lined with damp filter paper. The dishes were then placed in a cupboard and monitored over a 3 day period. The length of any growth after 3 days, was recorded and averaged for each treatment.

3.3.3 Soaked Seed Hardness

The hardness of seeds soaked for 1, 3, 6, 12, 18, and 24 hours was determined using a TA-XT2 Texture Analyser (Stable Micro Systems, Surrey, England). The test cell used was the Warner-Bratzler Blade. The peak force required to cut through five (5) seeds was determined. The seeds were placed longitudinally across the groove in the sample holder, and cut perpendicularly across the axis of the seeds. The test conditions used were; test speed of 1.5mm/s and distance of 11mm. The test was replicated five times and the average peak force recorded. The energy required to break and completely cut the seeds was calculated from the area under a force-deformation curve plotted using the XT.RA Dimension, version 3.78 computer software (Stable Micro Systems, Surrey, England).

3.3.4 Effect of Steaming and Storage on Cooked Bean Hardness

Steamed and unsteamed cowpeas were stored in polyethylene bags under two storage conditions, 4°C and room temperature (av. 28°C). The changes in the cooked bean hardness were determined after 0, 1, and 6 months in storage.

Cowpea seeds were soaked in water (1:3 bean-water ratio) for 24 hours, drained and cooked in water for a total of 3 hours, while maintaining the volume of water. At intervals of 30 min, a sample was removed from the lot and analyzed. The hardness of the cooked seeds was then measured using a TA-XT2 Texture Analyser (Stable Micro Systems, Surrey, England). Two test cells were used:

- a. Kramer Shear Press: The peak force required to compress, shear and extrude a 20 g sample of cooked beans was determined. Quadruplicate determinations were done at crosshead speed of 5 mm/s and a distance of 20 mm.
- b. Warner-Bratzler Blade : Five seeds were placed longitudinally across the groove in the sample holder, and cut perpendicularly across the axis of the seeds. The peak force required to cut through the whole seed was recorded for each test run and averaged. The test was replicated five (5) times at a crosshead speed of 1.5 mm/s and a distance of 11 mm.

The force-deformation curve was plotted using the XT.RA Dimension, version 3.78 computer software (Stable Micro Systems, Surrey, England).

3.3.5 **Cooked Bean Hardness - Instron Universal Machine**

Beans were soaked in water (1:3 bean:water ratio) for 18 hours, drained and cooked for a total of 2 hours. A sample was removed after 30 min. Cook water was replaced during the cooking. An Instron Universal Testing Machine with a 500 kg load cell fitted with a Kramer Shear test cell was used. The test cell was filled with 50 ± 0.2 g cooked beans and the test performed at a cross-head speed of 50 mm/min and chart speed of 50 mm/min. The maximum force required to compress and shear the beans was determined from the force deformation curve.

3.3.6 **Dehulling Efficiency**

The seeds were soaked in water for 2 min, drained and dried for 18 hours at 55°C in an air oven. A 100g sample was weighed and passed through a plate mill (Model 4E Grinding Mill, the Straub Co., Hatboro, PA) to crack the seeds. The split seeds were then aspirated in a seed aspirator (Almaco Seed Cleaner, Model ABSC - 1, Allan Machine Co., Ames, IA) to separate hulls. The aspirating step was repeated till about 90% of the hulls had been removed. This usually required 2 runs through the aspirator.

The total hull content of the seeds was determined by manually dehulling a known weight of seeds and calculating the weight of the hulls removed as a percentage of the total weight. A dehulling efficiency index (DE) was calculated based on the method of Reichert *et al.* (1984) shown below. The procedure was done in triplicate

and the mean value reported. The following equations were used in calculating the dehulling efficiency:

$$\text{Yield} = 100 - (\text{hulls} + \text{broken} + \text{powder})$$

$$\text{DE} = \frac{\text{hulls removed (g/100g seed)}}{100 - \text{yield (g/100g seed)}}$$

3.3.7 1000 seed weight

The weight of 100 whole seeds was determined and the corresponding 1000 seed weight calculated. This test was repeated 5 times and the mean value reported.

3.4 FUNCTIONAL PROPERTIES

3.4.1 Gelation Capacity

The method of Coffman and Garcia (1977) as reported by Sathe *et al.* (1982) was used. Serial dilutions containing between 2-30% cowpea flour were prepared in test tubes. These were boiled for 1 hour in a boiling water bath, followed by rapid cooling under running water. The samples were then kept at 4°C for 2 hours. The tubes were then inverted to determine the lowest concentration above which the heated sample did not run out of the tube i.e. remained in the bottom of the tube. This concentration was recorded as the least gelation capacity. The determination was done in duplicate and then averaged.

3.4.2 Seed Water Absorption

The water absorption patterns of the control and steam treated seeds were determined according to the method of Sefa-Dedeh *et al.* (1978). Ten gram samples were soaked in water at 25°C for 1, 3, 6, 12, 18, and 24 hours. After the soaking period, the seeds were removed, blotted to remove the surface water and weighed. The amount of water absorbed was determined from the increase in weight. All the determinations were performed in triplicate and average results reported as g water absorbed/100g dry matter. The corrected water absorption (WA_c) was calculated based on the equation used by Jackson and Varriano-Marston (1981):

$$WA_c = \frac{Wt \text{ after soaking} - \text{initial wt} + \text{solids lost}}{\text{Dry weight}} \times 100$$



3.4.3 Solids lost during soaking

A 10 ml aliquot of the soak-water drained from samples soaked for 1, 3, 6, 12, 18 and 24 hours was dried at 105°C in an air oven for 24 hours. The weight of the residue was determined after drying. This was done in triplicate and the mean value reported as g/g dry sample.

3.4.4 Protein Solubility

The method of Sathe *et al.* (1982) was used. About 10 mg of the flour was dissolved in 10 ml of 1M NaOH. The pH was adjusted to the desired value with 1M HCl. The determinations were done at pH values of 2, 4, 6, 8, 10 and 12. The sample was centrifuged at 5000 x g for 15 min. The protein content of the supernatant was

determined using the Lowry method for protein (Lowry *et al.*, 1951) The analyses were done in triplicate and the means reported as μg extracted protein/mg protein.

3.5 CHEMICAL ANALYSES

3.5.1 Trypsin Inhibitor Activity

a. Extraction of Trypsin Inhibitors

Trypsin inhibitors were extracted based on the method reported by Osei *et al.* (1996). This involved thoroughly mixing 2g of flour with 20 ml of 0.01M NaOH. The suspension was allowed to stand for 2 hours at room temperature followed by centrifuging at 5°C for 20 min at 5000g. The supernatant was decanted and an equal portion of 3% (w/v) TCA solution added to precipitate unwanted proteins. The resulting solution was centrifuged again at 5°C for 20 min at 5000g. The pH of the supernatant was raised to 8.3 with 2M NaOH and then clarified by centrifuging at 5°C for 20 mins at 5000g . The supernatant (trypsin fraction) was then used for the assay.

b. Assay for Trypsin Inhibitor Activity

The assay system used was based on a modification of the method of Erlanger *et al.* (1961) as reported by Osei *et al.* (1996). Benzoyl-D-L-arginine-p-nitroaniline HCl (BAPNA) was used as the substrate and pure trypsin as the enzyme. The assay mixture contained 1ml of each of the following solutions:

50mM Tris-HCl buffer pH 8.3;

0.253mM BAPNA/50mM Tris-HCl buffer pH 8.3; containing 20mM CaCl_2

0.005% Trypsin/50mM Tris-HCl buffer pH 8.3;

This was incubated for a minute at room temperature and the increase in absorbance at 410 nm read at 30 seconds intervals for a total of 10 mins against a blank which contained all the reaction reagents except the buffer which was replaced by 30% acetic acid. Trypsin inhibitor activity was determined by adding 1ml of the extract in place of the buffer solution. The absorbance readings were extrapolated from a calibration curve prepared with nitroaniline (NA). One trypsin unit was arbitrarily defined as an increase of 0.01 absorbance units at 410 nm per 10ml of the reaction mixture (Kakade *et al.*, 1974). Trypsin inhibitor activity was expressed in terms of trypsin units inhibited (TIU).

4.0 RESULTS AND DISCUSSION

4.1 EFFECT OF STEAMING ON PHYSICAL, FUNCTIONAL AND CHEMICAL CHARACTERISTICS

4.1.1 Moisture Content

All the samples showed an increase in moisture content with increasing steaming time. The moisture content after steaming ranged between 14.45-20.28% and 14.08-19.95% respectively for blackeye and asontem. These were reduced with drying to between 6.28-9.25% and 6.40-8.83% respectively (Table 4).

Table 4: Moisture Content of Cowpea Seeds after Steaming and Drying

STEAMING TIME (min)	STEAMING SYSTEM	BLACKEYE		ASONTEM	
		After Steaming (%)	After Drying (%)	After Steaming (%)	After Drying (%)
0	Unsteamed	-	11.18	-	12.42
2	Steam box	14.45	7.61	14.80	7.13
5	Steam box	15.48	8.61	15.20	8.26
10	Steam box	18.10	9.25	15.30	7.64
15	Steam box	20.28	8.93	19.95	8.83
2	Jacketed pan	16.45	6.28	14.08	6.40
5	Jacketed pan	16.66	6.44	14.44	6.96
10	Jacketed pan	16.77	6.70	15.11	7.02
15	Jacketed pan	17.02	6.96	15.55	8.18

The moisture content of grains in storage is very important in relation to insect infestation and in the development of the hard-to-cook defect. Insect pests obtain the moisture required for their life processes from the grains. Up to a certain point, increasing grain moisture favours a rapid increase in the number of insects.

However, at low grain moisture (<10%), the required water is obtained through the breakdown of food reserves in the fatty tissue of the body, leading to death of insects in most cases (Cotton and Wilbur, 1974).

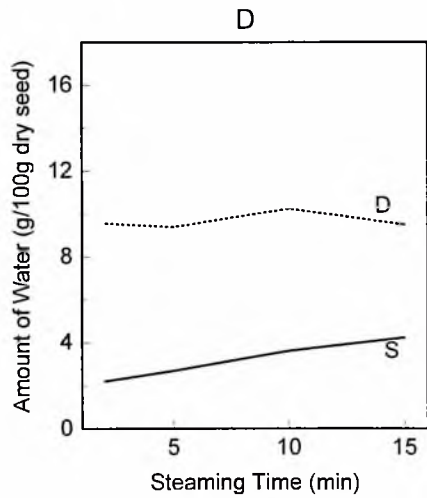
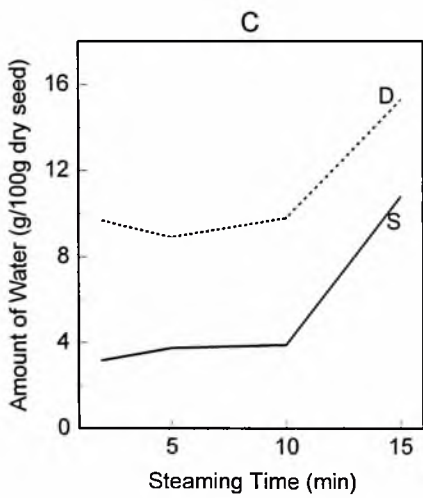
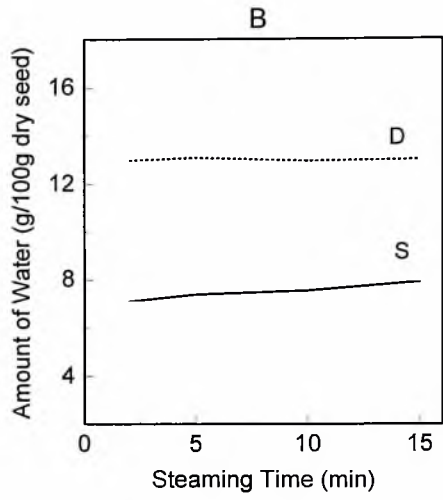
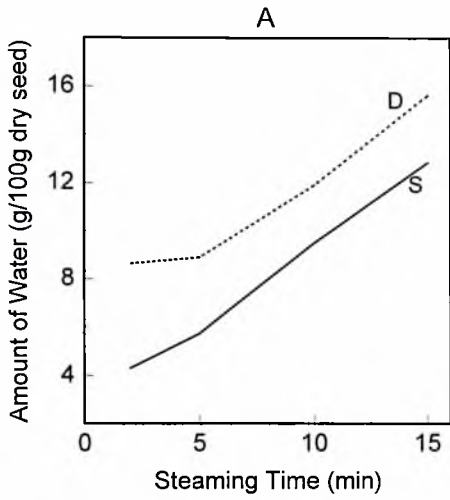
The development of the hard-to-cook defect in stored beans has been found to be highly correlated with the moisture content of the grains. Low storage moisture (< 10%), slows the development of the defect (Aguilera and Stanley, 1985) whilst storage at high moisture contents (>13%) actually favours the process (Aguilera and Ballivan, 1987; Uzogara and Ofuya, 1992).

In this study, all the samples were dried to moisture contents below 10%. This could have beneficial results both in terms of prevention of insect infestation and also for slowing the development of the hard-to-cook defect.

Figure 3 is a graphical representation of the amount of water added or removed during the steaming and drying processes. A examination of the amount of water absorbed by the seeds during steaming revealed differences depending on the steaming system and the cowpea variety being considered. For the asontem variety, all the samples steamed in the jacketed steam pan absorbed less water than those steamed in the steam exhaust box. It was however observed that the blackeye samples steamed for 2 and 5 min in the steam exhaust box absorbed less water as compared to those steamed for the same time in the jacketed steam pan. This trend changed as the steaming time was increased (i.e. 10 and 15 min), with the samples

Figure 3 Changes in the amount of water absorbed or removed during the steaming (S) or drying (D) of blackeye (A, B) and asontem (C, D)

A, C = Steam exhaust box
B, D = Jacketed steam pan



steamed in the steam box absorbing more water than the samples steamed in the jacketed steam pan. The difference in the amount of water absorbed after steaming could be due to differences in the design of the steaming systems. In the steam exhaust box system, metal trays were used, it is possible that the seeds absorbed moisture from the excess steam that had condensed in the trays in addition to that from the steam used in the process. However, in the steam jacketed pan system, the basket used was lined with a muslin cloth which could have absorbed any excess condensed steam. Molina *et al.* (1976) reported a favourable effect of heat treatment on the water absorption capacity of beans. It is therefore possible that there was a transfer of heat energy from the metal trays during the steaming process which could have improved the absorption of water by the seeds steamed in the steam exhaust box.

The differential between the two curves (amount of water absorbed and removed) was used as an indication of the ease of losing water from the steamed seeds during the drying process (Figure 3). This seemed to be influenced by the steaming method used. For all the samples steamed in the steam exhaust box, more water was lost in the samples steamed for the shorter times (2 and 5 min), whilst the samples steamed for a longer time did not lose as much water (Figure 3A, C). A completely different trend was observed in the samples steamed in the jacketed steam pan. In this case, there was not much change in the differential irrespective of the steaming time (Figure 3B, D). This implies that the samples steamed in the jacketed steam pan lost water more easily during the drying process as compared to those steamed in the steam exhaust box. This could be due to differences in the effect of the

steaming method on the structure of the seeds. Since it appeared to be more difficult for the samples steamed in the steam box to lose water, it suggests that these seeds became less porous as the steaming time increased and therefore the free movement of water was inhibited. In addition, the moisture content after steaming was lower for most of the samples steamed in the jacketed pan as compared to the samples steamed in the steam exhaust box. Therefore, since all the samples were dried for the same length of time, the initial lower moisture content of the samples steamed in the jacketed steam pan could have accounted for their lower final moisture content, since there was less water to be removed.

4.1.2 Germinating Capacity

The average length of germinated shoots was 6.66 cm and 5.42 cm respectively for unsteamed blackeye and asontem. Steaming had a negative effect on the germinating capacity, such that none of the seeds, for both varieties, retained its viability after the steaming process. A similar loss of viability following steam treatment was recorded by Osei (1993), Sefa-Dedeh and Saalia (1997) and Egyir-Yawson (1999).

Molina *et al.* (1976) investigating the possibility of using heat treatments to control the hard-to-cook defect in black beans, found that germinating capacity decreased as thermal treatment increased. They further indicated that viability was totally lost only in seeds exposed to steam (without pressure; 98°C) for 30 min. It was concluded from their study, that the heat treatment had a progressive inactivating effect on the enzymatic or enzyme-chemical pathways of the grain as measured

through the germinating capacity. Aguilera and Ballivan (1987) monitoring the effect of dry heat on black beans also found that a high viability was retained up to 80°C whilst roasting beyond 89.5°C resulted in a complete loss of germinating capacity.

The total loss of germinating capacity in this study could therefore be attributed to the high temperature used in the treatment which resulted in the complete inactivation of the enzymatic system of the cowpea seeds. The loss of viability observed in this study implies that seeds meant for later planting can not be treated hydrothermally and would have to be preserved through other means.

4.1.3 **Water Absorption Capacity**

The water absorption characteristics of the cowpea seeds was determined over a soaking period ranging between 1 and 24 hours. The trend obtained for all the samples was similar to those reported for other Ghanaian cowpea varieties (Sefa-Dedeh *et al.*, 1978; Saalia, 1995) and also for kidney beans (Moscoso *et al.*, 1984). There was a rapid rate of water absorption during the initial soaking times (i.e. first six hours), after which the rate slowed down as the saturation point was reached (Figures 4 and 5). Previous reports (Jackson and Varriano-Marston, 1981; Phillips *et al.*, 1988; Plhak *et al.*, 1989) have shown that water absorption capacity may be influenced by the amount of solids leached during the soaking period. In this study, however, similar results were obtained after correcting for lost solids to obtain the true water absorption capacity. This implies that the water absorption pattern was not dependent on the amount of solids leached during the soaking, explaining the very low correlation observed between water absorption and leached solids ($r = 0.1124$ and 0.2139 respectively for blackeye and asontem).



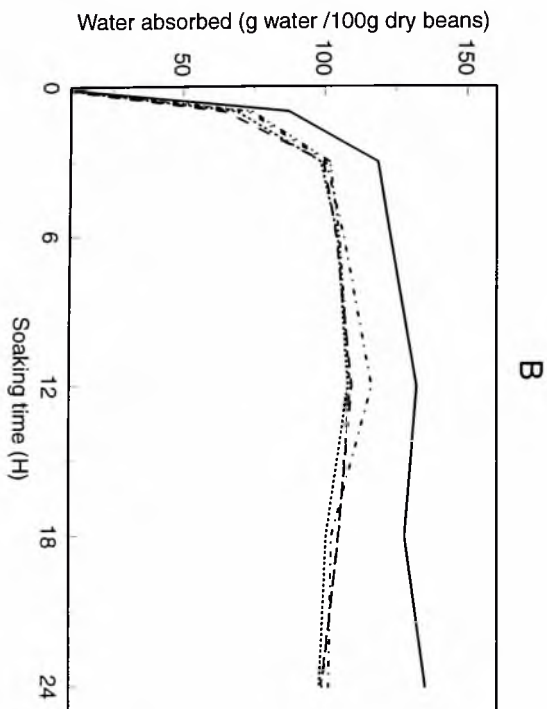
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Figure 4 Effect of steam treatment on water absorption characteristics of blackeye peas

A = Steam exhaust box;
B = Jacketed steam pan

—— unsteamed
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- - - - 5 min
- - - - 10 min
- - - - 15 min



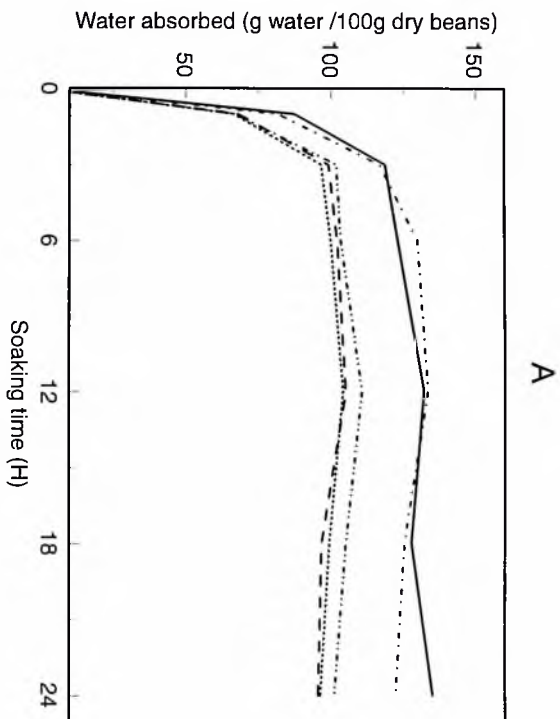


Figure 5 Effects of steam treatment on water absorption characteristics of asontem seeds

A = Steam exhaust box;
B = Jacketed steam pan

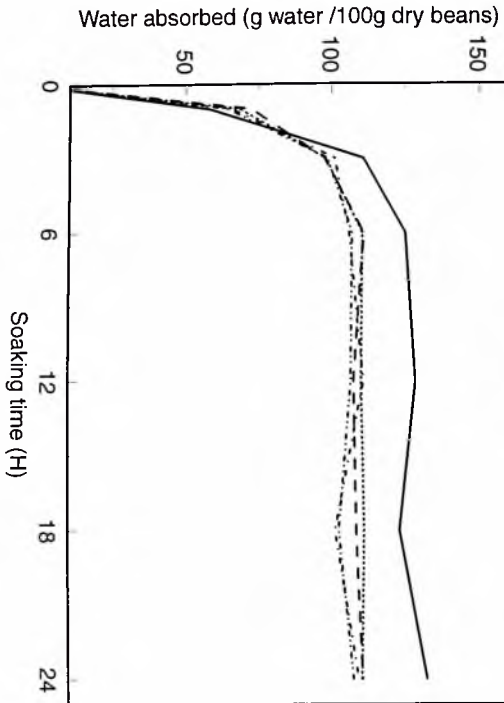
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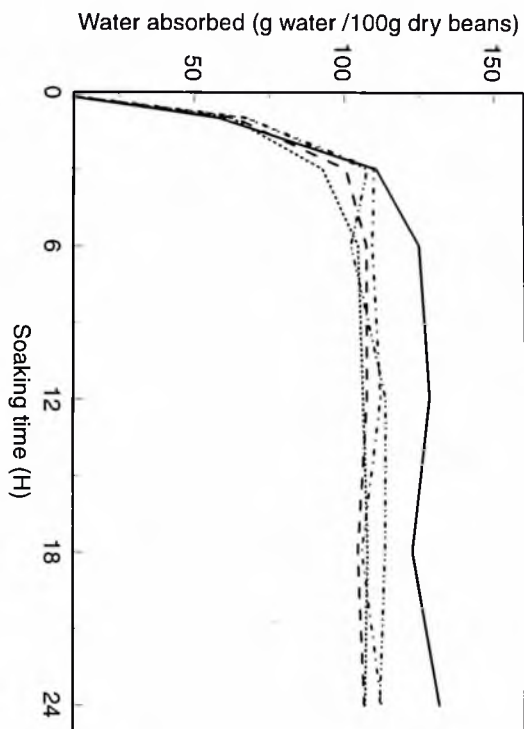
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Steaming appeared to have a reducing effect on the amount of water absorbed, since all the steamed seeds had lower water absorption values as compared to the unsteamed. This trend was observed in both sets of treated seeds. Contrary to other reports on seed (Molina *et al.*, 1976) and flour (Narayana and Narasinga-Rao, 1982; Abbey and Ibeh, 1988) water absorption capacity, where an increase in the index was observed in heated samples, the application of heat in this study did not increase the water absorption capacity. However, a similar decrease in seed water absorption was reported by Sefa-Dedeh and Demuyakor (1994) and Saalia (1995). Sefa-Dedeh and Demuyakor (1994) suggested differences in the mechanism for seed water absorption and that of flours, since in the seed, the seed coat and hilum all play an important role. The reduction could have resulted from the case hardening effect that the hydrothermal treatment is thought to produce in the seed which aids in the prevention of insect damage (Osei, 1993). This was further proved by results from scanning electron microscope studies on steam treated seeds by Saalia (1995), which showed a fusion of cotyledon cells following steaming. These fused cells act as a barrier to water uptake by the seeds.

Analysis of variance showed that steaming and soaking times had significant effects on the water absorption capacity of the seeds. However, the effect of the cowpea variety and the steaming method on the water absorption capacity were insignificant (Table 5). Further analysis of the effect of steaming time on water absorption, using multiple range tests revealed that the water absorption capacity of the unsteamed seeds was significantly different from that of all the steamed seeds. In addition, the

water absorption of seeds steamed for 2 min was also distinctly different from that of the seeds steamed for 5, 10 and 15 min. Multiple range analysis on the effect of soaking time also showed that the water absorption capacity of samples soaked for 1 hour was significantly different from the water absorption recorded for seeds soaked for 3 hours or longer. This seems to suggest that any differences in the rate of water absorption that might have existed between the samples were overcome as the soaking time increase beyond the first hour. It was further observed that soaking for 6, 12, 18 and 24 hours resulted in comparable water absorption capacities. It is possible that during this period (6-24 hours), the absorbing components of the seeds were becoming saturated and there was therefore not much change in their absorption capacity.

Table 5 : Anova summary table for water absorption capacity of steamed cowpeas

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	35052.114	11	3186.5559	73.958*
STEAMING TIME	6448.738	4	1612.1846	37.418*
SOAKING TIME	28490.765	5	5698.1530	132.251*
STEAMING METHOD	63.293	1	63.2927	1.469
VARIETY	49.319	1	49.3185	1.145
RESIDUAL	4653.2922	108	43.086039	
TOTAL (CORR.)	39705.407	119		

* - significant at $p \leq 0.05$

The unsteamed blackeye seeds had higher water absorption values as compared to the unsteamed asontem seeds. This could be due to differences in the thickness of the seed coats, reported as 2.15×10^{-3} cm for blackeye and 7.626×10^{-3} cm for

asonem (Sefa-Dedeh *et al.*, 1979; Osei, 1993). Sefa-Dedeh *et al.* (1978) and also Desphande and Charyan (1986) found that the seed coat played a dominant role only after its initial resistance to water uptake was overcome. They all concluded that together with the seed coat, the hilum and micropyle form an integrated water absorption system. Thus the thinner blackeye seed coat offered less resistance to water uptake and therefore absorbed more water after the same soaking time.

Smith and Nash (1961) reported that the rate of hydration of beans increases with moisture content. Moscoso *et al.* (1984) also observed that the maximum water absorbed by kidney beans during soaking was affected by both the initial moisture content and storage temperature. They also reported a high positive correlation between the initial moisture content and water absorption. The steam treated seeds in this study were dried to very low moisture contents (less than 10%). It is therefore possible that the low moisture contents of these seeds could account for their lower water absorption capacity relative to the unsteamed.

4.1.4 Leached Solids

Water absorption patterns depend on whether or not lost solids was accounted for and also the method employed for surface drying of beans after soaking (Plhak *et al.*, 1989). Reports have also shown that water absorption data may be misleading if recorded as percentage of fresh weight without correcting for lost solids (Jackson and Varriano-Marston, 1981). Therefore the amount of solids leached during the soaking treatments was determined. The results are shown in Figures 6 and 7 for both varieties.



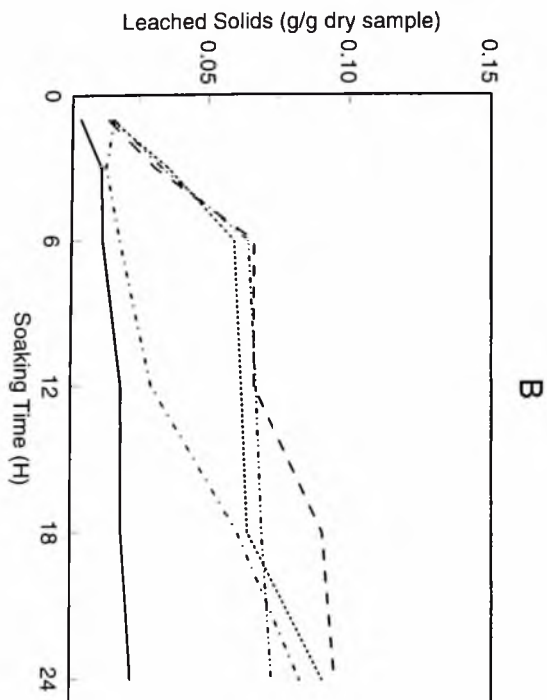
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Figure 6 Effect of steam treatment and soaking time on leached solids in blackeye peas

A = Steam exhaust box
B = Jacketed steam pan

—— unsteamed
- - - - 2 min
- - - - 5 min
- - - - 10 min
- - - - 15 min



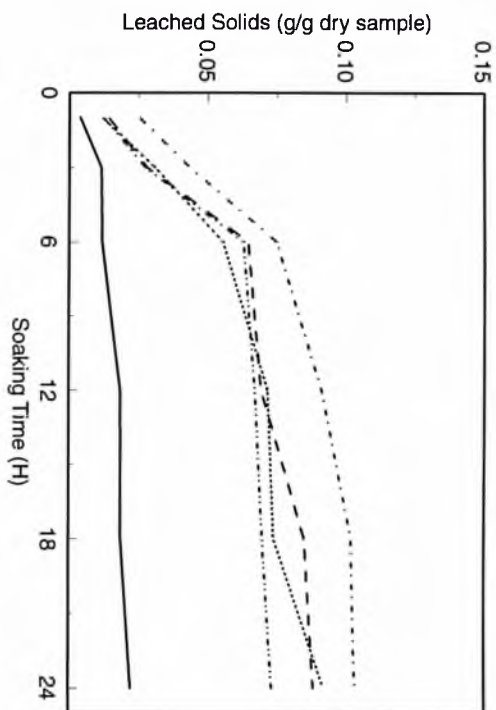
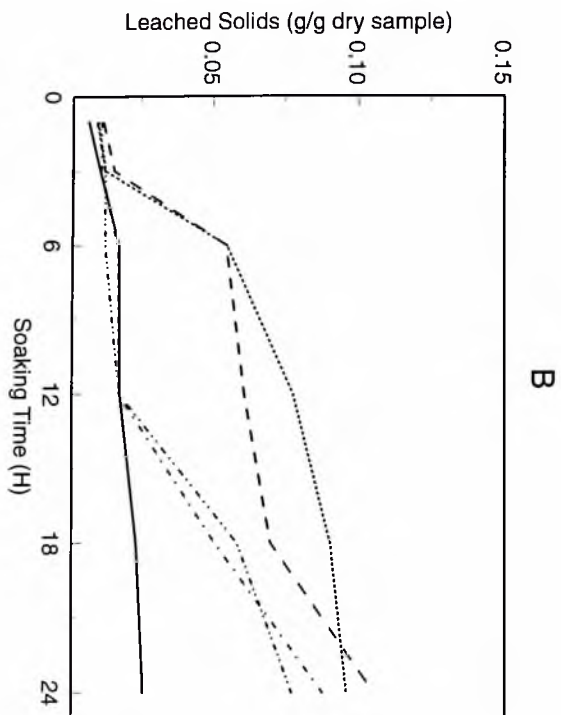
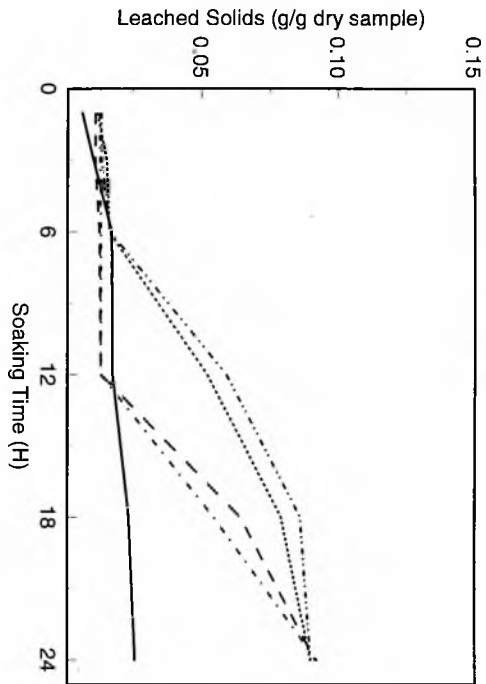


Figure 7 Effect of steam treatment and soaking time on leached solids in asontem seeds

A = Steam exhaust box
B = Jacketed steam pan

———— unsteamed
- - - - - 2 min
- - - - - 5 min
- - - - - 10 min
- - - - - 15 min





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A comparison of the steamed seeds for both varieties showed differences in the trend of leaching of solutes throughout the soaking period. For the blackeye samples, there was a sharp increase in the amount of solutes leached within the first 6 hours of soaking followed by a gradual increase up to a maximum after 24 hours soaking. The asontem samples showed a slightly different pattern. In these seeds, there was an initial lag in the leaching of solids during the first few hours of soaking (i.e. up to about 6 hours for most of the samples). Thereafter, the amount of solutes leached increased sharply reaching a peak after 24 hours soaking. These differences could be attributed to structural differences in the two varieties studied.

Comparatively, the seed coat of the asontem variety is thicker than that of the blackeye variety. Therefore the thicker seed coat in asontem could have acted as a barrier, preventing the immediate leaching of solutes. However as soaking progressed and the seed coat became hydrated, it lost its resistance and the solutes were able to leach out more freely.

Steaming appeared to increase the amount of solids leached at any soaking time and also more solutes were leached as soaking time increased. Statistical analysis of the data obtained for leached solids, showed significant differences between the two (2) cowpea varieties used. In addition, steaming and soaking times had significant effects on the amount of solids leached during the soaking period (Table 6). However, the steaming method used was insignificant. The effect of steaming time on the amount of solids leached was further analyzed with multiple range tests

(LSD). This showed that the amount of solid leached from the unsteamed seeds was significantly different from that recorded for any of the steamed seeds. All the steamed seeds however showed comparable leaching of solids. For the effect of soaking time, it was observed that even though the amount of solids leached during soaking for 1 and 3 hours were not significantly different, they were found to be distinctly different from the amount leached after soaking for 6, 12, 18 and 24 hours. There were also similarities between the amount of solids leached between 6 and 12 hours soaking and also between 18 and 24 hours.

Table 6 : ANOVA summary table for solids leached from soaked cowpeas

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	7.4483063	11	0.6771188	30.289*
STEAMING TIME	1.9327125	4	0.4831781	21.614*
SOAKING TIME	5.1973713	5	1.0394743	46.498*
VARIETY	0.3132430	1	0.3132430	14.012*
STEAMING METHOD	0.0049794	1	0.0049794	0.223
RESIDUAL	2.4143597	108	0.0223552	
TOTAL (CORR.)	9.8626660	119		

* - significant at $p \leq 0.05$

Proteins are the main water absorbing components in seeds although other seed constituents such as starch and cellulose also contribute to the overall absorption (Sefa-Dedeh, 1978). This seems to imply that an increase in leaching of these components would lead to less water absorbed. A similar relation between increasing leaching of solutes and reduced water absorption capacity has been reported for hard-to-cook beans (Shomer *et al.*, 1990). Even though results in this

study revealed that steaming increased the amount of solids leached, no correlation was observed between water absorption capacity and leached solutes. Therefore the reduced water absorption capacity of the steamed seeds relative to the unsteamed was probably due to other factors, such as the inability of the cotyledon cells to fully expand (Jones and Boulter, 1983).

4.1.5 Soaked Seed Hardness

The typical force-time deformation curves for the soaked seed hardness obtained using the Warner-Bratzler blade are shown in Figure 8. After 1 hour soaking, the unsteamed samples, for both blackeye and asontem, showed similar curves (Figure 8a, b). There was an initial sharp increase in cutting force up to a maximum as the whole seed was cut. The cutting force then dropped following the complete splitting of the seed. Soaking for 24 hours resulted in a different pattern for both unsteamed seeds. The curves showed 2 distinct peaks (Figure 8e, f). The first peak was the result of the force required to cut through both the seed coat and the first cotyledon. This dropped because of the reduced resistance of the space created by the inner curvature of the two cotyledons possibly due to leaching of solids. The second peak resulted from the cutting of the second cotyledon. This decrease in resistance was not observed after 1 hour possibly because of the higher amount of swelling of the seeds following imbibition of water and also because there was very little leaching of solids during this period. Sefa-Dedeh *et al.* (1978) reported similar results for the cowpea variety Adua Ayera, soaked for 1 hour. Hincks and Stanley (1986) studying the causes of black bean hardening also reported 2 distinct peaks for the raw bean and 24 hour soaked beans.

Figure 8 Typical force-time deformation curves for cowpea seeds

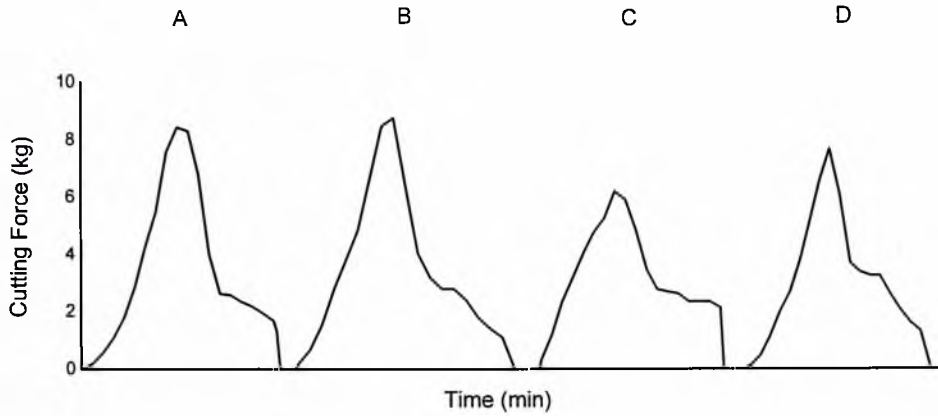
Soaked for 1 hour:

A - unsteamed blackeye; B - unsteamed asontem;
C - steamed blackeye; D - steamed asontem;

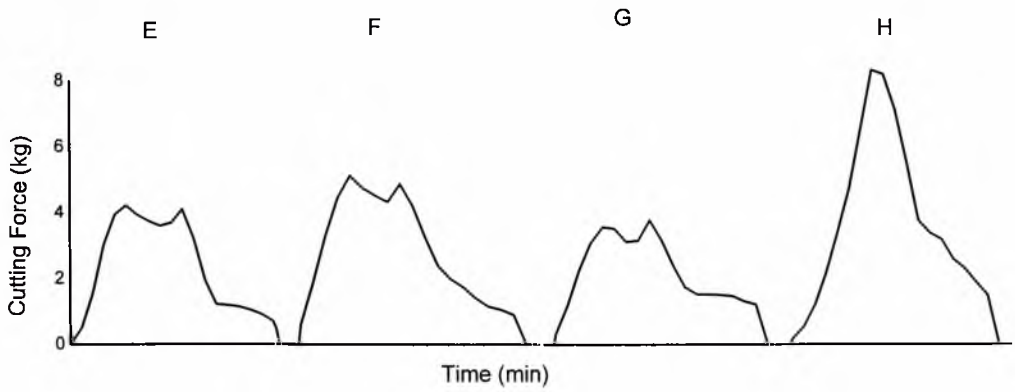
Soaked for 24 hours:

E - unsteamed blackeye; F - unsteamed asontem;
G - steamed blackeye; H - steamed asontem

Soaked for 1 hour



Soaked for 24 hours



The steamed blackeye seeds showed curves similar to those of the unsteamed blackeye seeds after soaking for 1 and 24 hours (Figure 8c, g). However, the decrease in resistance between the 2 peaks in the 24 hour soaked seeds was more pronounced in the steamed seeds possibly due to a greater degree of leaching of solids resulting in a more hollow seed. The force-deformation curve for the steamed asontem seeds however, showed only one peak for samples soaked for 1 and 24 hours (Figure 8d, h).

The changes in the amount of force required to cut through the seeds after soaking between 1 and 24 hours was determined using the Warner-Bratzler blade. The maximum cutting force required decreased with increasing soaking time (Figures 9 and 10). There was a sharp decrease in the maximum cutting force between 1 and 6 hours soaking for the unsteamed seeds. Thereafter, the decrease was gradual up to 12 hours soaking and then it leveled off for the blackeye samples. However, in the case of asontem, the peak force increased after 18 hours but then decreased again after 24 hours soaking. A slightly different trend was observed in the steamed seeds, where a general decrease in peak force with soaking time up to 12 hours followed by an increase in the peak force up to 24 hours soaking was recorded.

The variations in soaked seed hardness with soaking time can be explained based on the water absorption pattern. The highest amount of water was absorbed during the first six (6) hours for all the samples resulting in the sharp decrease in maximum cutting force. This was followed by a reduced rate of water absorption between 12

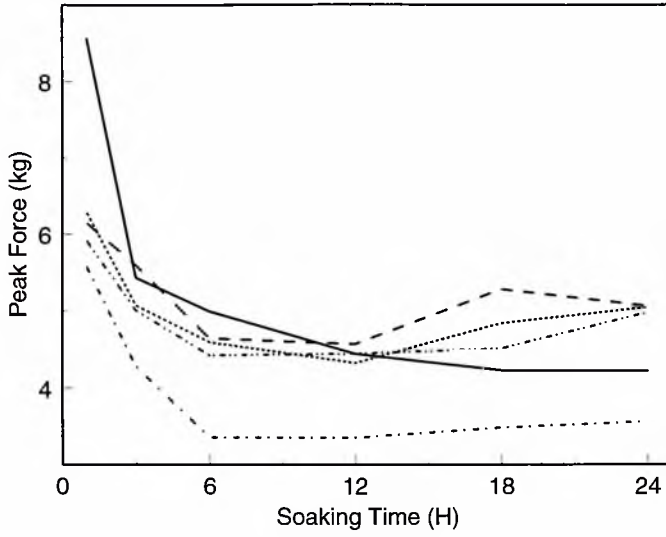
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Figure 9 Effect of steam treatment and soaking time on seed hardness of blackeye peas

A = Steam exhaust box
B = Jacketed steam pan

———— unsteamed
..... 2 min
- - - - 5 min
- - - - 10 min
..... 15 min

A



B

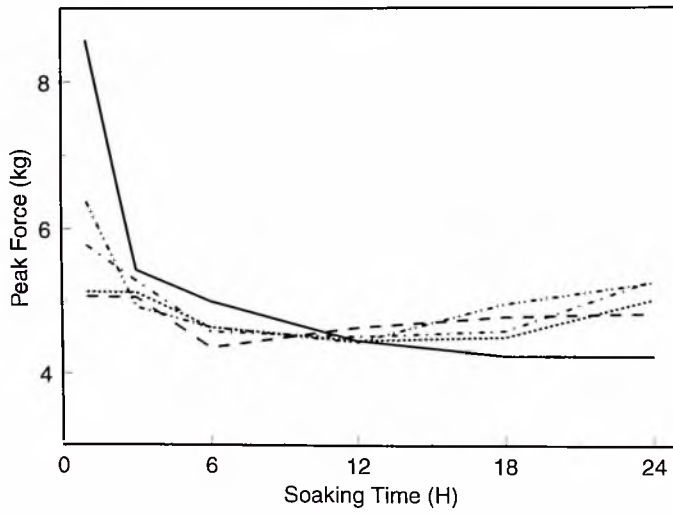






Figure 10 Effect of steam treatment and soaking time on seed hardness of asontem seeds

A = Steam exhaust box

B = Jacketed steam pan

———— unsteamed

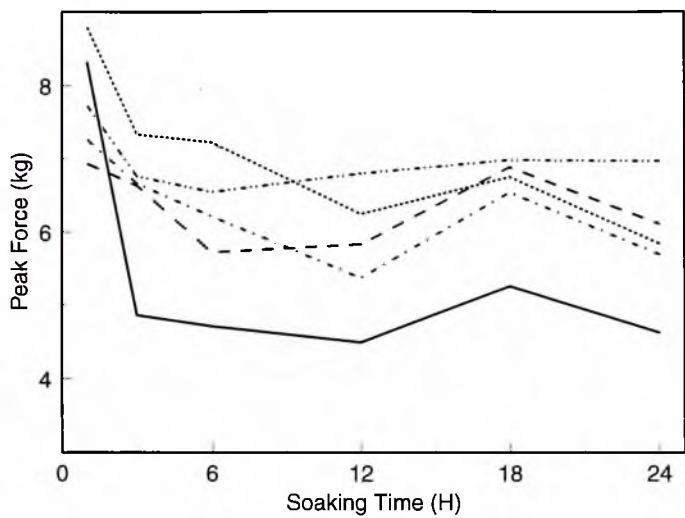
..... 2 min

..... 5 min

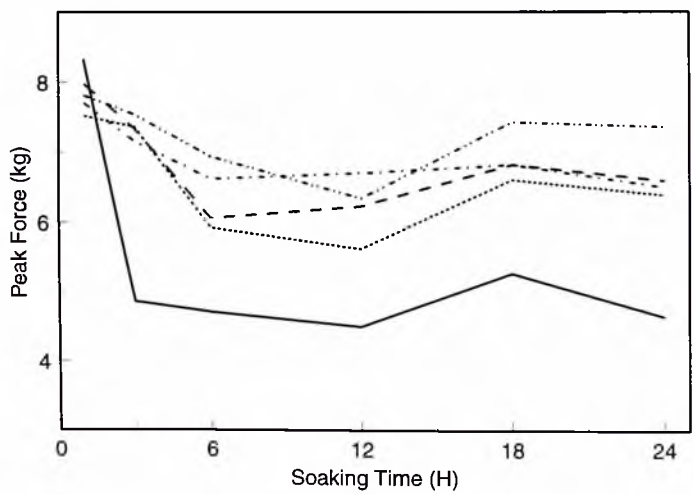
- - - - 10 min

..... 15 min

A



B



to 24 hours. Consequently, there was only a slight decrease in maximum cutting force, gradually attaining a constant value as the amount of water absorbed leveled off at the saturation point of the absorbing components.

The steam treatment caused an increase in soaked seed hardness. This effect was more noticeable in the asontem seeds which showed this increase at any soaking time. For the steamed blackeye samples, soaking for less than 12 hours resulted in less cutting force than the unsteamed. The trend was reversed after 12 hours, with the steamed seeds requiring more force. This was true for all the blackeye samples with the exception of the sample steamed for 2 min in the steam box which required less force than any of the other samples at any soaking time (Figure 9).

An examination of water absorption data showed that steaming resulted in a reduction of the amount of water absorbed as compared to the unsteamed seeds after any soaking time (Figures 5 and 6). There was a high negative correlation between soaked seed hardness and water absorption with correlation coefficients of -0.9883 and -0.9898 respectively for the unsteamed blackeye and asontem. Slightly lower correlation coefficients were obtained for the steamed seeds (Table 7). Other workers (Sefa-Dedeh *et al.*, 1978; Sefa-Dedeh and Stanley, 1979; Hincks and Stanley, 1986) also observed this high correlation between soaked seed hardness and water absorption. The negative correlation between the soaked seed hardness and water absorbed indicates a decrease in soaked seed hardness as the amount of water absorbed increases and the seed softens. This correlation could account for



the increase in soaked seed hardness following steaming. Since the steamed seed absorbed less water, it is to be expected that they would require a higher cutting force. The steam process is thought to result in a case hardening effect further emphasizing the recorded increase in soaked seed hardness of the steamed seeds.

Table 7: Correlation coefficients for soaked seed hardness and water absorption capacity

STEAMING TIME (min)	STEAMING SYSTEM	CORRELATION COEFFICIENT	
		Blackeye	Asontem
0	Unsteamed	-0.9883	-0.9898
2	Steam box	-0.9535	-0.4231
5	Steam box	-0.9424	-0.9174
10	Steam box	-0.7358	-0.6826
15	Steam box	-0.9607	-0.8862
2	Jacketed pan	-0.8498	-0.7875
5	Jacketed pan	-0.9858	-0.6941
10	Jacketed pan	-0.5765	-0.8913
15	Jacketed pan	-0.6589	-0.5573

The reported relationship between soaked seed hardness and amount of water absorbed was not clearly seen in the blackeye samples soaked for less than 12 hours. This is because the steamed samples which had generally absorbed less water than the unsteamed, showed lower maximum cutting forces. A consumer evaluation of the hardness of steamed seeds following soaking revealed similar results (Sefa-Dedeh and Saalia, 1997). The respondents reported that the soaked steamed seeds were softer to touch than the unsteamed, even though the latter had absorbed more water and had a higher swelling capacity. The presence of an excess of water at the seed coat/cotyledon interface was also reported for the

steamed seeds. Scanning electron microscope examination of steamed seeds by Sefa-Dedeh *et al.* (1995) and also Saalia (1995) showed a fusion of cotyledon cells following steaming. This fusion of the cells could account for the inability of the absorbed water to fully penetrate into the cotyledon, resulting in the entrapment between the seed coat and the cotyledon. However this resistance was overcome as the soaking time increased.

Analysis of variance on the data showed that steaming and soaking times had significant effects on the soaked seed hardness (Table 8). The cowpea variety used also significantly affected the soaked seed hardness. The steaming method was however, not significant. Multiple range analysis of the effect of steaming time on the soaked seed hardness revealed that there were significant differences between the soaked seed hardness of the unsteamed seeds and the hardness of the steamed seeds. However, the steamed seeds showed comparable soaked seed hardness. Multiple range analyzes also showed that the hardness of the one hour soaked seeds was distinctly different from the hardness of the seeds soaked for three (3) hours or longer. Whilst the seeds soaked for between 3 and 24 hours showed similar hardness.

Sefa-Dedeh *et al.* (1978) observed that the maximum force required to cut through soaked cowpea seeds decreased in three (3) distinct phases depending on the rate of water absorption. The first phase is characterized by a slow rate of water absorption and therefore the maximum cutting force depends on the initial moisture



content of the bean and also the seed coat thickness. This is followed by a second phase where water is absorbed more rapidly and consequently maximum force decreases sharply. During the third and last phase, the rate of water absorption again slows down as the absorbing components reach their saturation point and therefore there is only a slight change in maximum force.

Table 8: Anova summary table for hardness of soaked cowpeas

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	128540000	11	11685679	22.095*
STEAMING TIME	7281800	4	1820448	3.442*
SOAKING TIME	47711000	5	9542278	18.042*
STEAMING METHOD	682550	1	682551	1.291
VARIETY	72867000	1	72866732	137.775*
RESIDUAL	57119410	108	528883.43	
TOTAL (CORR.)	185660000	119		

* - significant at $p \leq 0.05$

Only two of these three phases, i.e. the second and third phases, was observed for the cowpea samples used in this study irrespective of the steaming treatment used. Sefa-Dedeh (1978) studying the soaked seed hardness of 8 varieties of cowpeas found that 7 of the varieties showed a similar pattern. This is because most cowpea varieties are known to absorb water very rapidly during the initial soaking period and therefore only the second and third phases are observed (Sefa-Dedeh *et al.* 1978).

Sefa-Dedeh (1978) also indicated that the first 6 hours of soaking appeared to be the most critical since a greater degree of seed softening occurred during this period. All the samples showed this trend, such that there was a relatively higher decrease

in maximum force between 1 and 6 hours soaking than between 6 and 12 hours. For example, the unsteamed blackeye seeds required 8.56 kg of force after 1 hour soaking, 4.99 kg after 6 hours and 4.45 kg after 12 hours. For the asontem sample steamed for 5 min in the jacketed pan, the peak forces were 7.81, 6.94 and 6.34 respectively for 1, 6 and 12 hours soaking.

The area under the force-time deformation curve measures the amount of work done by the instrument during the determination of the seed hardness (Bourne *et al.*, 1966). This gives an indication of the amount of energy required for the determination of hardness of the soaked seed. Figure 11 is a graphical representation of typical data obtained for the amount of energy required during the determination of the soaked seed hardness. Generally, higher values were observed for all steamed samples as compared to the unsteamed, with the exception of the blackeye seeds steamed for 2 min in the steam box which had lower values. This was to be expected since, this sample required less cutting force than the other samples after any soaking time.

The amount of energy required during the texture analyses of the soaked unsteamed seeds decreased with soaking time up to 12 hours for asontem and 18 hours for blackeye. Thereafter an increase in the energy required was recorded after 24 hours of soaking. For the steamed samples, the amount of energy required during the test decreased with soaking time up to 12 hours and then increased with further soaking. The changes in the energy required reflected the changes in the peak force recorded

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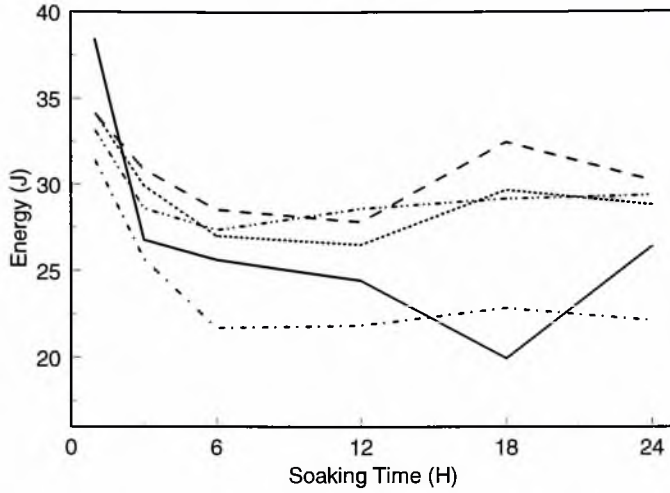
Figure 11 Effect of steam treatment and soaking time on the energy required during the determination of the hardness of soaked cowpeas

A = Blackeye
B = Asontem

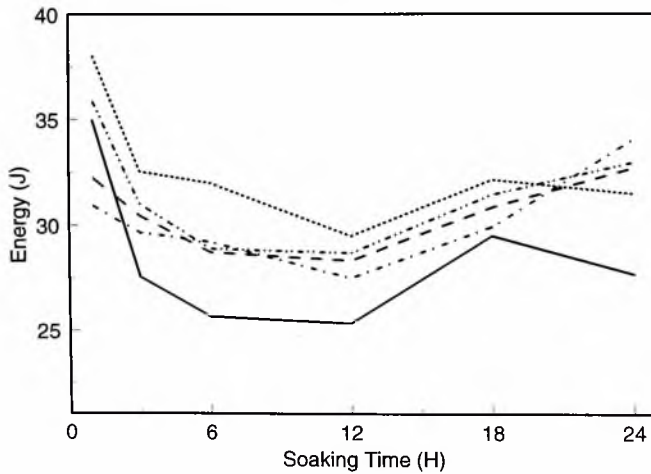
———— unsteamed
- - - - - 2 min
- - - - - 5 min
- - - - - 10 min
- - - - - 15 min



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B





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for the soaked seed hardness. This was further emphasized by a high correlation between the peak force for soaked seed hardness and the energy required during the test, correlation coefficients were 0.9287 and 0.9449 respectively for the unsteamed blackeye and asontem. In comparing data for the energy required and the soaked seed hardness for the blackeye samples, it was observed that more energy was required during the cutting of the steamed seeds as compared to values for the unsteamed. This implies that even though the peak forces recorded for the steamed seeds were in some cases lower than that of the unsteamed (blackeye samples), in general more energy was required during the test for the steamed seeds.

4.1.6 Least Gelation Capacity

The least concentration end point test which identifies the lowest concentration of sample which would form a gel following heating (Angel and Weinberg, 1981) was used in this study. This involved selecting the lowest concentration at which the heated flour suspension did not flow out of an inverted test tube. The least gelation concentrations of the cowpea flours are shown in Table 9. The concentrations required were 16 and 20% respectively for the unsteamed blackeye and asontem. In general, the concentration of flour required to form a stable gel increased as steaming time increased.

Analysis of variance of the data showed that only steaming time had a significant effect ($p \leq 0.05$) on the gelation capacity of the 2 samples, variety and steaming method were not significant (Table 10). Multiple range tests of the effect of steaming



time showed that the unsteamed samples were comparable only to the 2 min steamed seeds. There were however, no significant differences between samples steamed for 5 min or longer for both varieties.

Table 9: Gelation capacity of steamed and unsteamed cowpea flours

Steaming Time (min)	Steaming System	Concentration (%)	
		Blackeye	Asontem
0	Unsteamed	16	20
2	Steam box	18	24
5	Steam box	26	26
10	Steam box	30	26
15	Steam box	>30	26
2	Jacketed pan	20	24
5	Jacketed pan	26	24
10	Jacketed pan	30	24
15	Jacketed pan	>30	24

Table 10: Anova summary table for least gelation capacity of cowpea flours

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	277.6000	6	46.266667	6.112*
STEAMING TIME	276.000	4	69.0000	9.116*
STEAMING METHOD	0.8000	1	0.8000	0.160
VARIETY	0.8000	1	0.8000	0.106
RESIDUAL	98.4000	13	7.5692308	
TOTAL (CORR.)	376.000	19		

* - significant, $p \leq 0.05$

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Heat treatments have been reported to cause an increase in the least gelation concentration of cowpeas similar to what was observed in this study. Abbey and Ibeh (1988) working with raw and heat processed cowpea flour also recorded a higher concentration for the heated flour, i.e. 16% for the raw flour and 18% for the heat processed flour. Prinyawiwatkul *et al.* (1996) also recorded a higher concentration for a sample of heated cowpea flour.

Gelation is not only a function of protein quantity but it seems to be related to the type of protein as well as the non-protein components. Thus the higher values obtained for the cowpea flour used in this study as compared to the concentrations reported for other legumes, e.g. 10% for Great Northern bean and mung bean protein isolate, could be attributed to differences in varietal composition and also to the fact that whole flour was used in this study. This is supported by Sathe *et al.* (1982) who found that the seed coat fractions of winged beans interfered with the formation of the continuous network of molecules and therefore a higher concentration of whole flour was required to form gels.

Although the relative proportions of the different constituents (proteins, carbohydrates and lipids) appear to influence the gelling properties of legumes (Sathe *et al.*, 1982), protein concentration appears to be the most important factor affecting gel formation (Prinyawiwatkul *et al.* 1997). This is because below a certain minimum concentration, aggregation and increased viscosity of the cowpea flour suspension was observed, however gelation did not occur (Prinyawiwatkul *et al.*

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1997). Based on viscoamylogram data, Prinyawiwatkul *et al.* (1996) suggested that the ability of pre-heated flours to form a viscous paste and therefore form a gel on cooling was more a result of protein gelation and not merely due to starch gelatinisation. This implies that if denaturation of proteins and starch gelatinisation had occurred, higher amounts of this flour would be required for thermal gel formation as compared to the raw flour (Prinyawiwatkul *et al.* 1997).

4.1.7 Protein Solubility

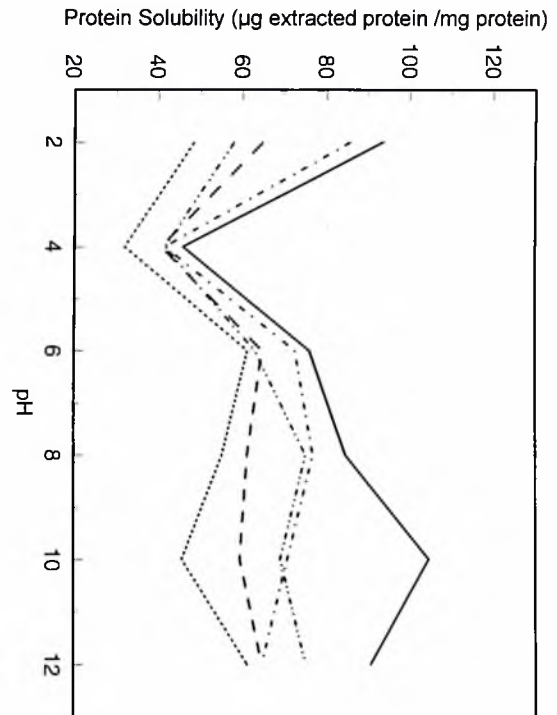
Protein solubility was determined over a pH range of 2-12. The least solubility was observed at pH 4 (the iso-electric point) for all the samples, whilst protein solubility increased on either side of the isoelectric point (Figures 12 and 13). The extracted proteins of the unsteamed samples for both varieties were the most soluble at any pH, implying that the steaming process had caused a reduction in protein solubility. This reduction appeared to increase with steaming time.

Protein solubility was significantly affected by cowpea variety, steaming time and the pH at which the determination was carried out (Table 11). Protein solubility values obtained from the 2 varieties were significantly different with the asontem samples recording higher protein solubilities. This could be due to the fact that asontem has a slightly higher protein content (24.1%) than blackeye (23.4%). Further analyzes of the effect of steaming time on protein solubility using multiple range analyzes revealed that the protein solubility of the unsteamed samples were significantly different from that of the steamed samples.

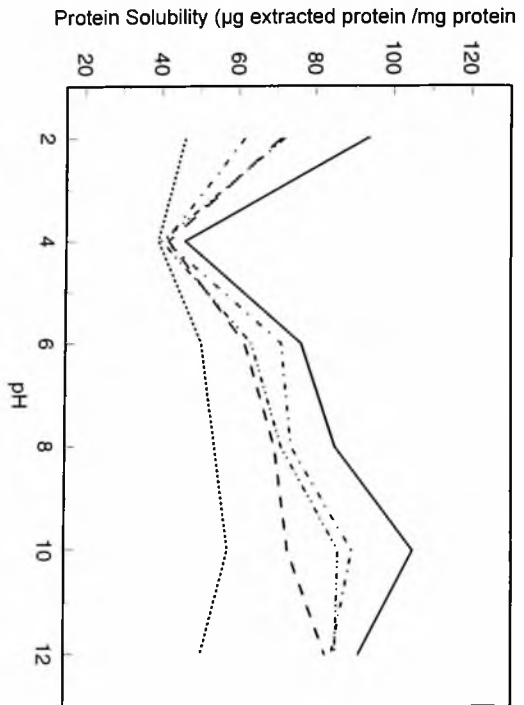
Figure 12 Effect of steam treatment on protein solubility of blackeye peas

A = Steam exhaust box
B = Jacketed steam pan

———— unsteamed
- - - - - 2 min
- - - - - 5 min
- - - - - 10 min
- - - - - 15 min



A



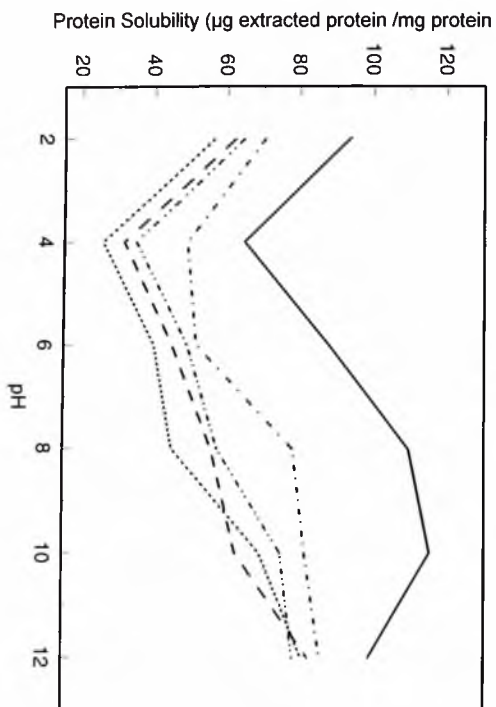
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Figure 13 Effect of steam treatment on protein solubility of asontem

A = Steam exhaust box
B = Jacketed steam pan

———— unsteamed
- - - - - 2 min
- - - - - 5 min
- - - - - 10 min
- - - - - 15 min

**B**

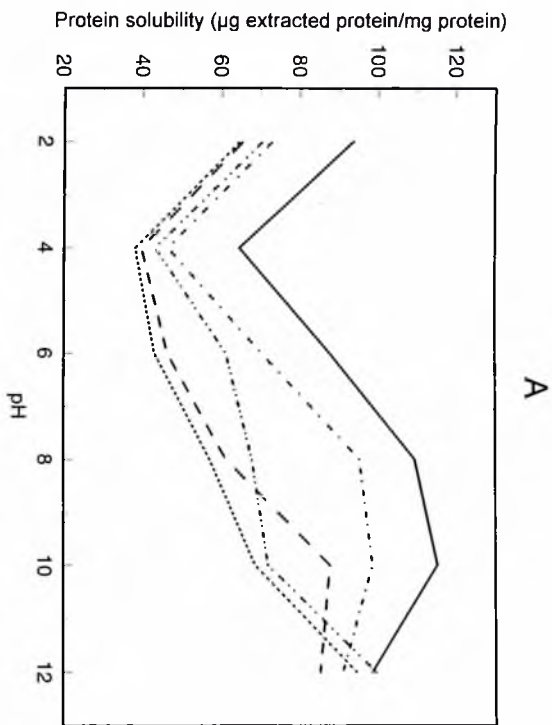


Table 11: Anova summary table for protein solubility of cowpea seeds

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	223321.53	11	20301.958	43.580*
STEAMING TIME	94878.47	4	23719.617	50.917*
pH	119753.87	5	23950.773	51.413*
VARIETY	7680.00	1	7860.000	16.486*
STEAMING METHOD	1009.20	1	1009.200	2.166
RESIDUAL	50311.933	108	465.85123	
TOTAL (CORR.)	273633.47	119		

* - significant at $p \leq 0.05$

Solubility is probably the most important of the functional properties of proteins since it affects other properties including foaming, emulsification and gelation (Kinsella, 1976). The solubility profile obtained for the samples are typical of those reported for other cowpea varieties (Abbey and Ibeh, 1988; Giami, 1993; Prinyawiwatkul *et al.*, 1997). Cowpea proteins are generally more soluble at alkaline pH than at acidic pH. A general increase in solubility was thus observed as the pH increased beyond the iso-electric point (pH 4).

The application of heat results in a marked and an irreversible reduction of protein solubility, which has been attributed to the exposure of hydrophobic groups and to the aggregation of the unfolded protein molecule (Cheftel *et al.*, 1985). The steaming process resulted in a reduction in the solubility of all samples indicating that some amount of protein denaturation had occurred. A similar decrease in protein solubility of heated cowpea flours has been reported by other workers (Enwere and Ngoddy, 1986; Abbey and Ibeh, 1988; Prinyawiwatkul *et al.* 1997). Protein

denaturation has been associated with changes in functionality including increased water absorption capacity. In this study, even though proteins were denatured (as indicated by reduced solubility), the expected increase in water absorption capacity was not observed after the steam treatment, there was instead a decrease in water absorption capacity. Phillips *et al.* (1988) also found no relationship between protein solubility and the water imbibition capacity of heated cowpea meal. They reported that protein solubility remained constant whilst water absorption capacity increased and then dropped as heating temperature increased. It is possible that an increased hydrophobicity of the proteins resulting from denaturation caused the reduced water absorption capacity (Kato and Nakai, 1980).

4.1.8 **Trypsin Inhibitor Activity**

The presence of naturally occurring protease inhibitors in cowpeas limits the efficient utilisation of cowpea proteins. This inhibitory activity is more associated with trypsin than with chymotrypsin (Kochhar *et al.*, 1988). The effect of steam treatment on trypsin inhibitor activity in blackeye and asontem seeds are shown in Table 12. In both varieties increasing steaming time resulted in a decrease in inhibitor activity. In most cases complete inactivation of the inhibitor was achieved after 10 min steaming. A comparison of data showed different effects of the steaming method on the degree of inactivation achieved. In the jacketed pan system, complete inactivation was attained after 5 min steaming whilst the same effect was obtained after 10 min in the steam exhaust box system.

Table 12: Effect of steam treatment on trypsin inhibitor activity of cowpeas

Steaming System	Steaming Time	Blackeye		Asontem	
		TIU ¹ /mg sample (x 10 ⁻³)	Inactivation of Inhibitor (%)	TIU/mg sample (x 10 ⁻³)	Inactivation of Inhibitor (%)
Unsteamed	0	19.85	-	20	-
Steam Exhaust Box	2	19.8	0	19.84	0
	5	17.84	10.08	18.35	10.08
	10	**	100	**	100
	15	**	100	**	100
Steam Jacketed Pan	2	7.34	63	20	0
	5	**	100	**	100
	10	**	100	**	100
	15	**	100	**	100

1 - trypsin inhibitor units; ** - No inhibitor activity

Trypsin inhibitors like most anti-nutritional factors are heat labile (Bressani and Elias, 1974). It has also been reported that the effect of heat on trypsin inhibitors is a function of temperature, time duration, particle size of sample, and moisture content (Liener, 1972). Varying degrees of inactivation of trypsin inhibitors has been achieved depending on the type of legume and processing method used. Collins and Beaty (1980) reported a 96.1% inactivation of trypsin inhibitors in fresh green soybeans after boiling over water for 9 min. Whilst Liu and Markakis (1987) observed that trypsin inhibitors were completely destroyed in mature soybeans only in seeds soaked prior to cooking.

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Different concentrations of cowpea trypsin inhibitor activities have been reported in literature. Elkowicz and Sosulski (1982) reported a trypsin inhibitor activity of 12.20 TUI/mg sample for cowpea flour whilst Ogun *et al.* (1989) reported a trypsin inhibitor range of 15.3-30.6 TIU/mg sample. Lower values were obtained in this study. However cultivar differences have been reported to cause variability in the level of trypsin inhibitor activity in cowpeas (Kochhar *et al.*, 1988). The variation could also have been due to differences in the extraction and assay methods.

The inactivating effect of the steam treatment on trypsin inhibitors is of significance since it would lead to an enhancement of the nutritional value of the beans.

Analysis of variance showed that both steaming method and steaming time significantly affected the inactivation of trypsin inhibitors in the two varieties of cowpeas (Table 13). In comparison, it can be seen that the steam jacketed pan was more efficient in inactivating the enzymes since complete inactivation occurred after a shorter time in this system. Similar trends were obtained in both varieties, i.e. variety did not have a significant effect on the rate of inhibitor inactivation. Multiple range tests further showed that the trypsin inhibitor activity of samples steamed for 5 min or longer was significantly different from the inhibitor activity in the 2 min steamed samples and also in the unsteamed samples. In addition, comparable trypsin inhibitor activities were observed in the unsteamed and the 2 min steamed samples.



DATE 1/10/1999

Table 13 : Anova summary table for trypsin inhibitor activity of steamed cowpeas

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	1491.9341	6	248.65569	10.139*
STEAMING TIME	1365.1391	4	341.28477	13.916*
STEAMING METHOD	117.7095	1	117.70952	4.800*
VARIETY	9.0855	1	9.08552	0.370
RESIDUAL	318.81036	13	24.523874	
TOTAL (CORR.)	1810.7445	19		

* - significant at $p \leq 0.05$

4.2 EFFECT OF STEAMING AND STORAGE ON COOKED BEAN HARDNESS

The quality and acceptability of foods are to a large extent influenced by their textural properties. Changes in textural characteristics (hardness) of cooked cowpeas after steaming was monitored over a 6 month storage period. The effect of storage was varied and depended on the duration of the steam treatment, the steaming system used and also the storage temperature. Cooking decreased the peak force for all the samples. The steam treatment appeared to increase the force required to cut through the cooked seeds such that even after 3 hours cooking all the steamed seeds required more force compared to the unsteamed cooked for only 30 min. This could have serious implications for the final utilisation of the hydrothermally treated seeds. This is especially important for cowpea dishes that involve the boiling of the whole seed since the increased hardness means longer cooking times and therefore increased fuel consumption and also loss of nutrients.

Two types of forces, compression and cutting, were used to determine the changes in cooked bean hardness.

4.2.1 Kramer Shear Test

The amount of force required to compress and shear the cooked beans was determined using the Kramer shear cell and the peak forces recorded. A lower peak force value is an indication of softness (Tinney *et al.*, 1995). Cooking reduced the peak force required to compress and shear the cowpea seeds indicating that the seeds were becoming softer with increasing cooking time (Tables 14 and 15).

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Table 14: Cooked blackeye pea hardness (peak force/kg) as determined in the Kramer shear test cell

Sample	Storage Time (month)	Storage Temp (°C)	Cooking Time (min)				
			60	90	120	150	180
Unsteamed	0	-	22.148	21.579	16.895	15.476	14.924
Unsteamed	1	28	19.300	16.182	13.697	13.082	12.751
10 min steam box	1	28	**	24.446	22.144	20.529	18.979
Unsteamed	1	6	22.395	20.068	18.461	16.000	14.361
2min jacketed pan	1	6	**	**	**	24.814	22.754

** - overload, peak force > 25 kg

Table 15: Cooked asontem hardness (peak force/kg) as determined in the Kramer shear test cell

Sample	Storage Time (month)	Storage Temp (°C)	Cooking Time (min)				
			60	90	120	150	180
Unsteamed	0	-	22.858	18.353	15.321	14.813	14.559
10 min steam box	0	-	**	**	**	25.046	24.481
15 min steam box	0	-	**	**	**	25.180	22.140
Unsteamed	1	28	24.937	23.056	20.419	18.499	17.477
2 min steam box	1	28	**	**	**	25.414	24.120
5 min steam box	1	28	**	**	**	24.599	22.794
10 min steam box	1	28	**	24.977	23.791	22.492	19.224
10 min jacketed pan	1	28	**	**	23.213	22.661	20.456
2 min jacketed pan	1	28	**	**	**	25.420	24.369
15 min jacketed pan	1	28	**	**	**	24.656	24.385
Unsteamed	1	6	22.795	20.687	18.953	18.250	16.927
10 min jacketed pan	1	6	**	**	**	24.146	23.499
15 min jacketed pan	1	6	**	**	25.273	22.878	21.156

** - overload, peak force > 25 kg

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However, for most of the steamed samples, the forces developed in the Kramer shear cell exceeded the load cell capacity of 25 kg, and therefore results were not obtained for all samples. These samples requiring more than 25 kg force are listed in Table 16. The results indicated that the steam treatment caused an increase in the cooked bean hardness. This was evidenced by the fact that before storage, 60 min cooking was sufficient to allow the unsteamed blackeye seeds to achieve a degree of tenderness corresponding to a peak force of 22 kg whilst all the steamed blackeye seeds required more than 25 kg force even after cooking for 3 hours (Table 16).

Storage of the cowpeas for 1 month at either 28°C or 6°C did not have any significant effect on the cooked bean hardness of steamed blackeye samples. This is because most of the steamed seeds still required compressive forces greater than 25 kg (Table 16). The steamed asontem samples showed a slightly different trend with storage. Samples stored at 28°C for 1 month appeared to have undergone some amount of softening such that after 3 hours cooking the force required ranged between 19 and 24 kg as compared to between 22 and 25 kg before storage. Cold room storage (6°C) did not have a similar effect, in this case only the samples steamed for 10 and 15 min in the jacketed steam pan, recorded peak forces less than 25 kg after cooking for about 2½ hours.

According to Aguilera and Stanley (1985), brief heat treatments produced an immediate increase in hardness which may be either a consequence of thermal

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Table 16: Steamed cowpea samples which recorded peak forces greater than 25 kg in the Kramer shear test cell

Before Storage		After 1 month storage at room temperature		After 1 month storage at cold room temperature	
Blackeye	Asontem	Blackeye	Asontem	Blackeye	Asontem
2 min steam box	2 min steam box	2 min steam box	15 min steam box	2 min steam box	2 min steam box
5 min steam box	5 min steam box	5 min steam box	5 min Jacketed pan	5 min steam box	5 min steam box
10 min steam box	2 min jacketed pan	15 min steam box		10 min steam box	10 min steam box
15 min steam box	5 min jacketed pan	2 min jacketed pan		15 min steam box	15 min steam box
2 min jacketed pan	10 min Jacketed pan	5 min jacketed pan		5 min jacketed pan	2 min jacketed pan
5 min jacketed pan	15 min Jacketed pan	10 min Jacketed pan		10 min Jacketed pan	5 min jacketed pan
10 min Jacketed pan		15 min Jacketed pan		15 min Jacketed pan	
15 min Jacketed pan					

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activation of phytase or case hardening with a corresponding reduction in water imbibition. The inability of the steam treated samples to germinate, indicates the absence of active enzymes. This therefore suggests that the increase in hardness of the steam treated seeds was more likely to be due to case hardening. This observation is further strengthened by the fact that there was a reduction in water absorption capacity in the steamed seeds and also by the presence of fused cotyledon cells observed after steaming as reported by Saalia (1995) and Sefaddeh *et al.* (1995).

Due to the difficulties encountered with the Kramer Shear Cell, it was not used in analyzing samples stored for 6 months and as such only the Warner-Bratzler blade was used.

4.2.2 Warner-Bratzler Blade

The effect of steam treatment and storage conditions on the amount of force required to cut through the cooked bean was monitored with the Warner-Bratzler blade during a 6 month storage period. Generally, there was a decrease in maximum cutting force with increasing cooking time for all the samples throughout the storage period. The typical changes in peak forces are shown in Figures 14 and 15. In general, higher peak force values were recorded for the steamed seeds implying that the steam treatment had induced some hardening in the cowpea seeds. Varying comments on the consequences of heat treatment on beans has been reported. Molina *et al.* (1976) observed that steamed black beans were softer than the

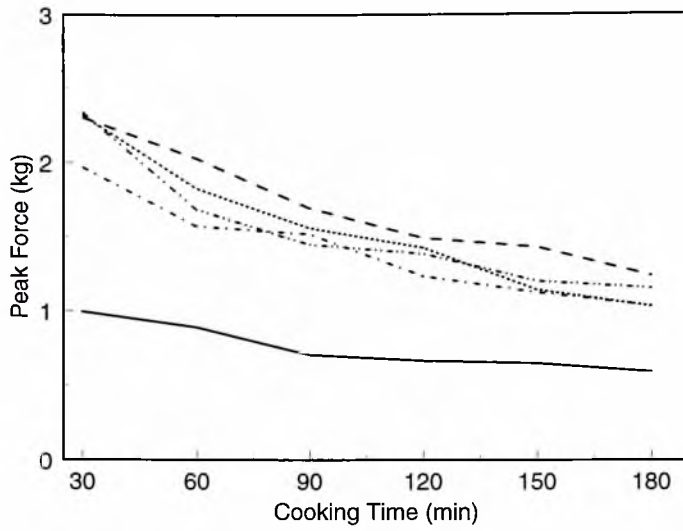
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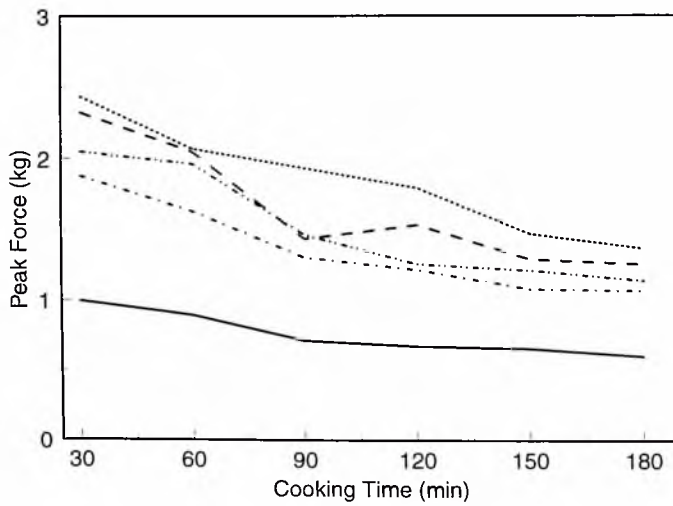
Figure 14 Effect of steam treatment on the hardness of cooked blackeye peas determined using the Warner-Bratzler blade

A = Steam exhaust box
B = Jacketed steam pan

A



B



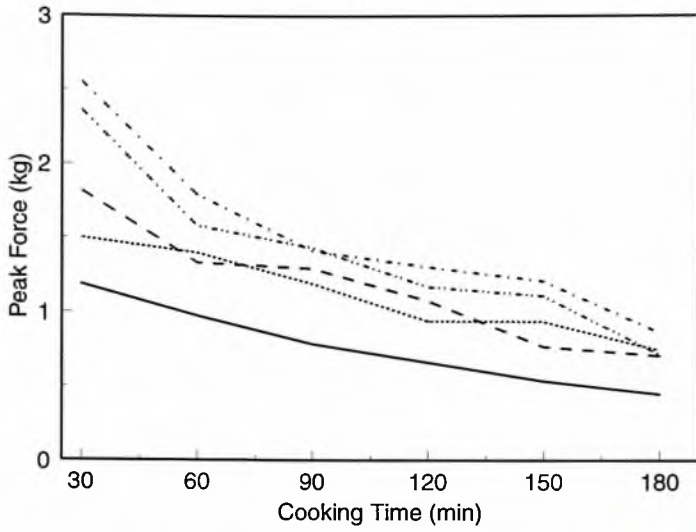
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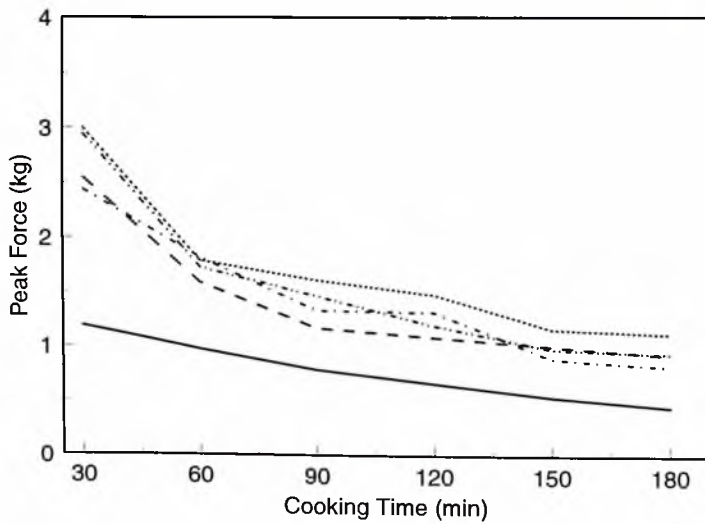
Figure 15 Effect of steam treatment on the hardness of cooked asontem seeds determined using the Warner-Bratzler blade

A = Steam exhaust box
B = Jacketed steam pan

A



B



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unsteamed. Aguilera and Ballivan (1987) confirmed these results only for black beans roasted between 80 and 90°C, whilst they recorded an increase in bean hardness above 95°C. According to Hung *et al.* (1988) pre-decortication drying treatments resulted in more brittle cowpea seeds as compared to the control. They further indicated that akara produced from the treated seeds increased in hardness as the temperature of the treatment increased.

Liu *et al.* (1992) hypothesized that the hard-to-cook defect in cowpeas was due in part to protein insolubilisation and reversible denaturation during storage. The proteins were thought to act as a physical and water-restricting barrier which prevented starch gelatinisation during cooking. Results from this work has indicated that the steaming process resulted in a significant decrease in protein solubility possibly due to protein denaturation. It is therefore suggested that the increase in cooked bean hardness of the steam treated seeds may in part be due to changes in protein functionality. This is further supported by the work of Phillips *et al.* (1988) who concluded that the changes in functional properties of cowpea meal, paste and final products were mainly due to the effect of the pre-conditioning treatment (heating between 50 - 130°C) on protein. Their report indicated no detectable change in starch functionality.

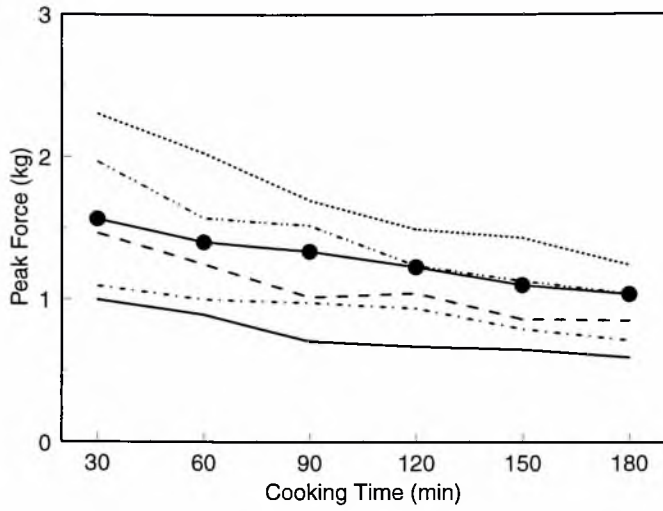
At the end of the storage period, all the samples were found to have undergone some changes as far as their textural characteristics were concerned. Changes in the maximum cutting force with storage time are shown in Figures 16 and 17.

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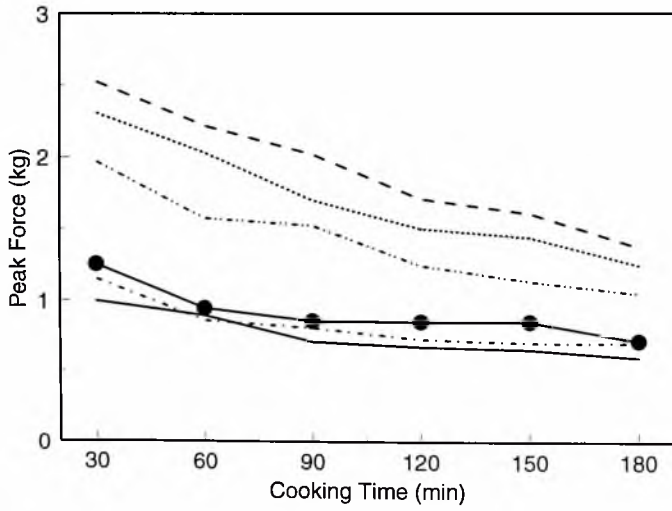
Figure 16 Effect of storage on the cooked bean hardness of steamed blackeye peas stored for 6 months at either 28°C (A) or 6°C (B)

- unsteamed, fresh
- - - - - Unsteamed, 6 months
- 2 min, fresh
- - - 2 min, 6 months
- 10 min, fresh
- 10 min, 6 months

A



B

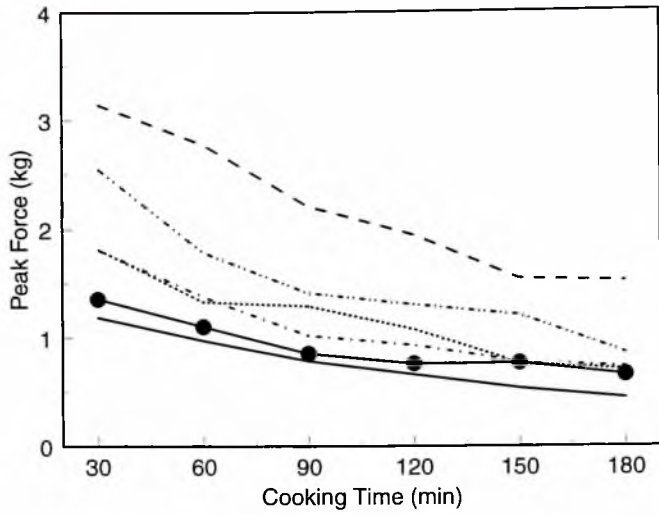


ADDITIONAL

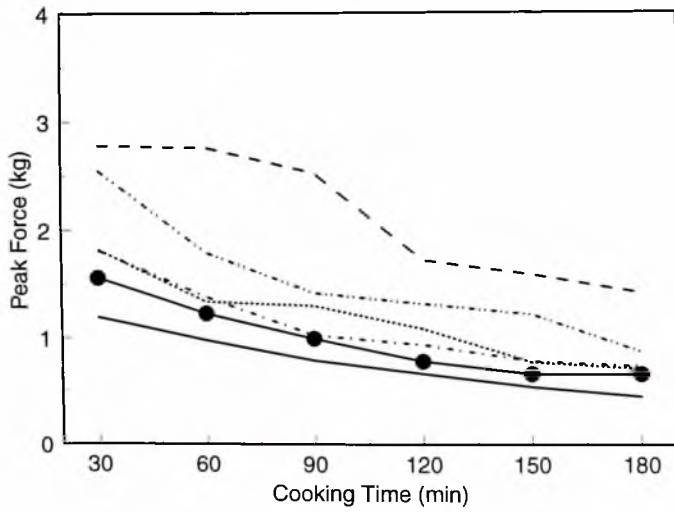
Figure 17 Effect of storage on the cooked bean hardness of steamed asontem seeds stored for 6 months at either 28°C (A) or 6°C (B)

- unsteamed, fresh
- - - - - Unsteamed, 6 months
- 2 min, fresh
- - - 2 min, 6 months
- 10 min, fresh
- 10 min, 6 months

A



B



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Similar trends were observed for both steaming systems. The unsteamed samples stored at either 6°C or 28°C required a higher maximum cutting force at the end of the storage period as compared to the force required at the beginning of the storage study. This indicates that the seeds had become harder with storage. This was true for both asontem and blackeye. Similar results were obtained for the asontem samples steamed for 2 min whilst the 2 min steamed blackeye samples showed this increase in cooked bean hardness only after storage at 6°C. A different trend was however observed for all the 10 min steamed samples where lower peak force values were recorded at the end of the storage period as compared to the force required at the beginning of the storage period, implying that these seeds had softened.

A slightly different pattern has been reported for the effect of storage on heat treated black beans. According to Hincks and Stanley (1986) even though black beans roasted at 105°C for 2 min, were actually softer than the regular dried samples prior to storage, the treated beans became progressively harder with storage (30°C/85%; 15°C/35%). Similar increases in cooked bean hardness with storage has been reported in other studies on heat treated black beans (Molina *et al.*, 1976; Aguilera and Ballivan, 1987). In their report, Aguilera and Ballivan (1987) suggested that the high temperature was sufficient to damage some protein fractions including key enzyme systems but not to impair fully the cause of hardening. The observed differences in the effect of storage could be attributed to varietal differences between cowpeas and black beans.



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The middle lamella has been described as the cementing factor which helps in maintaining the rigidity of the cell. The loss of cell integrity or softening following cooking has been attributed to the breakdown of the middle lamella (Sefa-Dedeh *et al.* 1978; Plhak *et al.*, 1989; Shomer *et al.* 1990). In hard-to-cook beans the unfavorable storage conditions (high temperature and humidity) activates phytase which causes phytin to release Ca and Mg. These become esterified to pectinic acid (produced from pectin hydrolysis) forming insoluble Ca/Mg pectinates. The pectinates remain in the middle lamella strengthening it and therefore resisting breakdown with cooking. This results in beans which do not soften with cooking. Sefa-Dedeh (1978) suggested that a reduction in phytate concentration (as a result of phytase activity) in beans would greatly influence the resulting cooked bean hardness. A similar relationship between low phytate concentration and increased cooking time has been reported (Kon and Sanshuck, 1981; Uzogara and Ofuya, 1992).

Results from this study has suggested that the lack of germinating capacity in steamed seeds could be due to the absence of active enzymes possibly including phytase. It is therefore possible that the inactivation of phytase led to the formation of the more soluble Ca/Mg phytates resulting in the softer cooked beans in the 10 min steamed samples. A similar trend was not observed in the 2 min steamed samples probably because of the short treatment time and also because bean hardening is a biological process caused by various complex mechanisms including non-enzymatic pathways (Aguilera and Ballivan, 1987).

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One of the major constraints to the utilisation of cowpeas is the prolonged cooking times due to the hard-to-cook defect and the consequent loss of nutritional value (Tuan and Phillips, 1992). Thus the softening of the hydrothermally treated seeds in storage is important in terms of reducing the cooking time and therefore improving the overall nutritional value and utilisation of cowpeas. Field studies have shown that the most efficient protection against insect infestation was attained in the 10 min steam treated seeds (Sefa-Dedeh and Saalia, 1997). Therefore the observed softening of the 10 min steamed seeds is of significance since it means that these seeds can be safely stored to achieve a desirable degree of softness whilst being protected from insect infestation.

Storage of high moisture beans especially at high temperatures and high humidity, has been found to accelerate the development of the hard-to-cook defect in beans (Sefa-Dedeh *et al.*, 1978; Aguilera and Stanley, 1985), whilst there is relatively no change in cooked texture at low moisture contents (< 10%). In this study all the steamed seeds were dried to a final moisture content of less than 10%, whilst the unsteamed seeds were stored at moisture contents of 11.18 and 12.42% respectively for blackeye and asontem. The moisture content could therefore partly account for the apparent softening of the steamed seeds after 6 months storage.

A high negative correlation was also observed between the cooked bean hardness and water absorption with correlation coefficients of -0.7564 and -0.7005 respectively for blackeye and asontem. This implied that a high water absorption capacity

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resulted in lower peak force values and therefore softer cooked bean. Thus the lower water absorption capacities of the steamed seeds could have influenced the resulting cooked bean hardness. Sefa-Dedeh *et al.* (1978) also reported this high correlation between cooked bean hardness and water absorption capacity.

Relative hardness (H_R) is described as seed hardness (H_t) at any storage time t , divided by the hardness at the beginning of storage (H_0) (Aguilera and Stanley, 1985; Aguilera and Ballivan, 1987). Samples with H_R greater than 1 have increased in hardness whilst those with values less than 1 show softening. Changes in relative hardness after 6 months storage at either 28°C or 6°C are shown in Table 17. The results shown are based on peak force data after 3 hours cooking. After 6 months storage, the unsteamed samples for both varieties showed relative hardness (H_R) greater than 1 indicating that some amount of hardening had occurred. This hardening during storage is typical of legumes. The changes in the relative hardness index of the steamed seeds did not follow a clear general pattern, the observed trend was slightly different for each variety, steaming time and storage temperature. All the 2 min steamed samples stored at 6°C, i.e. for both blackeye and asontem, showed an increase in relative hardness ($H_R > 1$). A similar increase was also observed in the asontem sample steamed for 2 min in the steam box and stored at room temperature. However, the other 2 min steamed samples stored at room temperature showed a decrease in H_R . This increase in hardness at the lower storage temperature (6°C) as compared to storage at 28°C was surprising since bean hardening is more associated with storage at high temperature and humidity

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(Sefa-Dedeh *et al.*, 1979; Hincks *et al.*, 1987; Hung *et al.*, 1995). The H_R ratios for the 10 min steamed samples confirmed the earlier observation that these seeds had softened with storage. This is because all the 10 min steamed seeds had an H_R ratio of less than 1 for any variety and at any storage temperature (Table 17). This softening could have resulted from an inactivation of the enzymatic pathways responsible for bean hardening as a result of the high temperature used in the treatment.

Table 17: Relative hardness ratio (H_R) of cooked cowpea seeds

Steaming Time (min)	Steaming System	Blackeye		Asontem	
		28°C	6°C	28°C	6°C
0	Unsteamed	1.2024	1.1688	1.7503	1.6418
2	Steam box	0.8186	1.3129	1.7666	1.6342
2	Jacketed pan	0.7622	1.0421	0.7619	1.1452
10	Steam box	0.8344	0.5707	0.8036	0.9257
10	Jacketed pan	0.5982	0.9044	0.4786	0.7880

According to Aguilera and Steinsapir (1985) subjective analysis indicated that a relative hardness index of 1.8 (from instrumental analysis) was the maximum tolerable for eating. From the results after 6 months storage, all samples (both steamed and unsteamed) had relative hardness ratios lower than this upper limit. This implies that storage could have a beneficial effect on the steamed seeds, especially as far as their final utilisation was concerned.

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Statistical analyzes showed that variety, steaming time, cooking time, length of storage and storage temperature significantly affected the peak forces recorded for all the samples (Table 18). The steaming method used was however, not significant. Further analyzes of the effect of steaming time using multiple range tests, showed that the cooked bean hardness of the unsteamed samples was distinctly different from the hardness of all the steamed seeds. It was also observed that the cooked bean hardness of the 2 min steamed samples was significantly different from that of the other steamed samples. For the effect of length of storage, multiple range tests showed that there were no significant differences in the peak forces recorded before storage and those recorded for samples stored for 6 months. However, these were distinctly different from the peak forces recorded for samples stored for 1 month. This could have been due to the observed softening of the seeds after storage for 6 months.

Table 18: Anova summary table for cooked cowpea hardness

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F-RATIO
MAIN EFFECTS	97315383	12	8109615	70.495*
STEAMING TIME	45212357	2	22606179	196.512*
STORAGE TEMP.	2916950	1	2916950	25.357*
STORAGE MONTH	2060358	2	1030179	8.955*
COOKING TIME	45472141	5	9094428	79.056*
VARIETY	1591457	1	1591457	13.834*
STEAMING METHOD	62122	1	62122	0.540
RESIDUAL	48200676	419	115037.41	
TOTAL (CORR.)	145520000	431		

* - significant at $p \leq 0.05$

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4.3 EFFECT OF DRYING CONDITIONS ON SOME CHARACTERISTICS OF STEAMED COWPEAS

4.3.1 Moisture Content

Samples used in this part of the study were freshly harvested and dried blackeye peas which were steamed in a steam retort. Steaming had a positive and increasing effect on the moisture content of all samples. The final moisture content, i.e. after drying ranged between 9.28 to 13.28% (Table 19), with the highest being recorded in the 6 min steamed sample dried at 35°C and 81% RH. Although the differences in the total drying time were not statistically significant, a general decrease in the total time required for drying was observed as the drying temperature increased. This was to be expected since the higher temperatures resulted in a more rapid loss of moisture and therefore the desired moisture content was attained in a shorter time. The highest moisture value was obtained for the low temperature and high humidity combination (35°C/81%) which required more than 24 hours to attain a moisture level of about 13%. This was possibly because the high humidity of the drying environment together with the lower drying temperature was not favorable for rapid drying. In general, however, the moisture contents was reduced to storage safe levels of about 10%.

The data obtained from the evaluation of the effect of steaming and drying conditions on blackeye peas was analyzed using step-wise multiple regression procedures after which models were generated to relate the independent variables to the observed differences in sample characteristics. Table 20 shows the coefficients of the independent variables in the models. A test for lack of fit and R^2 values were used

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as an indication of the adequacy of the resulting models. An insignificant F-ratio value for the lack of fit (Table 21) and an R^2 of at least 60% implies that the model selected was adequate (Draper and Smith, 1966; Malcolmson, 1993).

Table 19: Changes in moisture content of blackeye peas after steaming and drying

SAMPLE TREATMENT	MOISTURE CONTENT (%)			TOTAL DRYING TIME (h)
	Before Steaming	After Steaming	After Drying	
Unsteamed	11.06	-	-	-
2 min/35°C/56% ¹	12.33	14.29	10.47	5.5
2 min/45°C/16%	12.33	14.86	9.85	4
2 min/45°C/48%	12.58	15.34	10.62	5
2 min/55°C/20%	12.58	14.91	10.21	3
6 min/35°C/28%	12.13	15.13	10.86	5
6 min/35°C/81%	12.13	15.44	13.28	24
6 min/45°C/33%	12.19	16.1	9.86	6.5
6 min/45°C/33%	12.19	15.64	10.05	6.5
6 min/45°C/33%	12.19	15.97	9.64	6.5
6 min/55°C/10%	12.19	16.30	9.28	5
6 min/55°C/29%	11.11	15.14	9.92	5
10 min/35°C/56%	12.33	16.34	10.67	5
10 min/45°C/16%	12.33	15.80	10.10	4.5
10 min/45°C/48%	11.11	15.43	10.78	5
10 min/55°C/20%	12.58	16.76	10.21	4

¹ Sample Treatment - steaming time (min)/drying temperature (°C)/drying humidity (%)

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Table 20 : Coefficients of Variables and R² in the model generated

Variable	Water Removed	Water Absorption	Dehulling Efficiency	Peak force at 30 min	Peak force at 60 min	Peak force at 90 min
Constant	-0.165925	79.522512	-0.201108	-610.637583	-308.69782	229.217833
X ₁	0.001919	-	0.04625	-180.683958	-3.838719	-45.28525
X ₂	0.008046	-1.135598	0.016395	113.167238	52.515301	24.8079
X ₃	3.20125	-	5.666667	-	21656.1077	7212.84583
X ₁ ²	-	0.223026	-0.003307	9.507426	-	0.923971
X ₂ ²	-0.000076	0.014975	-0.000104	-1.618979	-0.716678	-0.363785
X ₃ ²	-101.25	-2693.59365	-29.166667	-4056323	-533755.2	-283334.6
X ₁ X ₂	-	-0.078697	-	1.512275	-	0.344677
X ₁ X ₃	-	-140.295547	0.5075	-1939.59494	-3145.1515	-
X ₂ X ₃	-	1.116616	-	607.023574	-	-
X ₁ X ₂ X ₃	-	3.863637	-0.021	-	60.5867	13.579583
R ²	0.6409	0.8149	0.8591	0.7571	0.8267	0.9348

X₁ - Steaming time (min); X₂ - Drying temperature (°C); X₃ - Drying humidity (g water/kg air)

Table 21: Analysis of Variance for the full regression of the models

Source of Variation	Water Removed	Water Absorption	Dehulling Efficiency	Peak force at 30 min	Peak force at 60 min	Peak force at 90 min
	F-ratio					
Model	5.998	6.116	15.088	7.071	11.775	19.486
Lack of fit	3.821**	3.545**	1.780**	7.515**	0.628**	8.125**

** - Not significant at p = 0.05

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The variations in the amount of water removed during the drying process is shown in Figure 18 for samples steamed for 6 min. A similar pattern was obtained after steaming for 2 and 10 min. The model generated could explain 64% of the variations in the rate of drying and a test of lack of fit showed a non-significant F-ratio of 3.82. This shows the adequacy of the generated model. Variables which had significant effects on the model were drying temperature and humidity and their quadratic terms. An increased rate of drying with increasing drying temperature was recorded at all humidities. The effect of drying humidity on water removal was most pronounced at 0.02 g water/kg air, whereas the rate of water removal decreased on either side of this maximum. The most efficient drying occurred at high temperature (55°C) and intermediate humidity (0.02 g water/kg air). On the other hand, the least efficient drying occurred at low temperature and high humidity because the humid environment coupled with the low temperature was not conducive for rapid removal of water from the steamed seeds.

4.3.2 **1000 Seed Weight**

The weight of 1000 seeds was used as an index of the density of the seeds (Table 22). The density ranged from 223 to 234 g/1000 seeds. There were no significant differences between results obtained for any of the steamed samples indicating that neither steaming nor the drying conditions affected the density of the seeds.

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Figure 18 Response surface plot for amount of water removed during drying of blackeye peas steamed for 6 min

Model

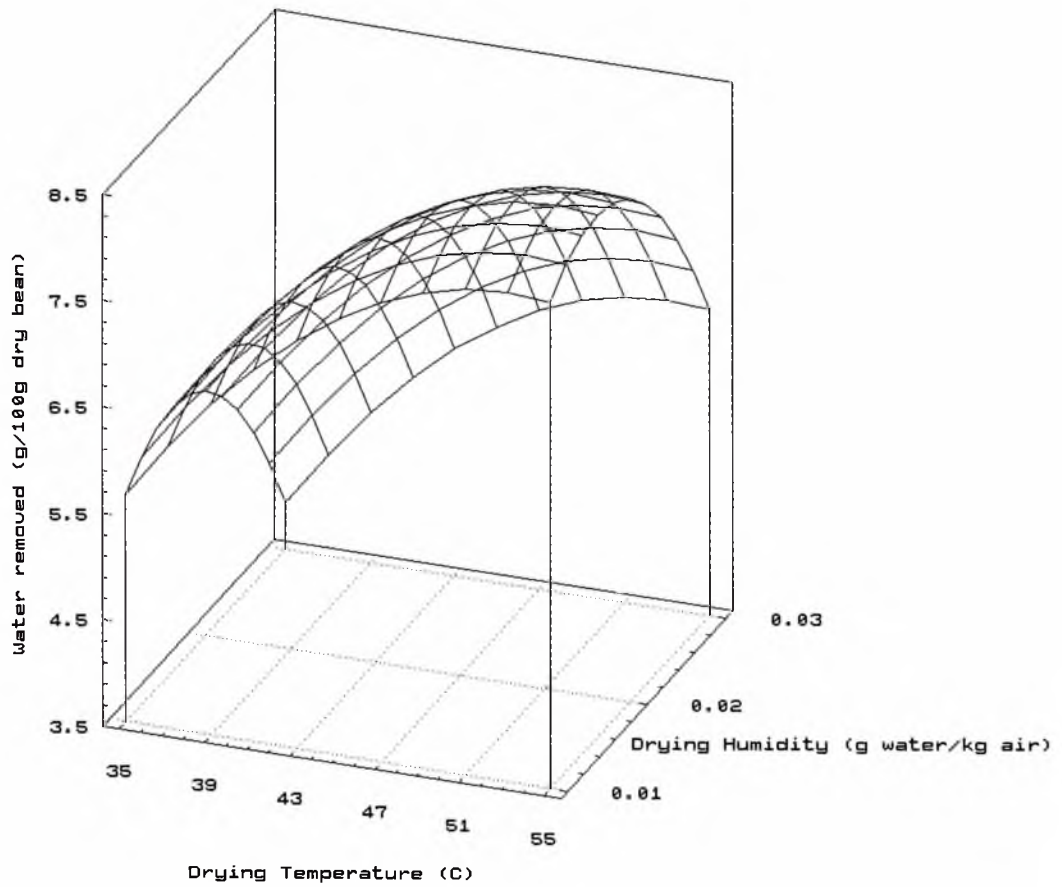
$$Y = -16.562988 + 0.191966X_1 + 0.803621X_2 + 319.705096X_3 - 0.007566X_2^2 - 10113.35X_3^2$$

$$R^2 = 0.6409$$

X_1 = Steaming Time (min)

X_2 = Drying Temperature (°C)

X_3 = Drying Humidity (g water/kg air)



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Table 22: 1000 seed weight of steamed blackeye peas

TREATMENT	1000-SEED WEIGHT (G)	TREATMENT	1000-SEED WEIGHT (G)
Unsteamed	222.3277	6 min/45°C/33%	229.0542
2 min/35°C/56% ¹	229.993	6 min/45°C/33%	227.2219
2 min/45°C/16%	228.5027	6 min/55°C/10%	223.2191
2 min/45°C/48%	232.911	6 min/55°C/29%	225.8116
2 min/55°C/20%	234.9038	10 min/35°C/56%	227.7118
6 min/35°C/28%	227.9577	10 min/45°C/16%	229.0017
6 min/35°C/81%	228.6441	10 min/45°C/48%	229.0077
6 min/45°C/33%	222.4171	10 min/55°C/20%	229.8059

¹ Sample Treatment - steaming time (min)/drying temperature (°C)/drying humidity (%)

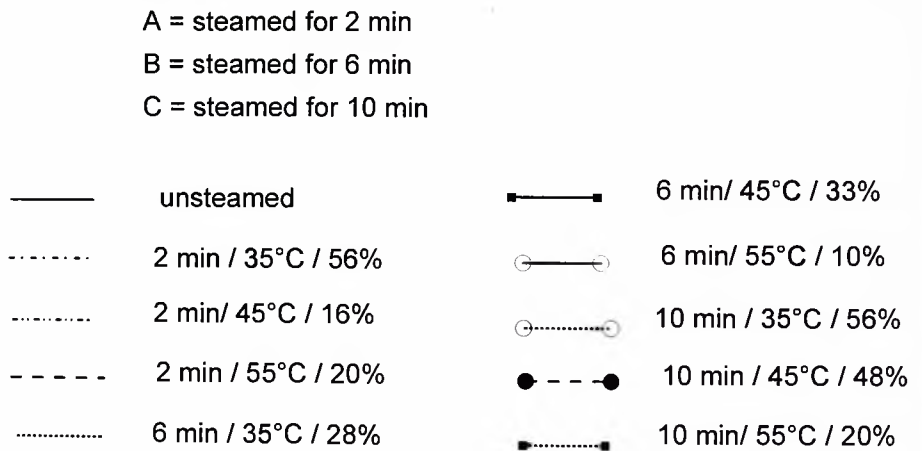
4.3.3 Water Absorption

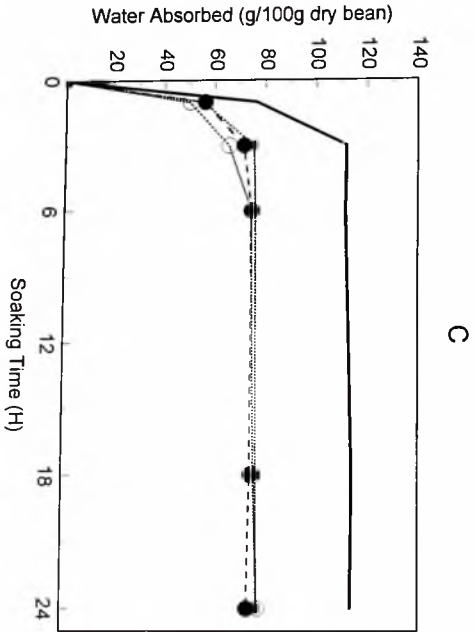
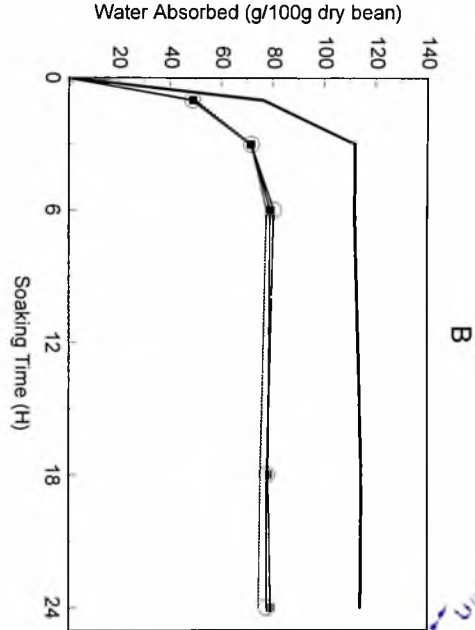
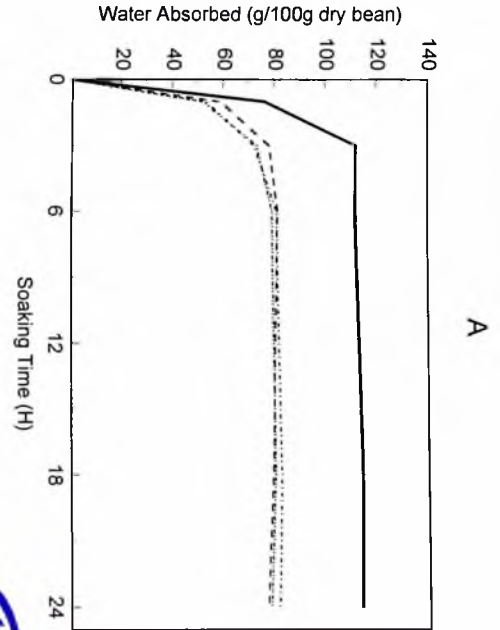
A general increase in the amount of water absorbed with increasing soaking time was observed in all the samples. There was a high rate of water absorption during the first 6 hours, gradually slowing after 18 hours (Figure 19). The blackeye and asontem varieties used in the earlier parts of this study (Section 4.1.3) showed a similar trend. Sefa-Dedeh *et al.* (1979) and Saalia (1995) also reported a similar pattern for water absorption of other cowpeas varieties.

A decrease in water absorption capacity was recorded in all the samples after the steaming process (Figure 19). A similar decrease in water absorption following steaming was observed for cowpeas steamed in the steam exhaust box and jacketed steam pan as reported in an earlier part of this work (Section 4.1.3). Conflicting results on the effect of heat treatment on water absorption capacity has been reported by various researchers. Whilst some workers recorded an increase in water

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Figure 19 Effect of steam treatment and drying conditions on water absorption characteristics of blackeye peas





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absorption capacity following the application of with heat treatment (Molina *et al.*, 1976; Narayana and Narasinga-Rao, 1982; Abbey and Ibeh, 1988) others have indicated that water absorption capacity decreased with heat treatment (Sefa-Dedeh and Demuyakor, 1994; Saalia, 1995). Phillips *et al.* (1988) investigating the effect of pre-treatment on some functional and nutritional properties of cowpea meal, reported that the water absorption capacity increased with mild heat treatment (up to 70°C) and then decreased as the treatment became more severe (90-130°C).

Statistical analysis showed that the water absorption capacity of blackeye peas soaked for 1 hour was significantly different from the absorption capacity recorded for the seeds soaked for 3 hours or longer. Cowpea samples steamed in the steam exhaust box and the jacketed steam pan also showed significant differences between the water absorption capacity of the 1 hour soaked seed and the water absorption capacity of the seeds soaked for between 3-24 hours. This was thought to be due to the initial resistance of the seed coat in addition to the resistance of fused cotyledon cells, this was however overcome as the soaking progressed.

The water absorption capacity of cowpeas is an important functional property which has been shown to be highly correlated with the cooking time (Sefa-Dedeh *et al.*, 1979). The reduction in water absorption capacity after steaming could therefore have an effect on the cooking time of the steamed cowpeas. Response surface methodology was used to determine the variable combinations at which optimum water absorption capacity was attained. A significant model was generated for water

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absorption data obtained after 1 hour soaking of steamed cowpeas. The model generated could explain 81% of the variations observed for the water absorption capacity and the test for lack of fit showed a non-significant F-ratio of 3.55. The water absorption capacity was significantly influenced by the drying temperature and the quadratic term of drying humidity. In addition, there were significant interactions between all the independent variables (steaming time, drying temperature and drying humidity).

The response surface plot of the model generated by regression analyses of water absorption data obtained after 1 hour soaking, showed that increasing drying temperature increased water absorption at high drying humidity (Figure 20). However, at low drying humidity, increasing drying temperature (up to 45°C), resulted in a slight decrease in water absorption and thereafter an increase was recorded as the drying temperature increased. Water absorption capacity also increased as drying humidity increased. The combination of high drying temperature and high humidity resulted in the highest water absorption capacity for any steaming time. The application of heat results in the denaturation of proteins which are the major absorbing constituent of legumes (Cheftel *et al.*, 1985). Denaturation results in the unfolding and aggregation of the protein molecule leading to an increase in water absorption among other effects. It is therefore possible that during the drying process, increasing drying temperature denatured the proteins and therefore resulted in the observed increased water absorption. Low moisture content also improves the absorption of water in seeds (Smith and Nash, 1961; Moscoso *et al.*, 1984). As noted

Figure 20 Response surface plot for water absorption capacity of blackeye peas steamed for 6 min and soaked for 1 hour

Model

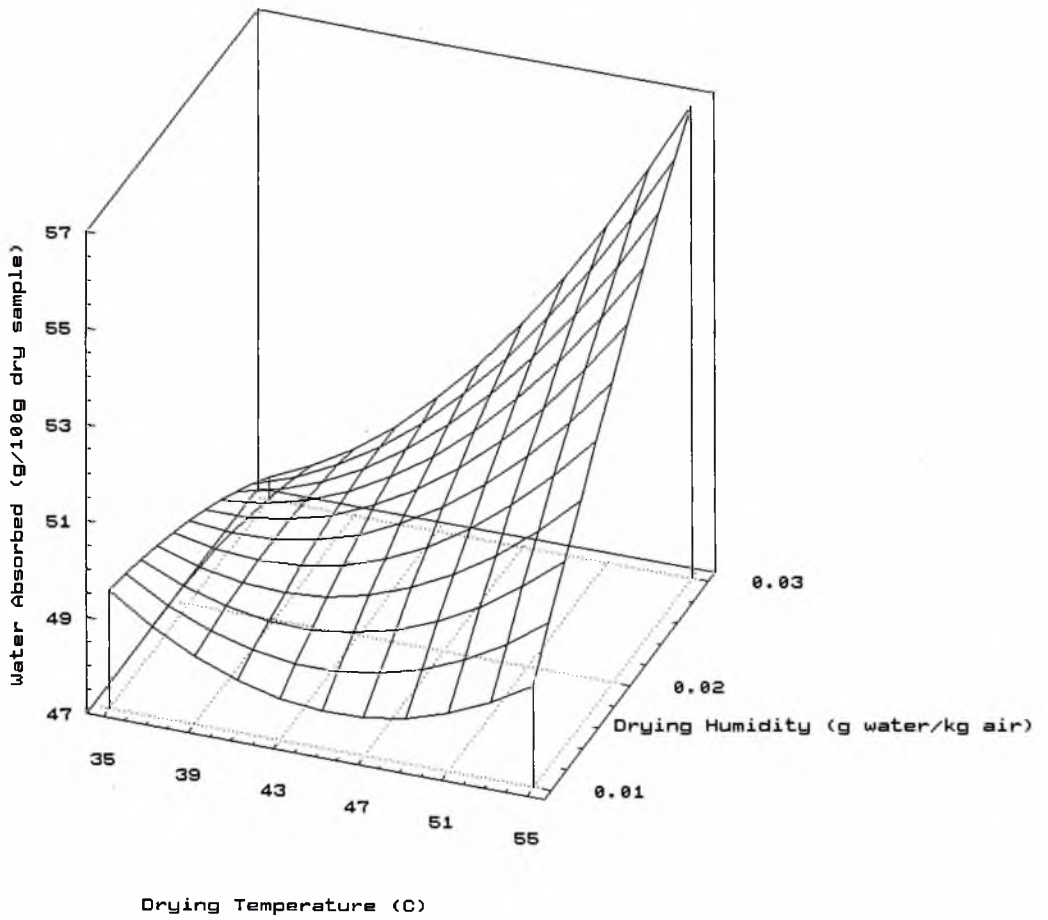
$$Y = 79.522512 - 1.135598X_2 + 0.223026X_1^2 + 0.014975X_2^2 - 2693.593647X_3^2 - 0.078697X_1X_2 - 140.295547X_1X_3 + 1.116616X_2X_3 + 3.863637X_1X_2X_3$$

$$R^2 = 0.8149$$

X_1 = Steaming Time (min)

X_2 = Drying Temperature (°C)

X_3 = Drying Humidity (g water/kg air)



previously in this study, the combination of high drying temperature and high drying humidity results in the removal of the highest amount of water, leading to very low moisture contents. This low moisture content could account for the increased water absorption as drying temperature and humidity increased.

4.3.4 Dehulling Efficiency

An index for dehulling efficiency based on the yield and the amount of hulls removed was calculated for each sample. Reichert *et al.* (1984) observed that seeds with dehulling efficiency values greater than 0.54 had loosely bound hulls making dehulling easier. These seeds were also more resistant to splitting. In this study, results showed that steaming improved dehulling of cowpea seeds with the dehulling efficiency index ranging from 0.4 to 0.55 as compared to 0.37 for the unsteamed. These values were higher than those reported for blackeye (0.25) and brown cowpea (0.11) by Reichert *et al.* (1984). This could have been due to inherent differences in the method used; their method involved abrasion whilst this study involved cracking and aspiration. According to McWatters *et al.* (1986), the increase in hardness of cotyledons of stored cowpeas could have contributed to the improved decortication efficiency. Cowpea seeds used in this study also showed an increase in cotyledon hardness after steaming, which could account for the improved dehulling efficiency exhibited by these seeds as compared to the unsteamed seeds.

Dehulling is an important means of improving the utilisation of cowpeas and other legumes. This is because it results in an improvement of protein digestibility through

the reduction of anti-nutritional factors such as tannins found in the seed coat. It also leads to faster cooking times and removes a large proportion of oligosaccharides which causes flatulence especially in children (Phillips and McWatters, 1991; Uzogara and Ofuya, 1992). The efficiency of the dehulling process is influenced by both inherent characteristics of the seed and external factors. These external factors can be controlled e.g. through the use of a pre-decortication treatment, to improve and facilitate the dehulling process.

A regression model was used to determine the effect of steaming and drying condition on the dehulling efficiency of cowpeas and also to select the variable combination that resulted in the most efficient dehulling. An R^2 value of 86% was obtained for the model with a non-significant F-ratio value (1.780) for lack of fit. This indicates the adequacy of the selected model in explaining the variations in the dehulling efficiency. The dehulling efficiency was significantly affected by the drying temperature and drying humidity, and the quadratic term of the steaming time. There were also significant interactions between all the independent variables (steaming time, drying temperature and drying humidity).

The model generated is represented as a response surface plot in Figure 21 for samples steamed for 6 min. A similar trend was observed for samples steamed for 2 and 10 min. The effect of drying conditions was found to be more pronounced than that of steaming. The most efficient dehulling was attained in the samples dried at high humidity and high temperature. Dehulling efficiency was also enhanced by increasing drying temperature at any steaming time or drying humidity. It is possible



Figure 21 Response surface plot for the dehulling efficiency index of blackeye peas steamed for 6 min

Model

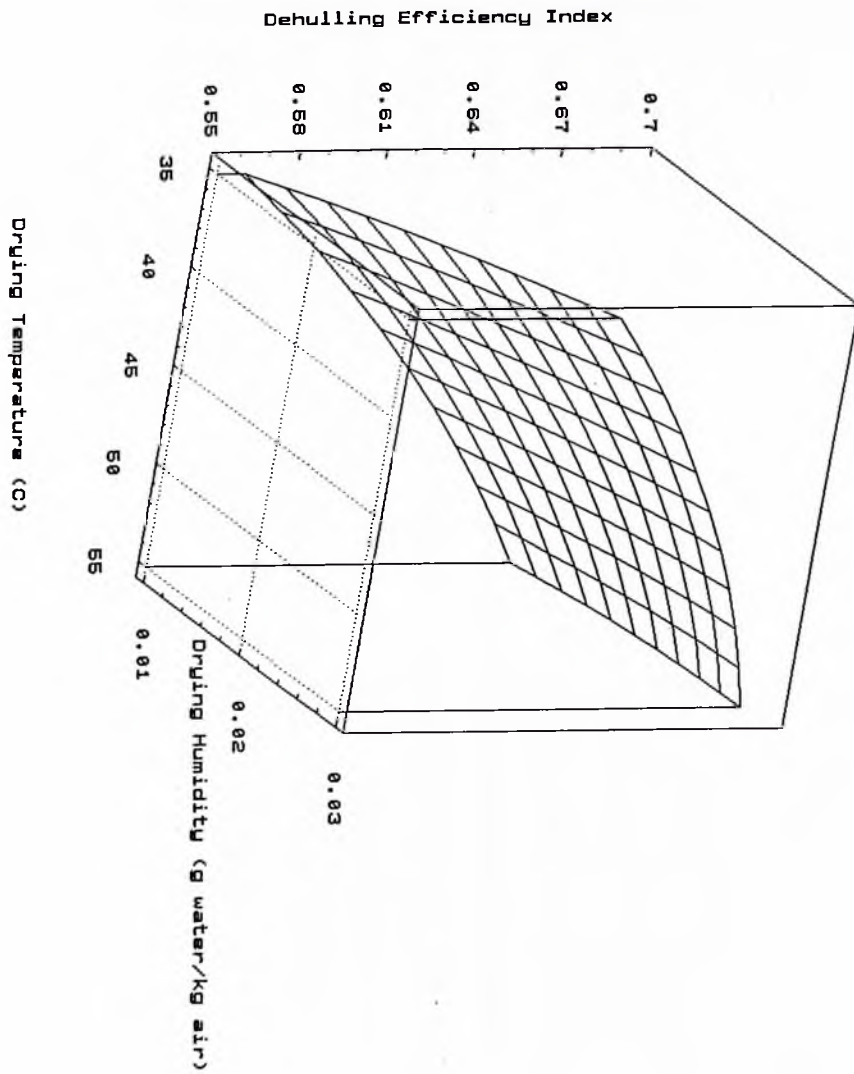
$$Y = -0.201108 + 0.04625X_1 - 0.016395X_2 - 5.666667X_3 \\ - 0.003307X_1^2 - 0.000104X_2^2 - 29.166667X_3^2 + 0.5075X_1X_3 \\ - 0.021X_1X_2X_3$$

$$R^2 = 0.8591$$

X_1 = Steaming Time (min)

X_2 = Drying Temperature ($^{\circ}\text{C}$)

X_3 = Drying Humidity (g water/kg air)



that as the drying temperature increased and moisture content decreased, the seed coat became less firmly attached to the cotyledon and therefore its removal was improved. Hung *et al.* (1988) also noted that high temperature drying was rapid and effective in promoting seed coat removal, although it had a negative effect on the functionality of the resulting seed.

4.3.5 Cooked Seed Hardness

The effect of steaming and drying conditions on the cooked bean hardness was monitored using an Instron testing machine fitted with a Kramer shear test cell. The maximum force required to compress and shear a known weight of the cooked sample was measured. There was a general decrease in cooked bean hardness with cooking time for all the samples analyzed (Figure 22). An increase in cooked bean hardness following the exposure to steam was recorded in all the seeds. In their reports, Sefa-Dedeh *et al.* (1995) and Saalia (1995) observed that the cotyledon cells of cowpea seeds became fused together following the application of steam. It is therefore possible that this resulted in a case hardening effect which caused the increase in hardness observed after the steaming process. However, some sample treatments resulted in cooked bean hardness comparable to the unsteamed control. These samples were mostly those dried at the high temperature and intermediate humidity. This implies that the drying conditions can be selected to yield steamed seeds with cooked textural characteristics similar to or even better than that of the unsteamed seeds.

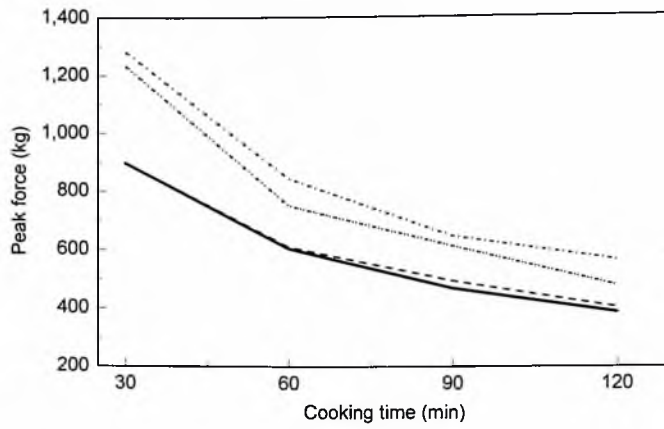


Figure 22 Effect of steam treatment and drying conditions on cooked bean hardness of blackeye peas

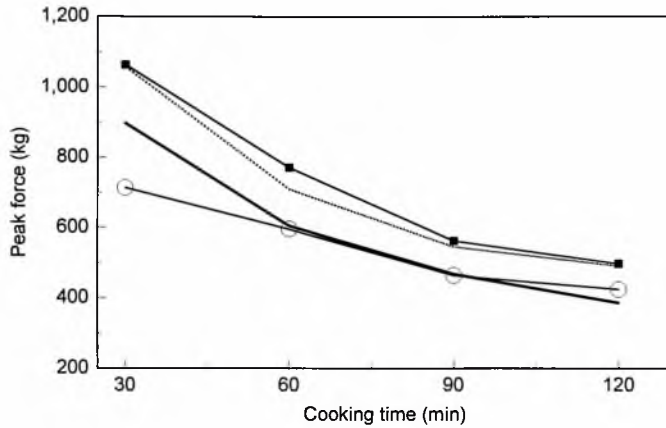
A = steamed for 2 min
B = steamed for 6 min
C = steamed for 10 min

————	unsteamed	—●—●	6 min/ 45°C / 33%
.....	2 min / 35°C / 56%	○—○	6 min/ 55°C / 10%
.....	2 min/ 45°C / 16%	○.....○	10 min / 35°C / 56%
- - - -	2 min / 55°C / 20%	● - - - ●	10 min / 45°C / 48%
.....	6 min / 35°C / 28%	■.....■	10 min/ 55°C / 20%

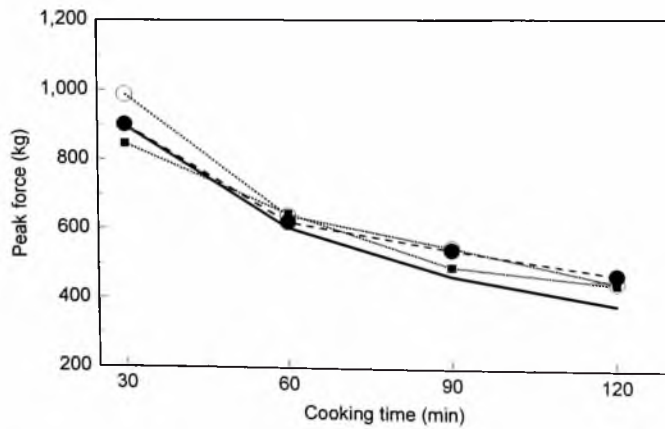
A



B



C





Statistical analyzes of the peak force data showed significant differences up to 90 min of cooking, thereafter the differences were not significant. Response surface methodology was used to optimize the effect of steaming and drying conditions on the cooked bean hardness. The models generated to predict the peak forces recorded after 30, 60 and 90 min cooking had R^2 values of 76, 83 and 93% respectively. In addition, all the models had non-significant F-ratios. Steaming time and drying temperature had significant effects on the cooked bean hardness after any cooking time. In addition, there were significant interactions between steaming time and drying temperature in samples cooked for 90 min such that at low steaming time, increasing drying temperature resulted in a decrease in peak force at any humidity.

The response surface plots for the combined effect of steaming and drying conditions on cooked bean hardness up to 90 min cooking are shown in Figures 23-25. Representative plots are shown where similar trends were observed at varying levels of the same independent variable. In general, higher peak force values were recorded at short steaming times and low drying temperature. On the other hand, increasing drying temperature had a reducing effect on the cooked bean hardness such that cooked bean hardness decreased with increasing drying temperature, indicating that seeds dried at the higher temperatures were softer. This trend was observed after any cooking time. The effect of steaming was however, more pronounced in the 30 min cooked samples where cooked bean hardness decreased with steaming time to a minimum after 6 min and thereafter increased. However, in

Figure 23 Response surface plot of hardness of steamed blackeye peas cooked for 30 min; for samples dried under humidity of 0.02 g water/kg air

Model

$$Y = -610.63758 - 180.68396X_1 + 113.167238X_2 + 9.507426X_1^2 - 1.618979X_2^2 - 405632.3X_3^2 + 1.512275X_1X_2 - 1939.594938X_1X_3 + 607.023574X_2X_3$$

$$R^2 = 0.7571$$

X_1 = Steaming Time (min)

X_2 = Drying Temperature ($^{\circ}$ C)

X_3 = Drying Humidity (g water/kg air)

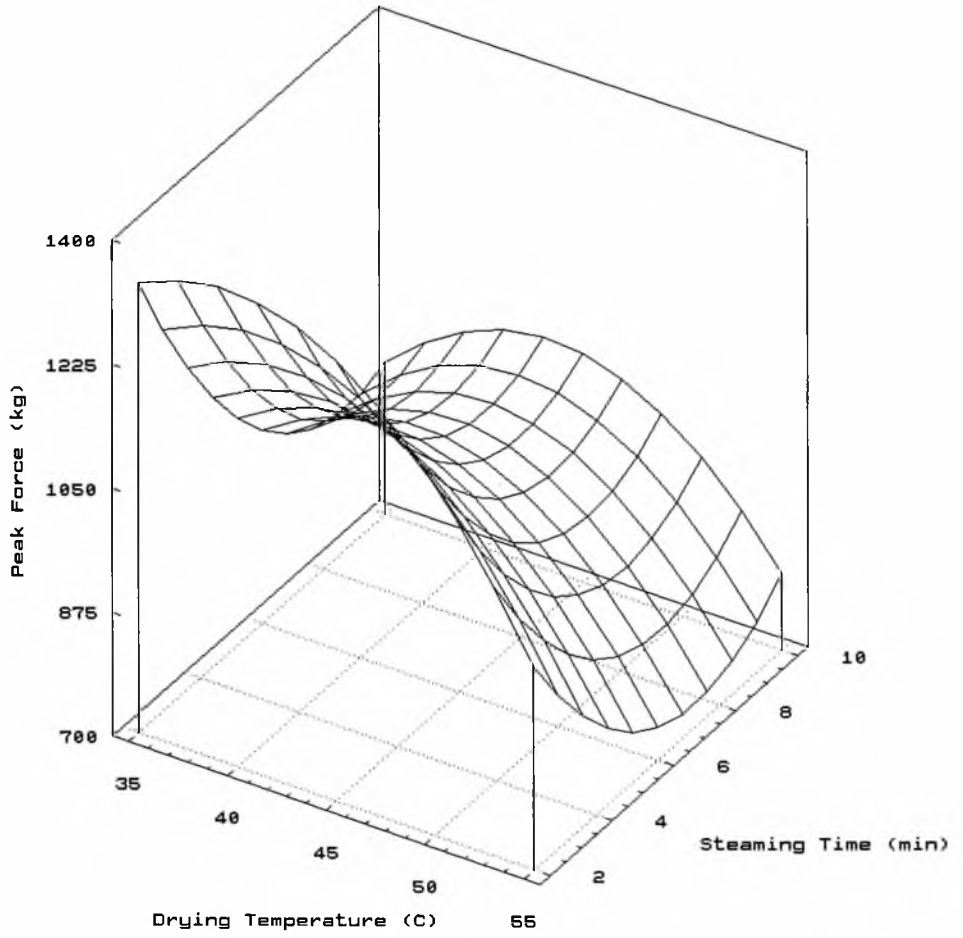


Figure 24 Response surface plots of hardness of steamed blackeye peas cooked for 60 min

A - dried under humidity of 0.01 g water/kg air
B - dried under humidity of 0.02 g water/kg air

Model

$$Y = -308.69782 - 3.838719X_1 + 52.515301X_2 + 21656.10769X_3 - 0.716678X_2^2 - 533755.2X_3^2 - 3145.1515X_1X_3 + 60.5867X_1X_2X_3$$

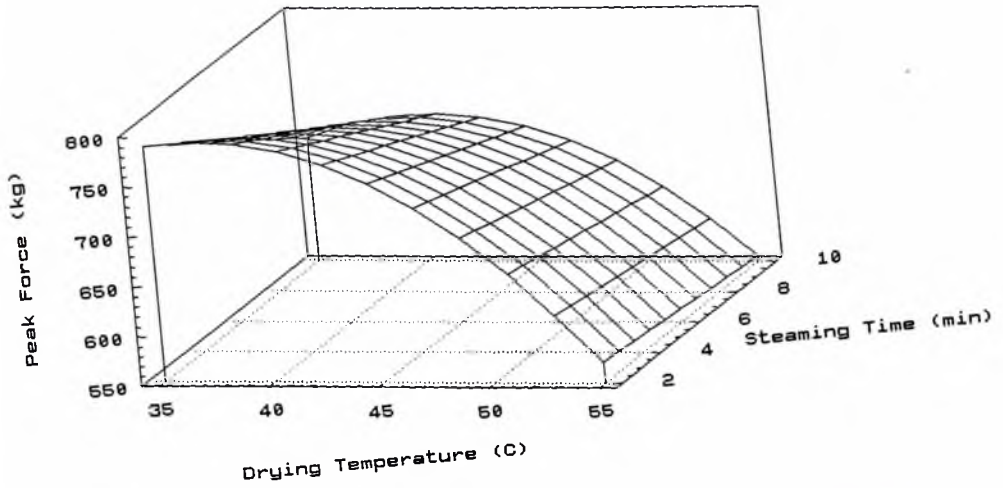
$$R^2 = 0.8267$$

X_1 = Steaming Time (min)

X_2 = Drying Temperature ($^{\circ}$ C)

X_3 = Drying Humidity (g water/kg air)

A



B

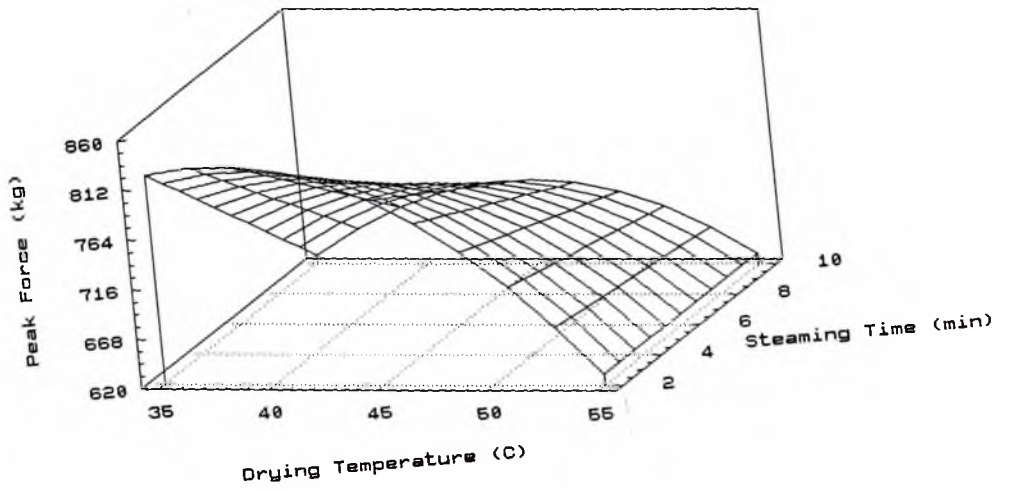


Figure 25 Response surface plot of hardness of steamed blackeye peas cooked for 90 min; for samples dried under humidity of 0.03 g water/kg air

Model

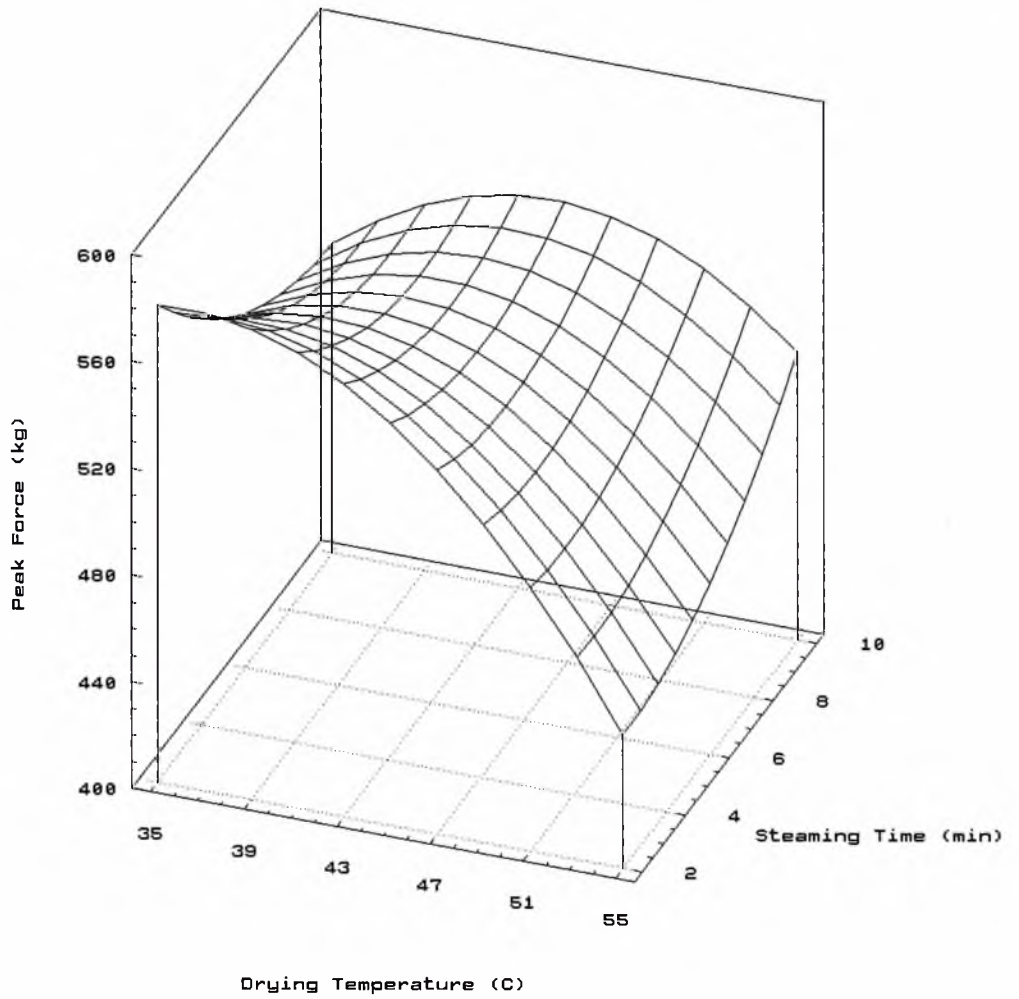
$$Y = 229.217833 - 45.28525X_1 + 24.8079X_2 + 7212.845833X_3 + 0.923971X_1^2 - 0.363785X_2^2 - 283334.6X_3^2 + 0.344677X_1X_2 + 13.579583X_1X_2X_3$$

$$R^2 = 0.9348$$

X_1 = Steaming Time (min)

X_2 = Drying Temperature (°C)

X_3 = Drying Humidity (g water/kg air)





the samples cooked for 60 and 90 min, steaming did not appear to have an noticeable influence on the cooked bean hardness.

Hung *et al.* (1990) suggested that the reduced shearing and fracturing forces observed with increasing pre-decortication drying temperatures of cowpeas was possibly due to damages in the middle lamella which aids in maintaining the integrity of the cell. The softening of beans during cooking has been attributed to the breakdown of the middle lamella (Sefa-Dedeh *et al.*, 1978; Shomer *et al.*, 1990; Hincks and Stanley, 1986). It is therefore possible that the steam treatment, in addition to the drying conditions, resulted in an alteration of the middle lamella. Due to this, it was relatively easy for the cell to loose its integrity following cooking and become progressively softer as the drying temperature increased and more damage occurred in the middle lamella.



5.0 CONCLUSIONS

1. An alternate steaming system based on the traditional method of steaming was designed and successfully used in the hydrothermal treatment of cowpeas. In most cases, similar results were obtained for all the indices measured irrespective of the steaming system used, indicating that the steaming method used did not have a significant effect on the indices measured. The new method proved more efficient in the reduction of trypsin inhibitor activity in cowpeas. This implies that the traditional method of steaming can be used in the hydrothermal treatment of cowpeas thereby making the technology more available.
2. The hydrothermal treatment had significant effects on the functional and chemical characteristics of cowpea seeds. The most notable effects were the reduced water absorption capacity and protein solubility. There was also a complete inactivation of trypsin inhibitors after steaming. These changes in functionality have both positive and negative consequences as far as the quality of the resulting steamed seeds is concerned.
3. The steam treatment resulted in an immediate and pronounced increase in cooked bean hardness. This is of significance since one of the major constraints to the efficient utilisation of cowpeas is the prolonged cooking times. However, storage resulted in some degree of softening of the seeds relative to what pertained at the beginning of the storage period. This softening was more obvious in the 10 min steamed samples stored at either

28°C or 6°C. Earlier reports on the hydrothermal treatment had identified the 10 min steaming as the optimum for the protection against insect infestation. It can therefore be concluded that exposing cowpeas to steam for 10 min would result in the most beneficial effect in terms of protection against insect infestation and also in the reduction of the hard-to-cook defect.

4. The amount of solids leached, soaked seed hardness, protein solubility and the cooked bean hardness were all significantly affected by the cowpea variety used. However, the variety had no significant effect on the other indices measured, i.e. water absorption capacity, least gelation capacity, trypsin inhibitor activity and germinating capacity.
5. The conditions under which the steamed cowpeas are dried influence the characteristics of the seeds. The drying temperature was the most important variable. Increasing drying temperature improved both water absorption capacity and dehulling efficiency. High drying temperature in combination with long steaming time and high drying humidity also enhanced the cooked bean hardness, giving seeds which were softer than the unsteamed. This means that in order to maintain and possibly improve the desired characteristics of steamed cowpeas, it is necessary to consider carefully, the drying conditions applied after steaming.

FURTHER STUDIES

Based on the results from this work, the following areas are suggested for further research:

1. Extensive studies on changes in protein and starch functionality to help understand and explain the hardening that results from the steam treatment. In addition, the variations in phytic acid and pectin concentration, and phytase and pectin methylesterase (PME) activity should be monitored.
2. The role of non-enzymatic mechanisms such as lignification, in the hardening process should also be investigated.
3. A study of the effect of storage time and condition prior to the hydrothermal treatment on the resulting steamed seeds.
4. The effect of different pre-cooking treatments such as soaking time, on the final cookability and utilisation of the treated cowpeas should also be investigated.

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