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Water Diffusion Coefficients Of Selected Cereals And Legumes Grown In Ghana As Affected By Temperature And Variety

BY

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WATER DIFFUSION COEFFICIENTS OF SELECTED CEREALS AND LEGUMES GROWN IN GHANA AS AFFECTED BY TEMPERATURE AND VARIETY

By

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DECLARATION

I, Antwi Godfred Isaac hereby declare that this submission is my own work towards the MSc Degree and that, no part to the best of my knowledge, contains material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledge has been made in the text.

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ABSTRACT

The kinetics of water absorption by six newly released maize (*Abrohemaa*, *Omankwa*, *Abotem*,*Abeleehi*, *Dorke SR* and *Akposoe)*, two cowpea (*Tona*and *Nhyira)* and two soybeans (*Nagbaar*and*Anidaso)* hybrids of cereals and legumes grown in Ghana were studied by a gravimetric method during soaking at four temperatures of 30, 40, 50 and 60ºC to determine their moisture diffusivity. The results showed that the absorption kinetics followed Fick's law of diffusion during the first hours of soaking and the water absorption patterns were dependent on temperature and variety. The estimated values for water diffusion coefficients varied from 2.54×10^{-10} to 4.89×10^{-10} m^2/s, 4.36×10^{-10} to 6.28×10^{-10} m^2/s and from 2.90×10^{-10} to $6.75 \times 10^{-10} m^2/s$ for maize, cowpea and soybean varieties respectively. An Arrhenius-type equation described the strong temperature effect on the diffusion coefficient with activation energies ranging from 7.04 to 9.09 kJ/mol for maize 7.73 to 8.56 kJ/mol for cowpea and 5.51 to 8.14 kJ/mol for soybeans

KEYWORDS: Maize, Soybean, Cowpea Arrhenius–type equation, Diffusion coefficient, Modelling, Water Absorption

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DEDICATION

I dedicate this piece of work to my wife, Christina Afua Armoh and my children, Andrew Kwaku Antwi, Ivy Kissi-Antwi and Kojo Yeboah-Antwi

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CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Cereals (maize, millet, sorghum) and legumes (soybean, groundnut, 'egusi' and cowpea) are important food and cash crops, mainly grown in the savannas of Sub-Saharan Africa (SSA). They provide cheap sources of energy and protein, and hence, are good substitutes or supplements to major food staples. They have the potential to become food of the future. They can also contribute to agricultural productivity and help meet the needs of Africa's teeming population.SSA produces 95% of the world's cowpea on 90% of the total global planting area; it also accounts for 15% of world maize production(IITA, 2009).

Maize (*Zea mays L.)* is a major staple food and source of calories for more than 300 million people. It is also an important fodder crop and industrial raw material. Cowpea is an important source of protein for over 200 million people in Africa. Over 90% of the total cowpea global production (4.3 million tons) is produced in West Coast of Africa. Cowpea (*Vigna unguiculata*) fodder is a great source of livestock feed in the dry savannah. Soybean (*Glycine max*) is emerging as an important food as well as raw material for producing high-quality protein products, which is currently grown on over one million hectares in Africa (IITA, 2009).

Cereals and legumes are mostly grown by small-scale farmers. Demographic pressure and the consequent demand for more food are driving small-scale agriculture towards greater intensification. Most crops are produced continuously without any fallow or use of external inputs. Such cropping practices lead to lowered soil organic matter content and soil biological diversity, and enhance the erosion risk. Other challenges to agricultural intensification and high productivity include the use of inappropriate varieties and cropping systems, high pest pressure, erratic moisture availability, high postharvest losses, poor access to input and output markets, lack of credit services, unfriendly policies, and low research and extension capacity in national programs. Most of these constraints interact in a very complex manner and result in unsustainable farming practices and land degradation, which have a significant impact on food security, levels of poverty and the environment in both rural and urban communities. The number of malnourished people continues to increase due to low intake of energy, protein, and micronutrients. Ghana produces and consumes significant quantities of cereals and legumes annually. These mainly comprise maize, millet etc. Table 1.1 shows the annual production rate and figures for the major cereals and legumes produced in Ghana.

Table 1.1Annual Production Figures of selected cereals and legumes ('000 Mt)

Crop	2004	2005	2006	2007	2008
Maize	82,819	99,751	108,409	86,128	131,859
Millet	50,489	71,499	50,458	37,815	66,108
Rice	83,274	84,504	90,857	51,405	105,496
Sorghum	72,786	79,631	81,499	53,020	98,908
Soybean	27,843	41,726	42,469	32,538	48,857
Cowpea	69,137	58,085	63,133	30,619	60,865
Groundnut	61,072	121,425	117,040	62,721	147,539

MOFA, (2008)

Legumes such as beans seed are protein-rich and commonly used in sauces, soups and other dishes in West African countries. The uses of cucurbit seed as sources of oils and proteins have been reviewed by Jacks et al. (1972). After the hull is removed, cucurbit seeds contain about 50 percent oil and up to 35 percent proteins. Most of their oil is made up of non-saturated fatty acids, thus of high nutritional values. (Conjugated fatty acid among some cucurbit oils make them highly useful as drying oils thus they combine readily with oxygen to form an elastic, waterproof film). The proteins on the other hand, are principally of the globulin type, and are deficient in lysine but also in sulphur-bearing amino acid.

Cereals and legumes often require a huge reduction in moisture content to ensure prolonged shelf life which would reduce or prevent deterioration in storage along the chain of distribution. However seeds need to be hydrated first to facilitate processing operations such as milling, cooking or canning. Adding water is a pre-treatment for the flour milling process (tempering). Tempering is a kernel moistening process that enhances milling efficiency. In tempering, temperature, variety, kernel size, and time of exposure affect the rate at which moisture enters into the kernel. Among these factors, temperature and variety have been shown to have the greatest effect. An increase in temperature results in an increase in the rate of moisture absorption (Kashaninejadl and Kashiri, 2007).Control of this process may be improved with better knowledge of the distribution and movement of moisture within the kernel.

1.2 Statement of the Problem

Soaking is an important operation during the processing of some foods as in rice parboiling (Engels et al., 1986). Dry cereals and legumes, whether used at home to prepare variety of dishes or in commercial practice (e.g. canning), need to be rehydrated by soaking in water or salt solution before further processing is done as in fermented soybean paste 'meso' (Minamiyama et al., 2003) and fermented maize products such as 'ogi' and kenkey (FAO, 1998). Soaking is considered necessary to achieve desired palatability and digestibility and to reduce cooking time, but its long duration has been and continues to be a major drawback (Deshpande et al., 1989).

Several investigations on how temperature, pH, physiochemical properties and other nutritional composition affect water absorption capacities of grains and beans have been conducted. Researchers have demonstrated that increasing the temperature of the soaking medium is an effective way to accelerate water uptake by various seeds and hence, shorten the soaking time (Quast and de Silva,1977 and Abu-Ghannam and Mckenna, 1997). Also, many studies (Hsu, 1983; Resio et al., 2003; Addo et al., 2006) have reported the influence of temperature on moisture diffusivity into soybean, amaranth grains and maize kernels respectively.

Smith and Nash (1961) studied the water absorption of U.S and Japanese soybeans. They reported that the principal controlling factor in absorption of water is the seed coat. They also found out that the rate of water absorption of sound whole beans is influenced by the initial moisture content in the bean.

Powers (1959) reported that the rate of water imbibitions of cowpeas and pinto beans was affected by the pH of the soaking solution, but he did not specify how the rate was influenced. Snyder (1936) observed that, for Great Northern beans, imbibitions were slower in weak acid solution. The rate of water imbibitions was also found to be conversely related to the peptic content of dry beans and cowpeas.

However, effects of varietal variations and processing variables on the rate of water uptake in some newly released cereals and legumes grown in Ghana, such as maize (*Abrohemaa, Omankwa, Abotem Abeleehi, Dorke SR and Akposoe)*; soybean (*Nagbaar and Anidasi*) andcowpea (*Tona* and *Nhyira*) have not been clearly established. It is thus necessaryfor this study to show how temperature and variety affect the water absorption characteristics of these newly released local varieties.

1.3 Significance of the study

Processing of cereals and legumes often requires that the seeds be hydrated first to facilitate operations such as milling, cooking or caning. Thus, absorption of water into these materials is of both theoretical and practical importance to processing industries (Hsu,1983; Taiwo, 1998 cited by Addo, et al 2006).

The amount of water absorbed by seeds during soaking is affected by different factors such as the initial moisture content, variety of the seeds, soaking duration, and temperature and acidity level of the water (Hsu et al., 1983; Karapantsios et al., 2002; Laria et al., 2005). Understanding these factors that influence the soaking medium is an effective way to accelerate water uptake by the grain as it shortens the soaking time.

From engineering point of view, one is interested not only in knowing how fast the absorption of water can be accomplished, but how it will be affected by processing variables such as temperature (Verma and Prasad, 1999 cited in Addo et al., 2006) and also how to predict the soaking time under given conditions. Thus, the quantitative data on the effect of processing variables are necessary for application to optimise and characterise the soaking conditions, design food processing equipment and predict water absorption as a function of time and temperature. Nevertheless, limited data on these varieties will hinder satisfactory prediction of duration of reaching equilibrium constant during soaking. Warm water soaking is a common method to shorten the soaking time, because higher temperature increases hydration rate. However, soaking temperature below starch gelatinization is recommended to minimize leaching of solids (Luh *et al.*, 1980). Many researchers have studied the drying of cereals and legumes from different points of view but there is less information about soaking of the newly released maize, cowpea and soybean hybrids grown in Ghana

The concept of enthalpy is routinely used to evaluate changes in heat content of steam or moist air (Stroshine and Hamann, 1995). It is particularly useful for food products because the enthalpy combines latent and sensible heat changes. Enthalpies of many food materials have been published and summarized in tables and charts given in the ASHRAE Handbook of fundamentals (ASHRAE, 1989), However, literature search on moisture diffusion data on newly released maize (*Abrohemaa, Abotem, Omankwa, Akposoe, Abeleehi and Dorke SR*); cowpea (*Tona* and *Nhyira*); and soybean (*Nagbaar* and *Anidaso*) hybrids grown in Ghana yielded scanty information. Thus the purpose of this study wasto determine the water absorption characteristics of these newly released hybridsin Ghana.

1.4 The Main Objective of the study

In sorption process and equipment design it is highly desirable and of practical importance to predict the moisture gain by seeds as a function of time and temperature. This however, depends on availability of moisture diffusivity data for the seeds being considered. Therefore, the main objective of this research was to determine water diffusion coefficients at different soaking temperatures for the newly released cereals and legumes grown in Ghana,

1.5 The Specific Objectives of Study

In order to achieve the above main objective, the following specific objectives were pursued:

1. To determine water absorption characteristics of six newly released maize (*Abrohemaa, Abotem, Omankwa, Akposoe, Abeleehi and Dorke SR*); two cowpea (*Tona* and *Nhyira)*; and two soybean (*Nagbaar* and *Anidaso*) hybrids in Ghana at different soaking temperatures
2. To generate moisture diffusivity data for the newly released hybrids.
3. To determine energy of activation of these ten newly released hybrids.

CHAPTER TWO

LITERATURE REVIEW

2.1 Economic value, nutritional and chemical composition of cereals and legumes

A number of cereals and legumes that are readily available in West Africa have been found to have nutrient potentials that could complement one another if properly processed and blended(Fernandez, 2002).

Researchers believe that complementary foods based on legumes and cereals formulated from locally available food commodities have great potential in providing nutritious foods that are practical, food-based approaches aimed at combating the problem of malnutrition among infants and children in Ghana in particular, and developing counties in general. A study conducted by Solomon (2005) revealed that ready-to-eat complementary food products formulated from locally available food commodities, can meet the macro nutritional needs of infants and children.

These assertions led to efforts to formulate composite blends and scientific studies carried out to ascertain the nutritive adequacy of these locally available blends (cereal and legumes) for possible use as complementary foods, especially by the rural and poor urban mothers during weaning period.

2.1.1 Uses of Maize

Maize is consumed in many forms in different parts of the world, from maize grits, polenta and corn bread to popcorn and products such as maize flakes. The grain is fermented to givecorn dough in Ghana, 'ogi' in Nigeria and other countries in Africa and is decorticated, degermed and precooked to be made into 'arepas'(Hesseltine, 1979).

In Egypt, maize flat bread, 'aish merahra', is widely produced. Maize flour is used to make a soft dough spiced with 5 percent ground 'fenugreek' seeds, which is believed to increase the protein content, improve digestibility and extend the storage life of the bread. The dough is fermented all night with a sour dough starter. In the morning the dough is shaped into small, soft, round loaves, which are left for 30 minutes to "prove". Before baking, the loaves are made into wide, flat discs. 'Aish merahra' keeps fresh for seven to ten days if it is stored in airtight containers. A similar product called 'markouk' is eaten in Lebanon.

Maize is also widely used to make beer/'pitoo'. In Benin, for example, malt is obtained by germinating the grain for about five days. The malt is then exposed to the sun to stop germination. The grains are lightly crushed in a mortar or on a grinding stone. The malt is cooked and the extract is strained off, cooled and allowed to stand. After three days of fermentation it is ready to be drunk as beer (FAO, 1998).

The lime-cooking process for maize is particular to Mexico and Central America (Brennan et al, 1990), although today the technology has been exported to other countries such as the United States. A dough prepared from lime-cooked maize is the main ingredient for many popular dishes such as 'atole', a beverage with a great variety of flavours, and 'tamalitos', made by wrapping the dough in maize husks and steam-cooking it for 20 to 30 minutes to gelatinize the starch. This form is usually prepared with young 'chipilín' leaves (*Crotalaria longirostrata*), the flowers of 'loroco' (*Fernaldia pandurata*) or cooked beans mixed with the dough, thus improving the nutritional quality of the product and its flavour

(Brennan, 1990). The dough is also used for ‘tamales’, a more complex preparation because of the number of ingredients it contains, in most cases with chicken or pork meat added to the gelatinized dough. It is also used to provide support for ‘enchiladas’, tacos’ (folded tortillas containing meat, etc.) and ‘pupusas’, the latter made with fresh cheese placed between two layers of dough and baked like ‘tortillas’. When the dough is fried and flavoured, it yields foods such as chips and ‘chilaquiles’. If the dough is allowed to ferment for two days, wrapped in banana or plantain leaves, it provides a food named ‘pozol’ from which a number of drinks can be made. It has been claimed that this preparation is of high nutritional quality.

There are many ways to convert maize into interesting and acceptable forms which, if presented in attractive and easily prepared products, could to some extent counteract the trend toward greater consumption of wheat derived foods in ‘arepa’- and ‘tortilla’-eating countries and elsewhere

2.1.2 Uses of Legume (soybean and cowpea)

Scientifically, it has been proved that breast milk is the perfect food for the infant during the first six months of life. It contains all the nutrients and immunological factors an infant requires to maintain optimal health and growth. Furthermore, breast milk also protects infants against the two leading causes of infant mortality, upper respiratory infections and diarrhoea (UNICEFBreastfeeding: Foundation for a healthy future. UNICEF, New York.1999).

However, at the age of six months and above when the child’s birth weight is expected to have doubled, breast milk is no longer sufficient to meet the nutritional needs of the growing infant. Nutritious complementary foods are therefore introduced - also known as weaning foods - which typically covers the period from six to twenty four months of age in most developing countries (WHO/OMSChild and Adolescent Health and Development: Nutrition and Infant Feeding 2000).

The study also indicated that a large proportion of nursing mother utilized soybean as source of protein to feed their children. This idea was as a result of the high price of commercial weaning and animal foods which cannot be afforded by many of the low-income families, and it was the believe of these mothers that fortifying the local weaning diets with soybean would ensure that infants and children consuming these soybean-supplemented diets would be able to meet their requirements for protein and some other nutrients. The study established that a high percentage of the mothers agreed that soybean was a good source of protein; and that Soybean could be used as protein substitute in weaning food.

Studies have shown that cowpea (*Vigna unguiculata*) and soybeans (*Glycine max*) are important sources of proteins, particularly for those nursing mothers who cannot afford to purchase commercial complementary foods for their children. The nutritional value of cowpeas lies in their high protein content, which is higher than that of cereals. The utilization of cowpeas as weaning diet is widespread in Ghana and Nigeria and other developing countries either alone or in combination with cereals or other food materials (FAO,1970; Dovlo *et al*., 1976)

2.2 Importance of soaking

For either feeding or extracting oil, most cereals and legumes are initially soaked in water. The hydration of cereals and legumes is an important step in the production of traditional food especially soybean derivatives, such as soy sauce (Nelson et al., 1976) and 'tofu'. The saturation process modifies the textural characteristics of legumes and makes protein extraction easier. The textural changes are known to result from the absorption of water during hydrationwhich also affects softening the hard pit to facilitate grinding(Liu, 1995). Additionally, hydration reduces: the cooking time, the bean processing mass losses, and improves the product quality (Wang et al., 1979).

In order to obtain better quality protein, it is necessary to reduce the cooking time, which can be achieved by soaking before cooking as reported by other researchers (Molina et al., 1975; Wang et al., 1979).

However, soaking of many agricultural seeds is a time-consuming process. For instance, corn kernels are soaked for up to 72 hours before milling (Ji et al., 2004). Kon (1979) also maintained that the hydration of beans at temperatures over 50°C has an adverse effect on cooking rate and that beans hydrated at 40°C have a shorter cooking time, which has led to the use of temperatures between 10 and 50°C.

Soaking grains (including oats and flour), nuts, seeds, and beans is very beneficial to our bodies, primarily because it helps the digestion process. Grains, nuts, seeds, and beans contain enzyme inhibitors, which make them harder to digest and less nutritious. Grains and beans contain phytic acid, which prevents the body from fully absorbing the nutrients like calcium, magnesium, iron and zinc. However, soaking grains and beans will mitigate the effects of these so-called anti-nutrients.Beans and grains cook faster after they have been soaked, and nuts and seeds will taste fresher and lighter.

Several studies have also demonstrated that legumes require hydration to thoroughly eliminate anti-nutritional factors, to improve proteindigestibility, and to reduce cookingtime (Ellenrieder et al., 1981; Silva et al., 1981; Kochhar, 1986).

Furthermore, all seeds need to remain secure until they are able to sprout. This stability is maintained via elements that suppress the enzymatic activity involved in germination-anti-nutrients.

Anti-nutrients may 'take' more nutrition than they provide. During healthy digestion our own enzymes work to disassemble food into usable molecules. This begins in the mouth with the enzymes present in saliva, and continues in various forms throughout the entire digestive tract. But antinutrients work by inhibiting our digestive enzymes and preventing them from breaking down food, interfering with healthy digestion. Also, anti-nutrients are bound to precious minerals like iron, zinc, magnesium, and calcium. Essentially, they steal these minerals from our bodies. A diet rich in anti-nutrient-containing foods can lead to mineral deficiency and may contribute to poor bone density.

Other anti-nutrients include flavanoids, like tannins, starches, and some proteins, such as lectins. All of these may irritate the stomach and interfere with digestion. However some, like flavanoids, are cancer-fighting and have other nutritive qualities. Soaking seeds initiates germination by 'kicking off' the sprouting process, anti-nutrients are disabled and enzymatic activity increases. Phytic acid is deconstructed and inhibitors are neutralized.

The acid used in the soaking medium breaks the bonds that bind important minerals, and they become bioavailable. Thus, the seeds become digestible – and nutritious.

Soaking also begins to 'pre-digest' the seeds. For example, soaking and sprouting can break down certain proteins, such as gluten. This can facilitate digestion as well – some people with gluten sensitivity can eat soaked and sprouted glutinous grains.

2.3 Effect of soaking and cooking on nutritional quality and safety of legumes

Legumes are widely grown and are consumed as a source of plant protein throughout the world. They rank second after cereals with respect to their consumption order. Legumes have anti-nutritional factors which make their uses limited.

Studies have revealed that dark colour legume (red kidney beans) has a high level of phytic acid and tannin compared with light colour (white kidney beans and white grams). Soaking and cooking of legumes result in significant reduction in phytic acid and tannin contents. Maximum reduction of phytic acid (78.05 per cent) and tannin (65.81 per cent) was found for sodium bicarbonate soaking followed by cooking. These treatments also result in a slight reduction in nutrients such as protein, minerals and total sugars.

Lestienne et al. (2004) and Garcua-Pascual et al. (2006) made similar observations when the effects of soaking whole cereal (maize, millet, rice, sorghum) and legume seeds (mung bean, cowpea, soybean) on iron (Fe), zinc (Zn) and phytate (Phy) contents were investigated.

In all the above cereals, except millet, the molar ratios of Phy/Fe were above 14, and ratios of Phy/Zn were above 20 while, in legumes, ratios were lower. Soaking whole seeds for 24 h led to leaching of iron and, to a lesser extent, of zinc ions into the soaking medium. Soaking led to a significant reduction in the phytate content of millet, maize, rice and soybean, but did not improve the Phy/Fe molar ratio, while decreasing the Phy/Zn molar ratio only slightly. Soaking on its own was not found to be a good method for improving mineral bioavailability but the results showed that, in combination with other treatments, or with optimized soaking conditions, it could nevertheless prove useful.

Tunde-Akintunde (2010) also studied the effect of soaking water temperature and time on some rehydration characteristics and nutrient loss in dried bell pepper. He reported that at higher soaking water temperatures, larger amounts of vitamin C leached into the soaking water. However, for calcium and Iron, larger amounts were leached into the soaking water at lower soaking temperatures.

Roiz (1997) reported that soaking of sun-dried products for half to two hours have been identified as giving an acceptable result while continuous soaking for up to six hours produced a tenderer product.

2.4 Effects of moisture content on physical properties of cereals and legumes

Among the engineering properties, the physical properties of materials are more important in the agricultural process engineering for the post harvest operations (Vaishnava et al., 2000). Knowledge of how the physicalpropertiesof grain vary with changes in moisture content is one of the prerequisites for the design and development of efficient processing and handling machines for the grains (Tavakoli et al., 2009; Lazaro et al., 2005). The relative percentage of moisture in food materials is dynamic and it influences the physical properties and product quality of nearly all food materials at all stages of processing and final product existence as well (Werolowski,2003). The moisture-dependent physical properties of the beans may affect the adjustment and the performance of equipment for processing, storage and handling. The optimum performance of a processing equipment may be attained within a certain moisture range and therefore knowledge about these physical properties of the cereals and legumes and their variation with moisture is very important in the construction of storage, handling and processing equipment (Baryeh, 2001).

Physicalpropertiesof two varieties ofsorghum (*Dionje* and *Jumbo*) and one variety of pearl millet were investigated at different moisture levels within the moisture range 12 to 25% dry basis.

The results showed that within this moisture range, all the physicalproperties studied varied linearly with moisture content. Linear dimensions (length, width and thickness), geometrical mean diameter, sphericity, surface area, volume, kernel density and porosity increased with increase in moisture content of the grain. On the other hand, bulk density decreased with increase in moisture content of the grain (Lazaro, et al., 2005).

Olayinkaet al. (2006) studied the effect of heat-moisture treatment on physicochemical properties of white sorghum starch. In the study, white sorghum starch was subjected toheat-moisture treatment (HMT) at moisture levels ranging from 18% to 27%. The treatments had a great impact on the physicochemical properties as studied with a Rapid Visco analyzer (RVA). The increase in onset temperature of viscosity development and the decrease in the peak viscosity observed with RVA as a consequence of HMTs were also attributed to the decrease in swelling power and solubility. The swelling power and solubility increased with increasing degree of alkalinity which revealed that they were pH dependent with higher values obtained at pH 12 in both native and modified starches.

Water absorption capacity, oil absorption capacity and alkaline water retention of the starches were enhanced after HMT.

Tavakoli et al. (2009) carried out a study to evaluate the effect of moisture content on some physical properties of barley grains. Four levels of moisture content ranging from 7.34% to 21.58% (d.b.) were used. The average length, width, thickness, arithmetic mean diameter, geometric mean diameter, thousand grain mass, sphericity, surface area and repose angle increased from 8.91 to 9.64 mm, 3.30 to 3.74 mm, 2.58 to 2.98 mm, 4.93 to 5.45 mm, 4.23 to 4.75 mm, 44.48 to 51.30 g, 47.55% to 49.35%, 56.66 to 71.09 mm^2 and 31.16° to 36.90°, respectively, as moisture content increased from 7.34% to 21.58% (d.b.). The bulk density, true density and porosity were found to decrease with increasing moisture content. The static friction coefficient of the grains increased linearly against various surfaces (plywood, glass and galvanized iron sheet) as the moisture content increased.

2.5 Absorption characteristics of Agricultural materials

Water absorption may be defined as (1) the amount of water absorbed by a composite material when immersed in water for a stipulated period of time. (2) The ratio of the weight of water absorbed by a material, to the weight of the dry materials. All organic polymeric materials will absorb moisture to some extent resulting in swelling, dissolving, leaching, plasticizing and/or hydrolyzing, events which can result in discoloration, embrittlement, loss of mechanical and electrical properties, lower resistance to heat and weathering and stress cracking.

The amount of water absorbed by seeds during soaking is affected by different factors such as the initial moisture content, variety of the seeds, soaking duration, and temperature and acidity level of the water (Hsu et al., 1983; Karapantsios et al., 2002; Laria et al., 2005). On the other hand, the agricultural seeds are not uniform and consist of three major parts, namely, seed coat, endosperm, and embryo. Since in most seeds the endosperm occupies the major part of the seed, a seed is usually considered as a uniform entity in many moisture transfer studies (Gaston et al., 2004; Bakalis et al., 2009).

Modelling the process of water absorption by agricultural seeds helps in understanding the dynamic and kinetic of this process and this knowledge is valuable for proper management of their soaking processes. Mathematical modeling of the agricultural seeds has been approached by three general methods: (1) empirical approach wherein a suggested model is fitted to experimental data (Hung et al., 1993; Turhan et al., 2002; Badau and Jideani, 2005; Noorbakhsh et al., 2006); (2) theoretical methods which are generally based on principles of moisture diffusion, sometimes coupled with heat or mass transfer equations (Vizcarra et al., 2003; Gaston et al., 2004; Gely and Giner, 2007); and (3) semi-theoretical approaches which are generally a modified form of theoretical models (Misra and Brooker, 1980).

Some crops are wellknown for their hygroscopic behaviour. However, it has been observed that the degree of swelling varies with varieties, condition of seed (e.g. raw or parboil rice) and processing methods (Juliano, 1985).

Waterabsorptioncharacteristics of sorghum and millet at temperatures 20 to 50^0C were investigated using the Peleg's model or equation. Two sorghum varieties and one pearl millet variety were used in this investigation. Waterabsorptioncharacteristicsof the grains were investigated by soaking samples of the grain in distilled water at temperatures of 20, 30, 40 and 50^{o}C and determining the amount ofwater absorbed after every one hour of soaking duration. The data obtained was compared to the one predicted by Peleg's model. The model was able to predict the hydration process adequately within the temperature range studied. Peleg's constant K_1 was found to be inversely related to soaking temperature while Peleg's constant K_2 was unaffected by the soaking temperature. Temperature dependency of the reciprocal of K_1 was investigated using the Arrhenius function. The activation energy for sorghum and millet during tempering was found to be in the range 24.6 - 39.5 kJmol^{-1}. Based on the Peleg's model and Arrhenius function, a general model for prediction ofwaterabsorption in sorghum and millet at any specified temperature was developed. The developed model was able to simulate the experimental data very well. (Lazaro and Favier,2001).

Sopade et al. (1994) made similar observation after studying water absorption characteristics during soaking of maize, millet and sorghum at 10°C, 30°C and 50°C. The report indicated that Peleg constants were obtained for the cereals. The constant K_2 was unaffected by temperature of soaking. The study further indicated that temperature dependence of the reciprocal of the Peleg's constant K_1 was determined using an Arrhenius equation. Activation energy y was in the range 13·99–16·23 MJ mol^{-1} compared to 19·02–19·56 MJ mol^{-1} obtained for soybean, cowpea and undehulled groundnut. They proposed an exponential relationship to describe the relationship between the rate of absorbed water per unit change in temperature and the activation energy.

Several investigations on how varietal difference affects the water absorption capacities of rice have been carried out. The physicochemical properties of the grain such as amylose content (Williams et al. 1958; Webb 1975; Agidi et al. 2009; Juliano 1979), amylographic gelatinization and paste viscosity characteristics (Hallick and Kelly, 1992), protein content (AACC, 1962), parboiling and canning stability (Webb and Adams, 1970) greatly affect the water absorption capacities of the rice grain. However, among these quality indicators, amylose content has been found to be the single most important characteristics for predicting rice cooking (water uptake) behaviour (Williams et al. 1958; Webb 1975; Juliano, 1979).

Juliano (1985) also carried out a study on the water uptake behaviour of raw and parboiled rice and found out that parboiled rice has lower water absorption capacity than raw rice and thus retains better shape, is fluffier, less sticky, more consistent and loses less solids during cooking.

Processing condition such as mode and degree of soaking of paddy influences water uptake capacity of the rice grain.

Shittu et al. (2009) also studied the typical hydration curves of paddy and brown rice ofITA 150 and WAB 189. The rate of moisture migration was dependent on the temperature of soaking. The higher the soaking temperature, the higher the rate of moisture absorption.Change in sorptive capacity of rice as a result of heat treatment which is usually influenced by the gelatinization temperatures of the kernel was also reported by otherresearchers (Bandyopadhay and Roy,1992; Ali et al., 1991) although, no explanation was given about the parameters of the heat treatment that caused the change in the sorptive capacity of the rice.

Shittu et al. (2009) further argued that the sudden jump in the moisture absorption pattern as the soaking temperature increased from 30°C to 45°C might be due to some microstructure details that are yet to be studied for the different rice varieties. At the beginning of the soaking period, a higher rate of absorption was observed in the case of brown compared to paddy over the entire temperature range. The hydration rate curve indicates that there were some adjustment periods when paddy was soaked at 30°C. The hydration rate curves were generally characterized by approximately two falling rate periods. However, the first falling rate period occupied less than 12% of the total soaking period. The capacity of the grain components to absorb moisture over an infinitely long soaking period is given by the equilibrium moisture content (EMC). The water absorption capacity of soaked grain affected the mechanical behaviour of grain during processing operations like wet milling (Ituen et al., 1985) and could also have textural implications for the cooked product. They indicated that the soaking temperature and the grain component are the major factor that accounted for the variation in the EMC values. This has a lot of techno-economic implications. For example, in the study conducted by Soponronnarit et al. (2008), water uptake capacity of rice grain showed some significant correlations with volume expansion and solid loss during cooking. Hirannaiah et al. (2001) suggested that higher solid loss in soaked rice was due to surface cracking which in turn enhanced leaching of soluble solids. However, for these new rice varieties, the varietal effect on cooking characteristics is yet to be investigated. Insignificant differences were observed in the EMC values of the rice cultivars. Generally, EMC increased with soaking temperature

The water absorption characteristics of 'acha' (*Digitaria exilis*) was investigated at temperatures between 40°C and 100°C. The Peleg's equation was used to model the hydration behaviour of the hydrated grains. The correlation coefficient for Peleg's equation, which varied from 0.9931 to 0.9986, suggests that the equation gave a good fit to the experimental data. The water absorption capacity and hydration equilibrium water contents of the grain increased as the hydration temperature increased. The gelatinization temperature of ‘acha’ was 60°C and the activation energy was found to be 0.35 kJ mol^{-1} and 2.00 kJ mol^{-1} above and below this temperature.

2.6 Water Absorption characteristics of maize

There have been several reports in the literature on the water uptake of corn kernels and other cereal grains during steeping. It has been found out that addition of either Sulphur dioxide (SO_2) (Fan et al., 1965; Haros et al.,1995) or latic acid (LA) (Ruan et al., 1992;Haros and Suárez,1999) accelerates the rate of moisture absorption in dent corn hybrids. Accelerated hydration of the kernel could result in shorter steeping times and, consequently, lower milling costs.

Dailey (2000) determined the influence of the addition of LA, SO_2, or both, to the steepwater exerted on water absorption by the germ and endosperm, and assessment of variability in the hydration of individual kernels. He observed that the composition of the soak solution with the addition of either LA or SO_2 or both LA and SO_2 did not significantly affect the rate of hydration of either the germ or endosperm. The studies further indicated that, in many instances, there was considerable variation in the moisture content of individual germ and endosperm for a given steep time. The results of the study was in contrast with some earlier laboratory studies which indicated that the addition of either LA (Ruan et al., 1992; Haros and Suárez, 1999) or SO_2 (Fan et al., 1965; Haros et al., 1995) results in a change in water absorption in the kernel. This provides a better understanding of the steeping process, specifically on the hydration of the germ and endosperm components of corn kernels and the influence of steeping chemicals. The high variability in the measured moisture content of an individual germ or endosperm for a given steep time demonstrates that determination of the moisture content of the individual germ and endosperm components of one or a few kernels may not be descriptive of the bulk material.

2.7 Hydration kinetics of cereals and legumes

Soaking of cereals and legumes is an important part of processing operations like germination, cooking, flour milling process (tempering) and preparing a product from it. Hydration is a complex process and indicates the physical and chemical changes caused by processing. Processing of cereals often requires that the seeds be hydrated first to facilitate the consecutive extraction or cooking. Thus penetration of water into these materials is of theoretical and practical interest to the processing industry. The rate of water absorption has significance in the formulation of foods. In the canning industry, knowledge in hydration characteristics of grains prior to further processing is necessary to know the changes such as leaching losses, and grain expansion in the can during a thermal process. In order to control and predict the process, optimizing the hydration condition is vital since hydration governs the subsequent operations and the quality of the final product (Kashaninejad et al., 2007).

Water diffuses into the grain and some components leach out during soaking. Both phenomena are functions of time and temperature (Chiang et al., 2002). Soaking is a slow process controlled by the diffusion of water in the grain (Engels *et al.*, 1986). Thus soaking at room temperature may provoke microbial contamination, which affects quality attributes (such as colour, taste and flavour) of the product (Bello et al., 2004). Warm water soaking is a common method to shorten the soaking time, because higher temperature increases hydration rate. However, soaking temperature below of starch gelatinization is recommended to minimize leaching of solids (Luh et al., 1980). The behaviour of starch in water is temperature and concentration dependent (Whistler and Paschall, 1967). Grain starches in general show very little uptake of water at room temperature and their swelling power is also small. At higher temperature water uptake increases and starch granules collapse, which lead to solubilisation of amylase and amylopectin to form a colloidal solution. This is because temperatures above the gelatinization temperature of starch (approximately 60ºC) can result in loss of crystallinity, increased diffusion of water into granule, increased hydration and swelling power of starch (Eckhoff and Tso, 1991).

Many researchers have studied the drying of cereals and legumes from different points of view but there is less information about soaking of legumes and cereals. Moisture content distributions within a wheat kernel was predicted from a finite element diffusion model, and moisture diffusion coefficients for wheat kernel during isothermal moisture soaking were determined (Kang *et al.*,1999). Kang and Delwiche (2000) described the relationship between moisture movement in the wheat kernel and the shape and composition of the kernel with an analytical solution of the diffusion equation. Many studies (Hsu, 1983; Resio *et al.*, 2003; Addo *etal.*,2006) have reported the influence of temperature on moisture diffusivity into soybean amaranth grains and maize kernels to follow Arrhenius relation. Seyhan-Gurtas et al. (2001) determined the diffusion coefficients of water in selected legumes grown in Turkey at various temperatures ranging from 15 to 40°C and mentioned that the effective water diffusivity values of the selected Turkish legumes varied from 4.35x 10^{-11} to 3.79 x 10^{-9} m^2/s, giving nearly 90-fold variation. The temperature dependency of diffusivity was adequately described by an Arrhenius equation with the activation energies ranging from 34 to 51 kJ/kg-mol.

Addo and Bart-Plange (2009) studied the kinetics of sorption by egusi melon seed and reported that the diffusion coefficient of the grain at temperatures between 30^oC and 70^oC were in the range of 5.18×10^{-8} to 20.99×10^{-8} m^2/s with activation energy of 28 KJ/mol. Tagawa et al. (2003) also observed that water absorption of wheat kernel was in the second falling rate period. If the two phenomena (i.e. drying and water absorption of wheat kernel) are reversible, then the water absorption process of wheat kernel could be explained using the theory of diffusion in the same manner as drying models can be used to describe water absorption behaviour of wheat kernels. Furthermore, Pabis and Henderson (1961) reported activation energy of 32.2kJ/mol, while Tolaba and Suarez (1988) found a value of 27.6kJ/mol for maize drying process. The difference in values could be due to varietal characteristics arising from the genetic constitution of each hybrid.

Pinto (2004) and Esin (2004) at different periods conducted experiment to examine the swelling power of chickpeas as they are soaked in water to show phenomenon such as osmotic flow, mass transfer, diffusion, kinetics of hydration, modelling, and estimation of activation energy. They analysed the experimental data using an empirical model (Peleg equation) for the description of moisture sorption curves for different foods soaked in water. The equations that fit adequately with experimental data allow the calculation of initial hydration rates at different temperatures, and subsequently, the estimation of the activation energy, E_a, of the process. The obtained values of activation energy show that the process was controlled by diffusion and not by chemical reaction. It was also observed that, for a given temperature, the increase in concentration of NaCl in the immersion solution results in the decrease of hydration kinetics.

2.8 Factors affecting water absorption in Soybeans

The weight gains are expressed as a fraction of total amount of water absorbed at time t.The water absorption by soybeans during hydration depends mainly on thetime-temperature binomial, increasing with the hydration time and watertemperature (Wang et al., 1979; Sopade et al., 1990; Chopra and Prasad, 1994).

The phenomenon became less obvious at higher temperatures, due largely to the increased diffusion rate at these temperatures.The kinetics of water absorption by legumes during hydration has been described by empirical models by Peleg (1988), Singh et al. (1987), Sopade and Obekpa (1990), Pan and Tangratanavalee (2003), Saguy et al. (2005), and by phenomenological models derived from Fick's diffusion law (Hsu, 1983, Tang et al., 1994, Coutinho et al., 2007). Of these, the Peleg (1988) model and phenomenological models derived from Fick's diffusion law stand out as the most used in the rehydration of legume seeds (Abu-Ghannam, 1998; Hung et al., 1993; Ibarz et at., 2004; Sopade and Obekpa, 1990). Although the empirical model is simple to apply, and they adequately describe the hydration of several seeds (Sopade and Obekpa, 1990; Hunget al., 1993; Abu-Ghannam and McKenna, 1997), they are not derived from any physical law or diffusion theory.

Tunde-Akintunde (2010) also observed that as the temperature of the soaking water increased, rehydration became faster and higher moisture contents were reached within the same time interval. This is probably due to the fact that increase in the temperature of the soaking water resulted in the rapid absorption of water as a result of a more open structure which favoured rapid rehydration. This assertion is similar to the observation of Brennan et al. (1990) that reconstitutability of food products depends principally on the internal structure of the dried pieces, extent to which water-holding components like protein and starch have been damaged during drying. They also indicated that the rate at which air-dried food products reconstitute is increased when the food has an open, porous structure.

Salts are often added to the soaking water to induce certain features in the products. For instance, sodium bicarbonate is used to reduce cooking time of beans (Rockland and Metzler, 1967) and ethlenediamine tetraacetic acid and citrate are used to aid in the retention of color and flavour (Junek et al., 1980; Luh et al., 1975). Bicarbonate was also used in the Illinois Process for making soy milk.

The effect of these additives on the rate of water absorption of soybeans was studied by Hsu et al.(1983). The result of the study revealed that bicarbonate concentration up to 0.5% did not cause significant changes in the rate of water absorption from that of deionized water. At 1% concentration (pH 8.8), a slightly lower absorption rate was observed, and at 5% concentration (pH 9.5), this slower water-uptake rate was even more pronounced. This observation did not agree with results reported by Snyder (1936), which showed that lower pH slows water uptake. Because soy protein is quite soluble between pH 7 and 9, a faster rate of water uptake rather than a slower one can be expected at this range. Other factors might have contribution toward the slower rate observed. These factors might include the higher viscosities and lower water activities associated with the more concentrated bicarbonate solutions

Studies on the rate of water penetration into wheat kernels have indicated that high protein content, compact endosperm structure, and greater kernel hardness hinder the rate of absorption (Stenvert and Kingswood 1976). An experiment designed to correlate the total water absorption and absorption rate with the protein content, size, and density of the soy beans revealed that, total absorbed water ranged from 120 to 140% of the original weight of the beans, depending on the variety. The study also showed that there was no correlation between total absorption and protein content. Likewise, similar plot of total absorption versus soybean size and density did not result in any meaningful correlations. However, a linear correlation between absorption rate and kernel size was depicted. They further indicated that a significant correlation was found with the correlation coefficient being -0.53. The negative correlation between absorption rate and kernel size was reasonable because smaller kernel size tends to provide a larger surface area per unit mass for mass transfer.

Water absorption by faba beans (*Vicia faba*) was determined by recording the weight increase in beans with respect to time. Temperature affected the rate of water absorption since the rates increased with increasing temperatures. The study also covered the effects of soaking the bean in different concentrations of sodium bicarbonate. It was observed that the rate of water absorption decreased with increasing concentrations of sodium bicarbonate in soaking solutions. The rate of water absorption did not correlate with protein content and it showed little correlation with the size and density of faba beans. A diffusion model was used to describe the absorption of water by the beans. Diffusivity was not dependent upon the water content in beans (Kader,1995).

The water absorption by soybeans during hydration depends mainly on the time-temperature binomial, increasing with the hydration time and water temperature (Wang et al., 1979; Sopade et al., 1990; Chopra and Prasad, 1994).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Preparation of Samples

All the physical analyses of this research work experiment were carried out at the Food and Postharvest Engineering laboratory, Department of Agricultural Engineering, College of Engineering, Kwame Nkrumah University of Science and Technology, Kumasi. However, the water absorption experiment was carried out at the Physics Laboratory, Department of Science, St Josephs' College of Education, Bechem.

The cereal and legume varieties, grown in Ghana, were obtained from the experimental farm of Crops Research Institute (CRI), Fumasua, Kumasi. The varieties used in this work were six newly released varieties of maize; *Aborohemaa*, *Omankwa*, *Abotem*, *Dorke SR*, *Abeleehi* and *Akposoe* two new varieties of soybean(*Anidaso* and *Nangbaar*) and two new varieties of cowpea (*Tona* and *Nhyira*). Experimental samples were taken using the quartering procedure of Lees (1975).

The *Abeleehi*varietyof maize is a relatively old variety produced by theCRI while the cowpea and the soybean varieties are entirely new varieties developed by the same Institute to be adapted to the dry conditions yet to be released to farmers for cultivation.

The samples were husked manually. Only good grains were weighed and used for the experiment.The broken grains and dust were separated from the husk using a standard mesh. The samples of each variety were separately packed into air-tight polythene bags to prevent moisture loss and recontamination.

3.2 Moisture content determination

The initial moisture content of each variety sample was determined using the standard oven drying method of AOAC (2003) and expressed on dry basis. Five samples of 5g were weighed using digital top-pan balance to an accuracy of 0.01 g and placed in numbered dishes made of heavy gauge aluminium. The dishes were equipped with tightly fitting covers that were inscribed with the same numbers as the dishes.

The dishes were covered and reweighed. The dishes were uncovered and placed in a standard oven which is well insulated and uniformly heated for 4h to temperature of $103 \pm 2^{o}C$. After the heating, the lids were replaced on the dishes and placed in desiccators to cool to room temperature and then reweighed. The weight of water in the sample was considered to be equal to the loss of weight of the container. The procedure was replicated three times for each sample, and the average value was taken and recorded.

The moisture contenton dry basis (M_d) was computed as follows:

$$M_d = \frac{W_w}{W_d} \times 100\% \quad (1)$$

$$W_d = W_t - W_w$$

Where:

W_t = total weight of sample,

W_d = weight of dry matter in the material and

W_w = weight of water in the material

3.3.0 Determination of Physical Properties

3.3.1 1000-kernel weight determination

The weight of 1000 kernels was determined using a method described by Varnamkhasti et al. (2008). One thousand grains were randomly selected from each sample into flat plates which were carefully weighed using an electronic balance to an accuracy of 0.01 g. The procedure is replicated three times for each sample, and average value was taken and recorded. The weight of the kernel was thus determined by dividing the 1000-kernel weight by 1000.

3.3.2 Size determination

The principal dimensions of the kernels were measured in three directions using a digital micrometer screw gauge with accuracy of 0.01 mm. The major diameter is the length of the kernel, the intermediate diameter is the width, and the minor diameter is the thickness of the kernel. The minor diameter is taken perpendicular to the intermediate diameter. The micrometer screw gauge was held perpendicular to the direction of the dimension being measured. Length was measured on 100 kernels and width and thickness on 50 kernels (Hauhouot-O'Hare et al. 2000) and average value was determined for each sample.

Owing to the irregular or non-uniform nature of the shape of the kernels, the greatest value of both the width and the thickness were taken as indicated in Figure 3.1

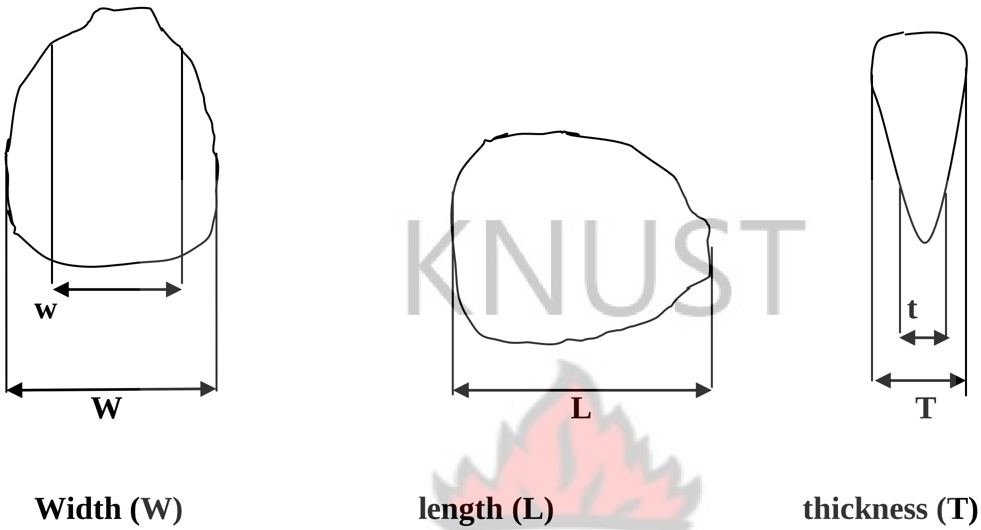

Figure 3.1The principal dimensions of grains

3.3.3 Determination of equivalent radius

The average equivalent radius was calculated for 50 seeds. This was based on the assumption that the volume of the kernel can be approximated by calculating the volume of a sphere with radius equal to half diameters of the kernel.

The volume of the kernel was determined by filling a 100-ml measuring cylinder with 50 ml of water. Then, 50 kernels of each variety (separately) were immersed in the water. The amount of displacement in water was recorded. The procedure is replicated three times and the true volume was calculated as:

Final volume – Initial volume = Volume of water displaced

Average volume of kernel = Volume of water displaced / 50

Average volume of the kernel was equated to the volume of a spherical object (i.e. $4\pi R^3/3$) and equivalent radius R was obtained

Thus $R = \sqrt[3]{3v/4\pi}$ (2)

3.3.5 Surface Area

The surface area (SA) was determined using a formulae described by McCabe et al. (1986).

$SA = (\pi D_g)^2$

Where:

Geometric diameter (Dg) = $(WTL)^{0.5}$ (3)

3.4 Soaking Experiment

The water absorption characteristics of the six hybrids of maize and two hybrids of cowpea and two hybrids of soybean were determined by soaking experiment and modelling techniques. This experiment was carried out on all the ten hybrids at four different water temperatures (30±2°C, 40±2°C, 50±2°C, and 60±2°C in a thermostatic water bath. Three replicates of sample size 5± 0.02g each sample was separately placed in nylon mosquito net, tied and labelled before they were placed into the portable water bath. The maize samples were removed at predetermined time interval of 60 min for water temperatures of 30±2°C, 40±2°C, 50±2°C, and 60±2°C. Thereafter, measurements were carried out at 30 min for the cowpea and the soybean hybrids. The soaked samples were quickly blotted with tissue paper to remove residual surface moisture on the surface of the kernels (Seyhan-Gurtas et al., 2001) and then reweighed (Becker, 1960; Fan et al., 1963; Lu et al., 1994).

The operation was conducted at each predetermined time until the test was completed. The increase in sample mass during soaking in water was considered to be an increase in sample moisture content.

3.4.1 Saturated moisture content

During the soaking, there was a rapid initial water absorption followed by slower rate in the later stages and then asymptotically as it approaches a point where no more water or very little water was absorbed. The saturation moisture content (M_s) was determined when the subsequent increase in weight of soaked grain was less than 0.01 g. The saturated moisture content of the eight varieties was recorded for all the four soaking temperatures.

3.5 Mathematical Model

3.5.1 Analytical approach

During a diffusion process at constant temperature, it is assumed that the process follows Fick's second law of diffusion. For an axisymmetric diffusion, Fick's three-dimensional (3D) equation was given by:

$$\frac{\partial M}{\partial t} = D\left(\frac{\partial^2 M}{\partial x^2} + \frac{\partial^2 M}{\partial y^2} + \frac{\partial^2 M}{\partial z^2}\right), \qquad \textbf{(4)}$$

where*M* is the instantaneous moisture content at a specified time *t* and *D* is the diffusion coefficient. A solution for the above equation for an object with a spherical shape of radius *r* was presented by Crank (1975) and Seyhan-Gurtas et al.(2001) as:

$$MR = \frac{M - M_i}{M_e - M_i} = 1 - (\frac{6}{\pi^2}) \sum_{i=1}^{\infty} (\frac{1}{i^2}) \exp(-Di^2 \pi^2 \frac{t}{r^2}), \qquad \textbf{(5)}$$

where MR is the moisture ratio, and M_i and M_e are, respectively, the initial and the equilibrium moisture contents, *i* is the number of terms in summation (equal to 1000 in this study), *Di* is the effective water diffusion coefficient, and *r* is the characteristic length of the seed (equal to radius for sphere of the same volume as the volume of the kernels) and *t* is the soaking time. In this case, only a finite number of Eq. (5) was used for estimating MR values. All moisture terms were computed on wet-basis.

We then formulated the problem as a root finding equation:

$f(Di) = MR_{expt.} - MR_{calc.}$

and searched for the D*i* value which made the function f (D*i*) = 0. MR_{expt} represents moisture ratio from experimental data and MR_{calc} represents moisture ratio from model predictions. In this research, the experimental MR values at specific time intervals were calculated and used as input to the curve fitting tool box of Microsoft Excel, 2010) software and the diffusion coefficient of the selected cereals and legumes, *Di* were estimated.

Temperature dependency of D*i* was described by an Arrhenius type equation:

$$Di = D_o e^{-E/RT} \qquad (6)$$

where Do (m^2/s) is a constant, E (kJ/mol) the activation energy, R (8.314 J/mol K) the gas constant and T (K) the absolute temperature. Activation energy values were obtained from the linear regression (D_{ff} vs. 1/T) analysis.

The Diffusion constant (Do) and the slope (E/R) in the equation were determined using the least squares method. The value of the energy of activation (Ea) was determined by multiplying the value of the slope by the gas constant value

CHAPTER FOUR

RESULTS AND DISCUSSIONS

Initial moisture contents, dimensions, and radius of each kernel of the cereals and legumes studied in this work are given in Table 4.1 and Table 4.2

4.1 Physical properties of selected cereals and legumes grown in Ghana

Table 4.1 Moisture content and physical characteristics of selected cereals

Cereal	Moisture content(%db)	Length (mm)	Width (mm)	Thickness (mm)	Radius (mm)	surface Area (mm^2)
Aborohema	11.76	11.03	8.98	4.74	4.04	596.65
Abotem	12.13	10.10	8.61	4.50	3.91	527.62
Omankwa	11.76	10.47	9.02	4.53	4.02	560.79
Abeleehi	12.60	11.40	8.80	4.00	3.93	537.34
Dorke SR	13.49	10.50	8.50	4.30	3.86	521.21
Akposoe	13.66	10.20	8.80	4.10	3.65	507.23

Table 4.2 Moisture content and physical characteristics of selected legumes

Legume	Moisture content(%db)	Length (mm)	Width (mm)	Thickness (mm)	Radius (mm)	Surface Area (mm^2)
Tona	10.9	7.55	5.79	4.52	3.24	335.08
Nhyira	10.4	6.95	5.75	4.39	3.04	309.54
Nagbaar	10.4	7.53	6.21	5.09	3.42	379.35
Anidaso	9.9	7.74	5.98	5.09	3.33	376.77

The data presented inTable 4.1and 4.2 are in general agreement with those reported by Gurses (1981). Based on the equivalent dimensions given in Table 4.1 and 4.2 the surface area (SA) ranged from 507.23 mm^2 (*Akposoe*) to 596.65 mm^2 (*Abrohemaa*) for the cerealsand 307.59 mm^2 (*Nhyira*) to 379.35 mm^2 (*Nagbaar*) for legumes. In general, for different cultivars of a cereal and legume, one can expect an inverse relation between the rate of absorption and seed size, since a larger seed provides a smaller surface area per unit mass (specific surface area) for moisture transfer (Hsu et al., 1983).

4.2 Hydration kinetics of selected local cereal and legume hybrids

The water absorption curves of dry cereals and legumes at four soaking temperatures are shown in Figures 4.1, 4.2 and 4.3. The rate of water absorption by the cereals and legumes was found to increase with the increase in temperature of the soaking water. This assertion has also been observed for other legumes (Quast and de Silva, 1977; Kon, 1979; Sopade and Obekpa, 1990; Abu-Ghannam and McKenna, 1997; Tang et al., 1994; Hung et al., 1993; Hsu et al., 1983 and Seyhan-Cutas et al., 2001)

The samples exhibited the characteristic moisture absorption behaviour. There was a rapid initial water absorption followed by a slower rate in the later stages and asymptotically approached the saturation moisture content (SMC) at all the four soaking water temperatures. Saturation moisture content was attained at 12h for soaking water temperature of 30ºC but reduced to 8h as the water temperature increased to 60^{o}C forall the samples studied (See Appendix A for the tables). Addo et al. (2006) obtained similar curves during the soaking of two varieties of maize –*Obatanpa and Mamaba.* Other researchers, Bhattacharya (1995), Sopade et al. (1994), Abu-Ghannam and McKenna (1997) and Tagawaet al. (2003) obtained identical curves during the soaking of semolina, red kidney beans, and wheat and barley respectively.

Also, water absorption capacity increased with increase in soaking temperature for all the varieties although the rates of increment between the initial and final soaking temperatures were not the same for the varieties. This could be as a result of the difference in nutritional composition of the varieties considered. Shittuet al. (2009); Bandyopadhay et al. (1992); Ali et al.(1991) made similar observation when they studied the water absorption characteristics of rice. At each soaking temperature, *Akposoe* had a relatively higher moisture gain than all the maize varieties used in this study. At the soaking temperature of 30 and 40^{o}C,*Abrohemaa* obtained the lowest moisture gain as expected whiles *Omankwa* obtained the lowest moisture gain at 60^{o}C soaking temperature. The water absorption rate was found to be affected by the soaking temperature,the higher the temperature, the greater the water absorption because of an increased water diffusion rate. The effect of temperature agreed with other published studies (Addo et al., 2006; Addo and

Bart-Plange, 2009; Seyhan-Gurtas et al., 2001; Hsu, 1983; Sopade and Obekpa, 1990; Lu *et al.*, 1994; Abu-Ghannam, 1998; Tagawa*et al.*, 2003).

Figures 4.1a, 4.1b, 4.1c, 4.1d, 4.1e and 4.1f show the time variation in water absorption by *Abrohemaa*, *Abotem*, *Omankwa*, *Abeleehi*, *Dorke SR* and *Akposoe* at four different soaking temperatures respectively.

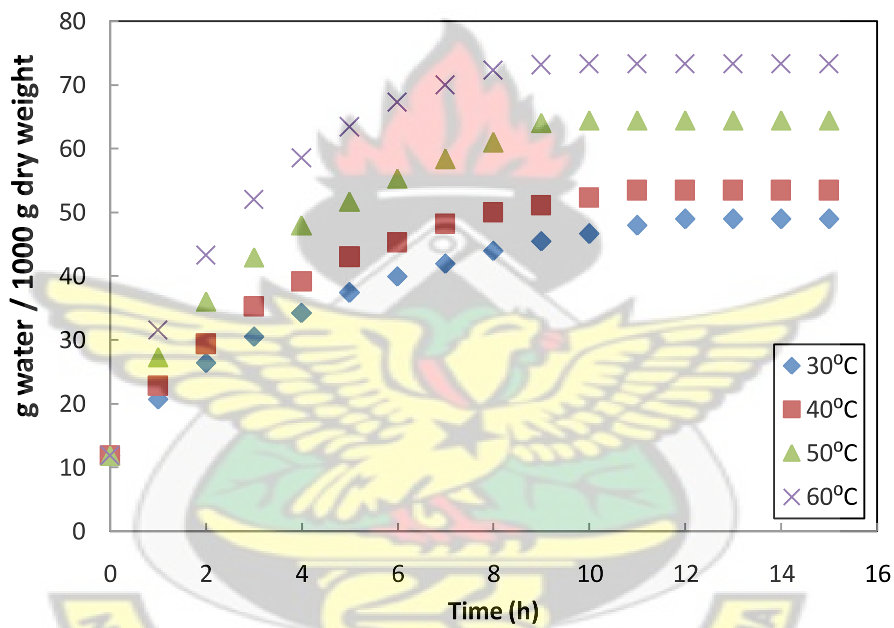

Figure4.1a Water absorption characteristics of *Abrohemaa*

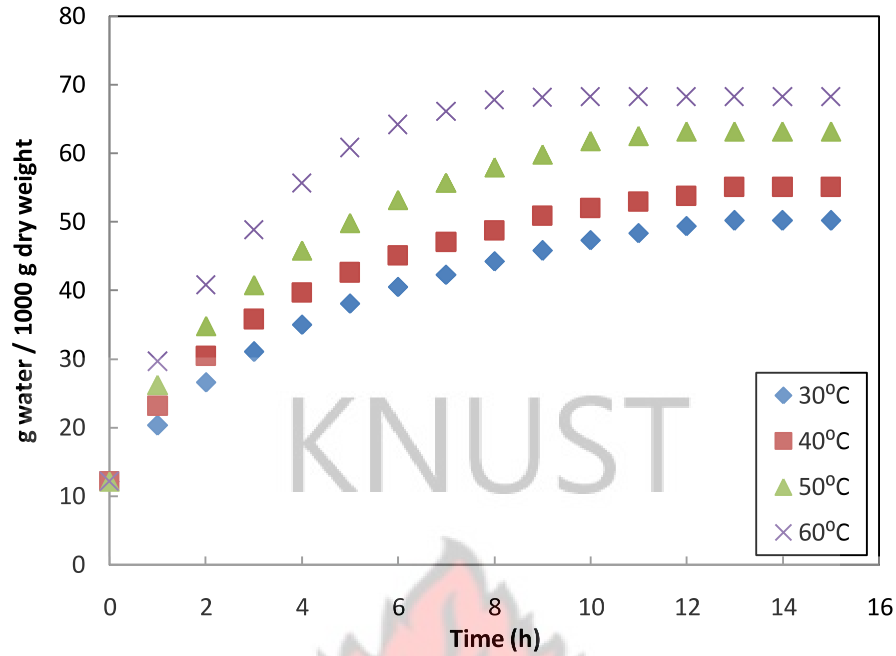

Figure 4.1b Water absorption characteristics of *Abotem*

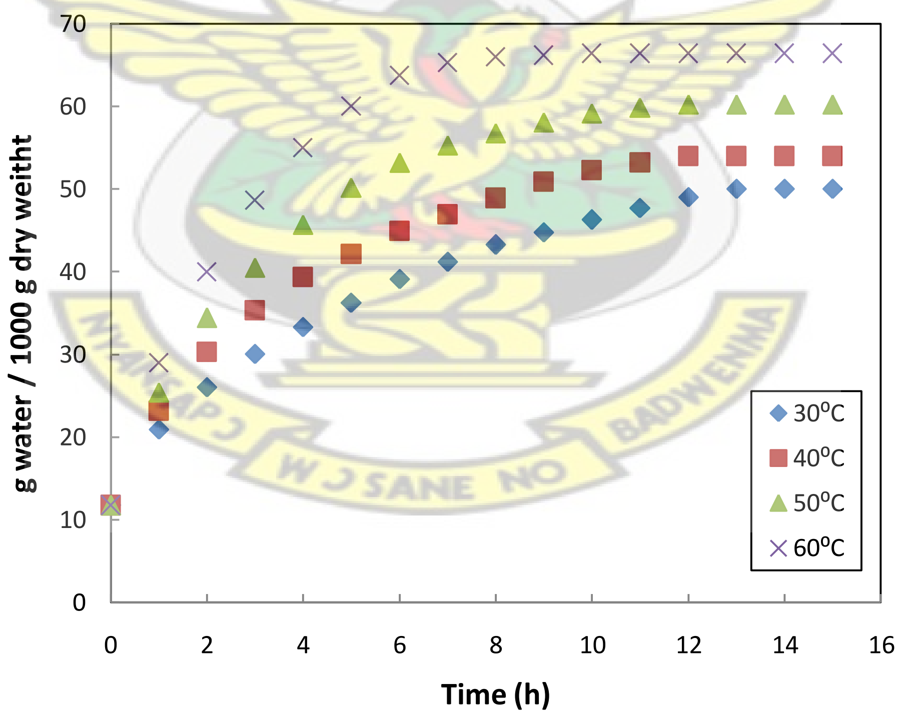

Figure4.1c: Water absorption characteristics of *Omankwa*

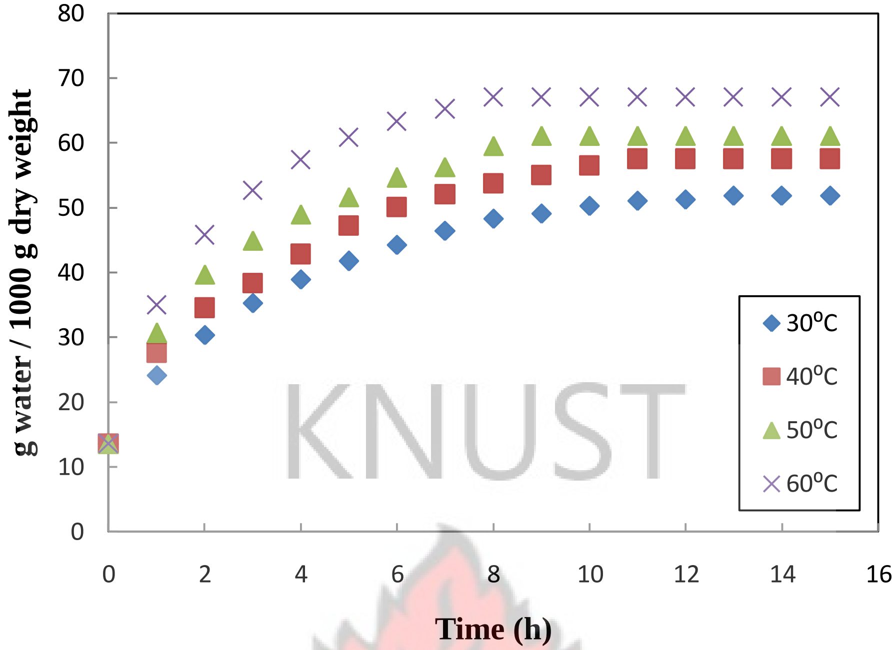

Figure 4.1d Water absorption characteristics of *Abeleehi*

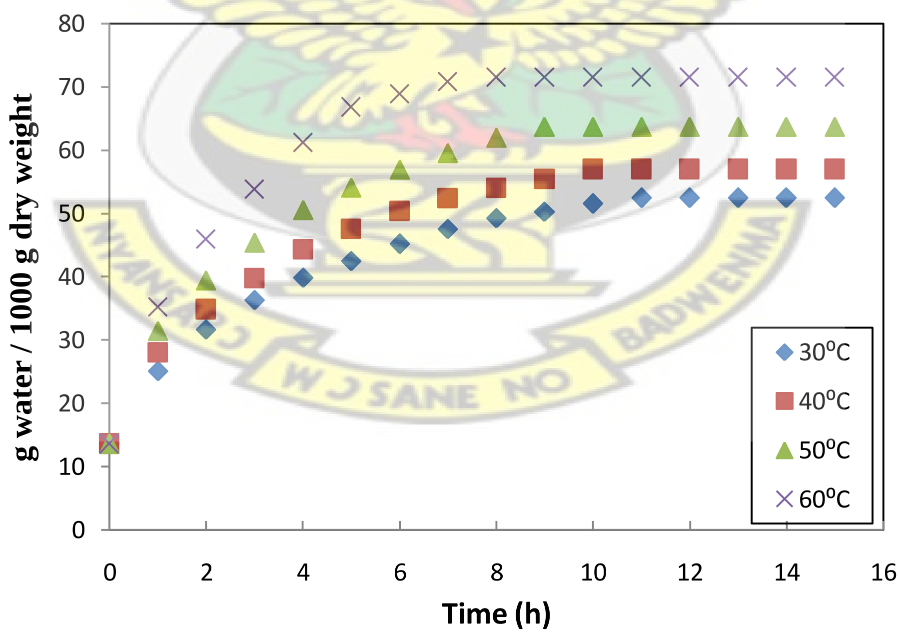

Figure 4.1e Water absorption characteristics of *Dorke SR*

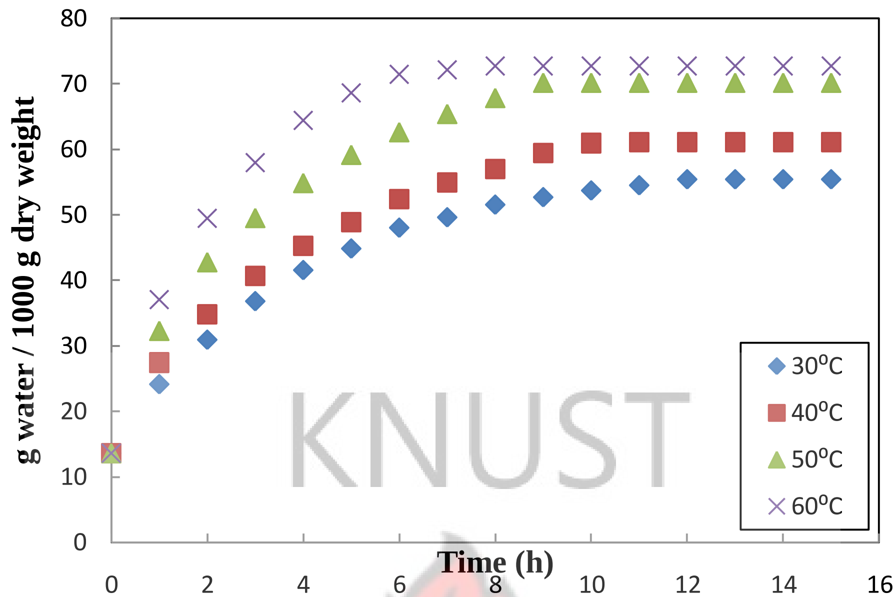

Figure 4.1fWater absorption characteristics of *Akposoe*

Sopade and Obekpa (1990) and Tang et al. (1994) reported that the smaller a seed is, the larger is its water absorption capacity because of the increased specific surface area for absorption. This phenomenon was observed in this study for five of the varieties (*Abotem*, *Omankwa*, *Abeleehi*, *Dorke SR* and *Akposoe)*. *Akposoe,* which has a smaller kernel size as compared to *Abeleehi*, *Abotemand*, *Omankwa and Dorke SR*had a higher uptake of water. On the contrary,*Abrohemaa* seed is relatively larger but had the highest water absorption capacity at 50^0 C and 60^0 C water temperatures. This may probably be due to the difference in severity of disorderliness arising from the different levels of temperature used as a resultof differences in nutritional composition. This observation could indicate a strong possibility of *Abrohemaa* having higher starch content than the rest of the maize varieties . Addo et al. (2006) observed similar behaviour when they reported that the higher starch content in Obatanpa was responsible for the higher uptake of water even though Obatanpa seed is larger than Mamaba. This observation is in line with Ituen et al. (1985) who reported that the soaking temperature and the grain component are the major factors that accounted for the variation in the EMC values. This assertion is also similar to the observation of Brennan et al. (1990) that reconstitutability of food products depends principally on the internal structure of the dried pieces, extent to which water-holding components like protein and starch have been damaged during drying. Additionally, studies on the rate of water penetration into wheat kernels by Stenvert and Kingswood (1976) indicated high protein content, compact endosperm structure, and greater kernel hardness hinder the rate of water absorption.

The behaviour of starch in water is temperature and concentration dependent (Whistler and Paschall, 1967). Grain starches in general show very little uptake of water at room temperature and their swelling power is also small. At higher temperature water uptake increases and starch granules collapse, which lead to solubilisation of amylase and amylopectin to form a colloidal solution, hence, the increase in moisture absorption with increase in temperature. The saturated moisture content was attained in 12h at 30ºC but reduced to 8h at 60ºC. This is because temperatures above the gelatinization temperature of starch (approximately 60ºC) can result in loss of crystallinity, increased diffusion of water into granule, increased hydration and swelling power of starch (Eckhoff and Tso, 1991). Figures 4.2a, 4.2b, 4.2c, and 4.2d show the time variation in water absorption by *Tona*, *Nhyira*, *Nagbaar* and *Anidaso* at four different soaking temperatures respectively.

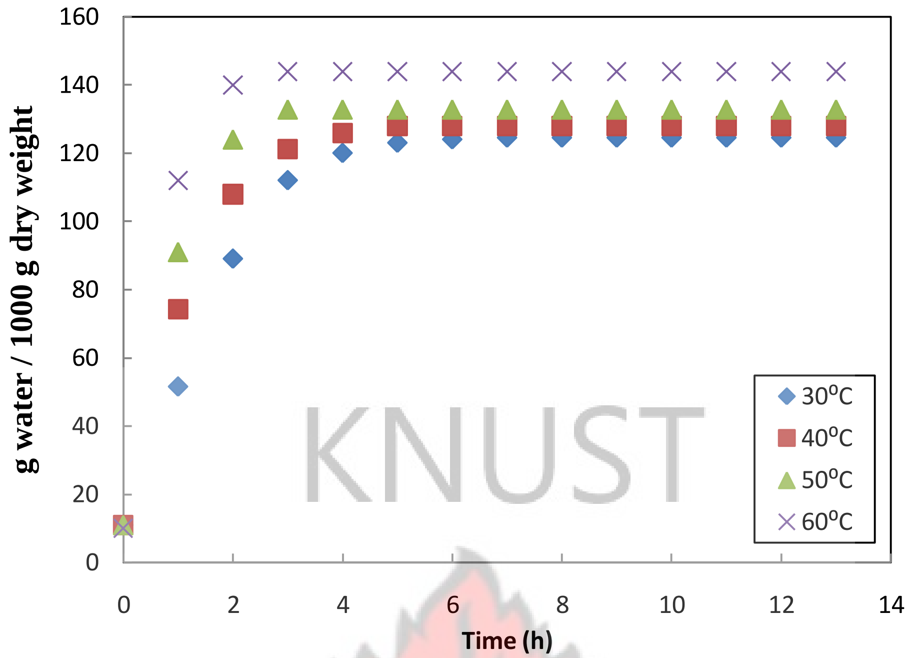

Figure 4.2a Water absorption characteristics of *Tona*

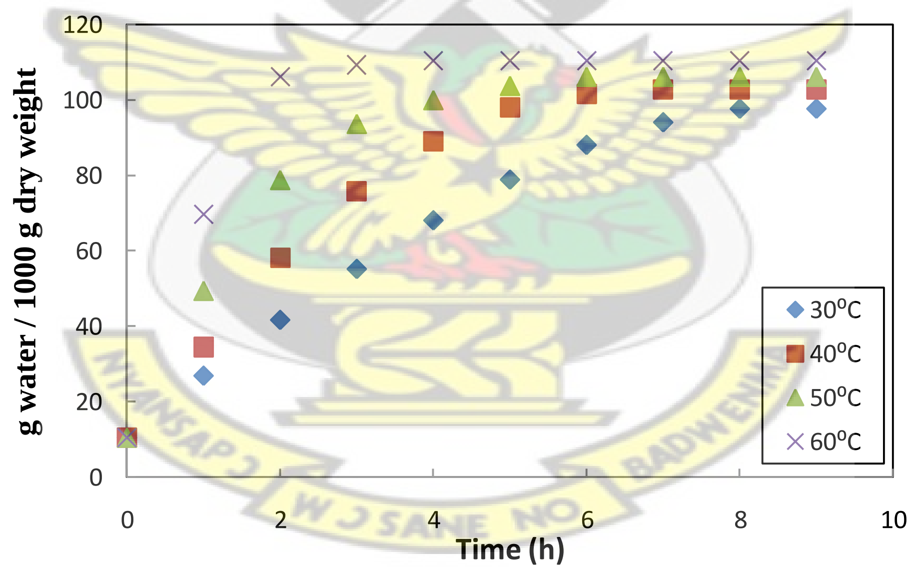

Figure 4.2bWater absorption characteristics of *Nhyira*

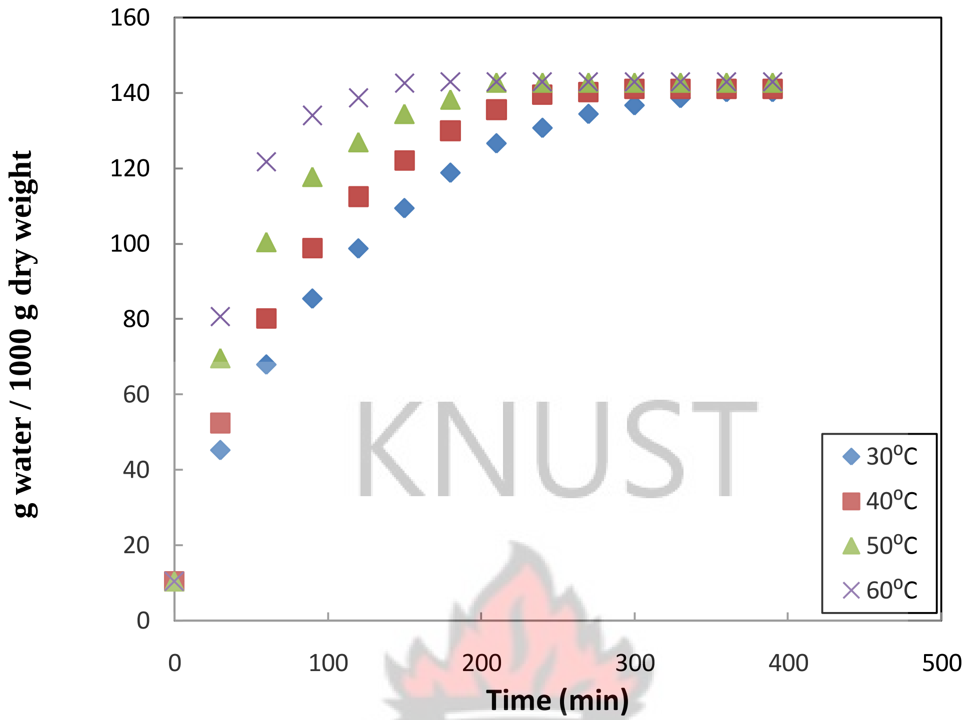

Figure 4.2cWater absorption characteristics of *Nagbaar*

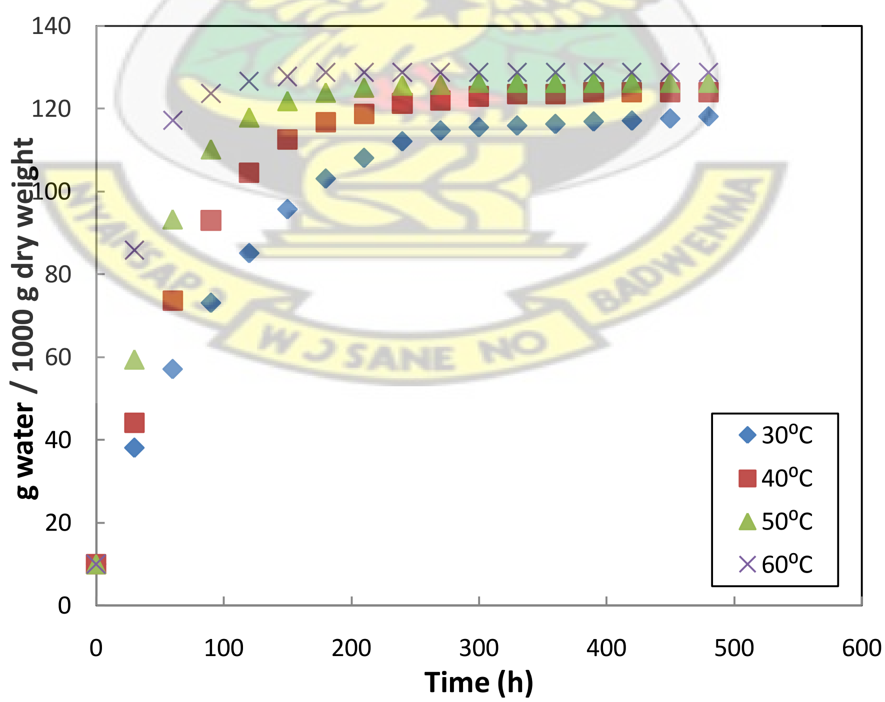

Figure 4.2d Water absorption characteristics of *Anidaso*

It can be seen that the water absorption curve from the diffusion model closely followed the water absorption curves of cereals. At 40°C, all the legumes reached their maximum water absorption level within 8 h of soaking. The time of soaking was reduced to 4 h as the temperature was increased to 60°C (See Appendix B for the tables). Therefore, as expected, the temperature of the soaking medium was a major factor in reducing the soaking time of dry legumes. A shorter soaking step not only means less processing time but also signifies retention of more soluble solids in the seeds. As Kon (1979) showed, losses of total solids, N-compounds, total sugars, oligosaccharides, Ca, Mg, and vitamins (thiamine, riboflavin, niacin) were very small at soaking temperatures up to 50°C, but increased three to four times at soaking temperatures of 60°C or above.

Tona whose size is larger than *Nhyira* had larger water absorption capacity than *Nhyira*. Also, *Nagbaar* and *Anidaso* have similar seed size yet their degree of moisture gain was quite different. This observation is in contrast to earlier reports by Sopada and Obekpa (1990) and Tang et al. (1994) that the smaller a seed is, the larger is its water absorption capacity. In legumes, it appears, the size of kernel is not a dominant factor that influenceswater absorption capacity. This confirms earlier reports by Wang et al. (1979); and Chopra and Prasad (1994).

4.3 Water Absorption Rates of selected local cereals and legume

Experimental data on water soaking of the selected legumes and cereals were plotted against the square root of soaking period for the four different soaking temperatures. Based on equation (1), the diffusion coefficients of the cereals and legumes during water absorption were estimated. The Saturated Moisture Content used in equation (5) are listed in Table 4.3 for each variety and soaking temperature.

Table 4.3Saturation moisture contents and diffusion coefficients of maize hybrids

	30			40			50			60		
Maize	D_{ff}*	R^2	M_s	D_{ff}*	R^2	M_s	D_{ff}*	R^2	M_s	D_{ff}*	R^2	M_s
Abrohemaa	3.66	0.99	48.95	3.96	0.98	53.47	4.21	0.99	64.5	4.74	0.98	73.27
Abotem	2.54	0.97	50.17	2.76	0.98	55.09	3.61	0.98	63.21	3.49	0.94	68.20
Omankwa	3.19	0.99	50.02	3.48	0.99	54.00	3.75	0.97	60.27	4.33	0.94	66.41
Abeleehi	2.64	0.97	51.85	2.96	0.98	57.52	3.12	0.98	61.10	3.59	0.97	67.06
Akposoe	2.91	0.97	55.37	3.13	0.99	61.10	3.38	0.99	70.12	3.95	0.96	72.74
Dorke	3.21	0.98	52.41	3.34	0.98	56.96	3.67	0.99	63.66	4.20	0.98	71.44

*$x10^{-10} m^2/s$

4.4 Fitting of Model Equation

Estimated values of diffusion coefficients of water absorption of the selected cereals and legumes at different soaking temperatures are shown in Table 4.3. Generally, the diffusion equation was able to fit the data for the grain components with high accuracy. The parameters from the linear regression analysis are also shown in Table 4.3 and the coefficient of determination R^2 varied from 0.94 to 0.99. This indicates a very good fit to the experimental data. The values of diffusion coefficient for *Abrohemaa*, *Abotem*, *Omankwa*, *Abeleehi*, *Akposoe*, *Dorke* ranged from 3.66 – 4.74 x 10^{-10} m^2/s; 2.54- 3.49 x 10^{-10} m^2/s; 3.19-4.33 x 10^{-10} m^2/s; 2.64-3.59 x 10^{-10} m^2/s; 2.91-3.95 x 10^{-10} m^2/s; 3.21-4.2 x 10^{-10} m^2/s respectively. These values are slightly higher than those reported for *Mamaba* and *Obatanpa* hybrids as reported by Addo et al. (2006). The difference in the physicochemical and nutrient composition of the maize varieties might be responsible for this observation. This assertion agrees with the findings of other researchers (Williams et al. 1958; Juliano

1979; Addo et al. 2006; and Agidi et al. 2009). Webb (1975)further reported that among the physiochemical and nutrient characteristics, amylose content has been found to be the single most important characteristics for predicting rate of moisture gainin rice cooking.

The water absorption rates for *Abrohema*, *Abotem*, *Omankwa*, *Abeleehi*, *Akposoe*, *Dorke* are shown in figure 4.3a ,4.3b, 4.4c, 4.3d, 4.3e and 4.3f

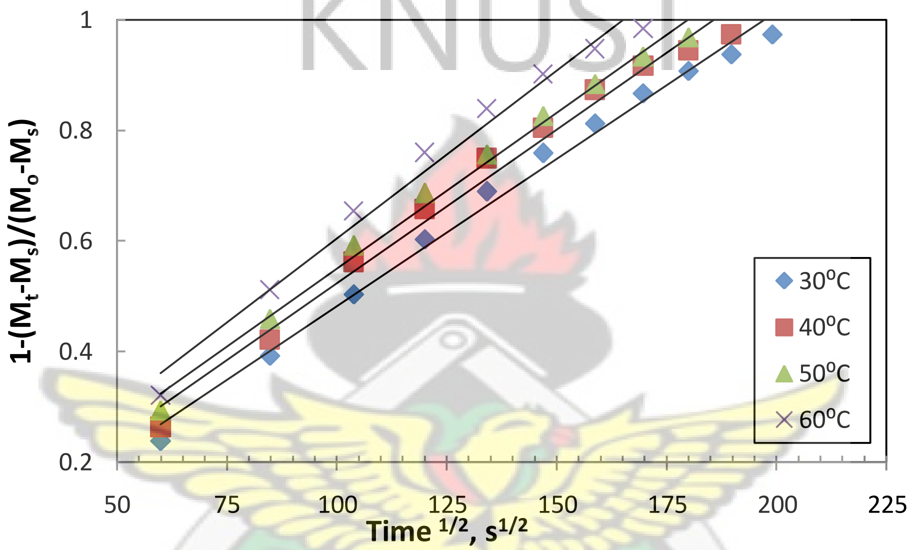

Fig. 4.3a Water absorption rate for *Abrohemaa*

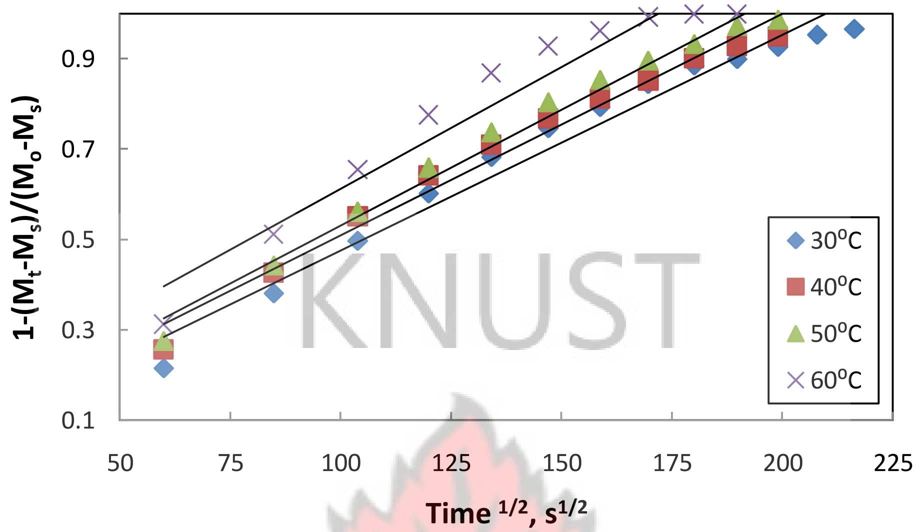

Fig. 4.3b Water absorption rate for *Abotem*

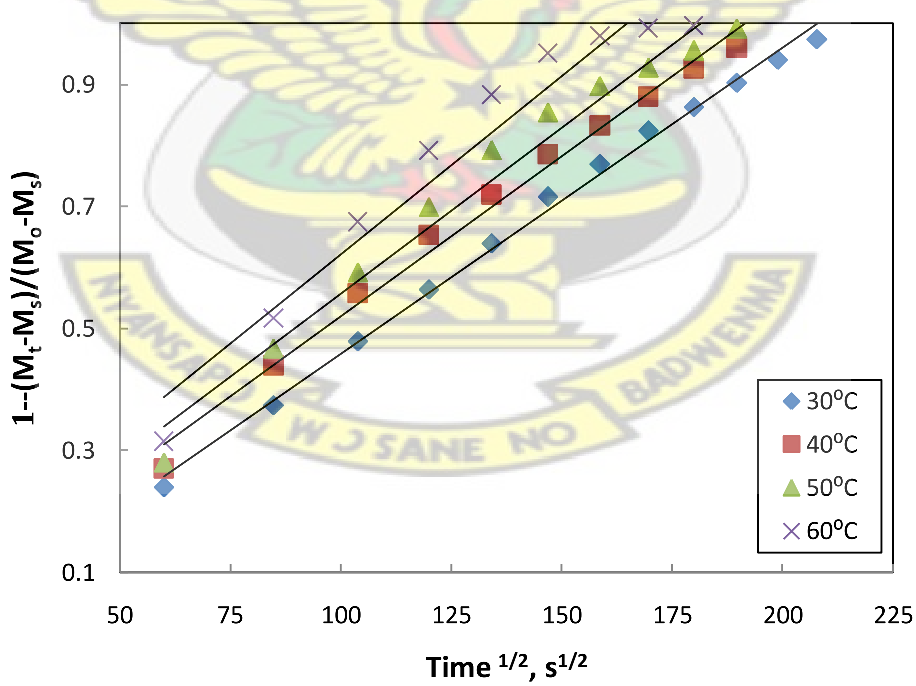

Figure4.3c: Water absorption rate for *Omankwa*

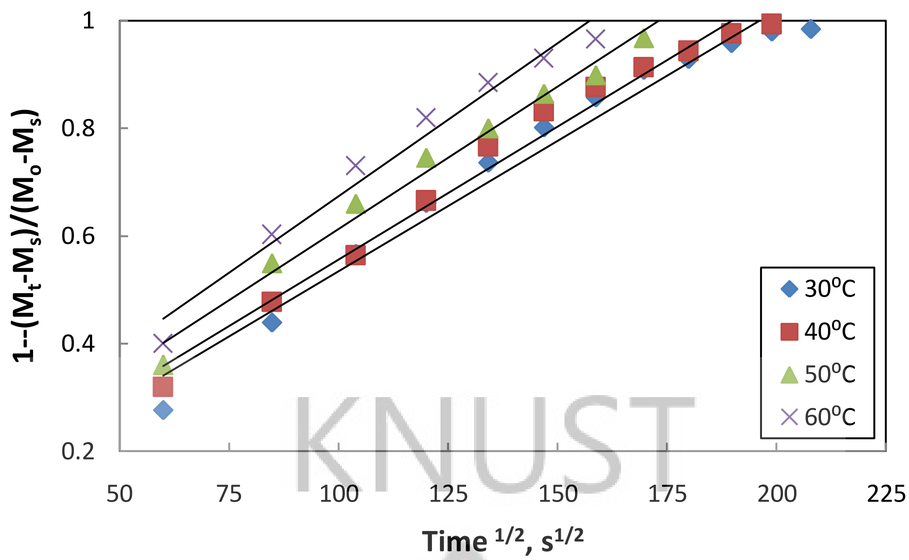

Figure 4.3d Water absorption rate for *Abeleehi*

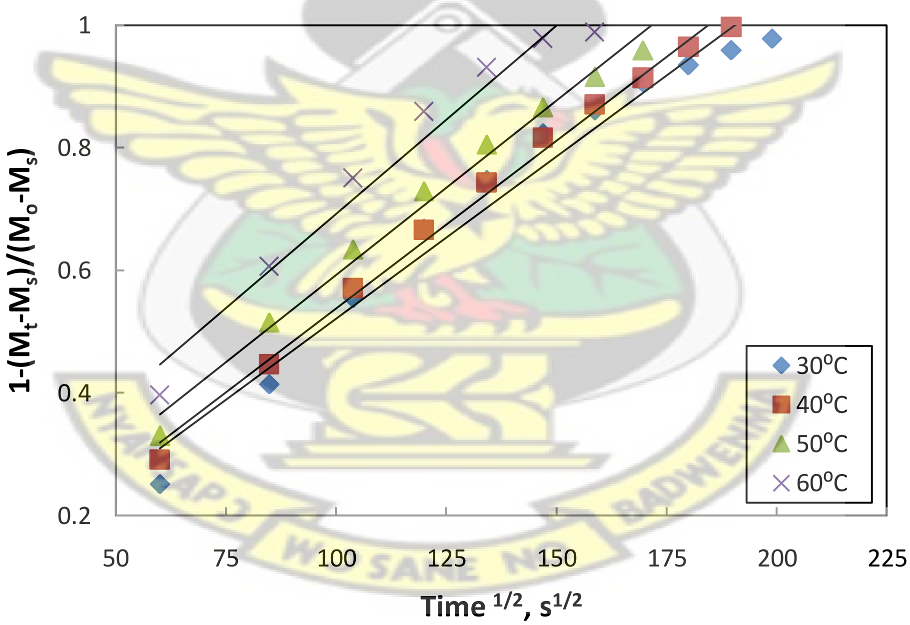

Fig. 4.3e Water absorption rate for *Akposoe*

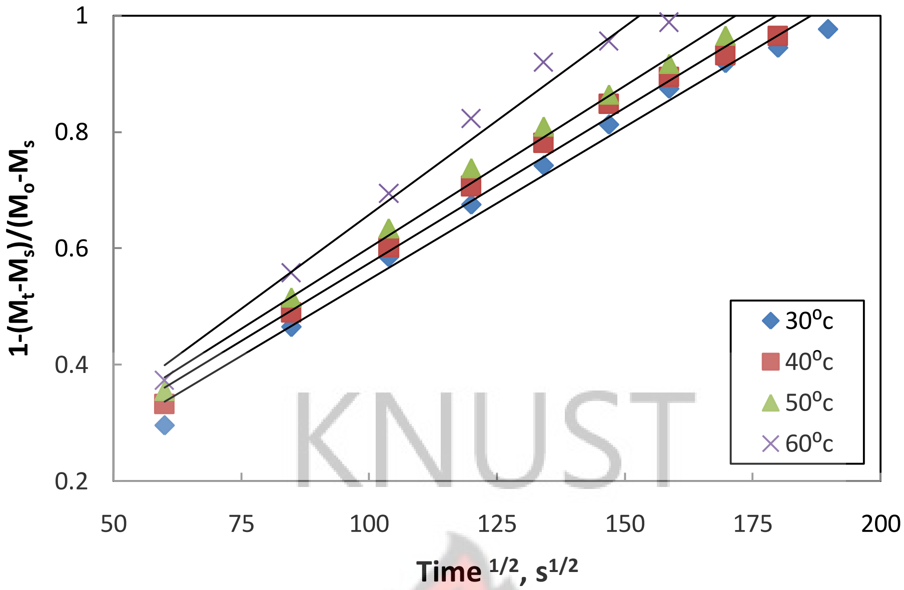

Fig. 4.3f Water absorption rate for *Dorke SR*

Table 4.4 Saturation moisture contents and diffusion coefficients of selected local legumes

	30			40			50			60		
Legumes	D_{ff}*	R^2	Ms	D_{ff}*	R^2	Ms	D_{ff}*	R^2	Ms	D_{ff}*	R^2	Ms
Tona	4.36	0.88	124.5	4.54	0.93	128.0	5.12	0.94	132.8	5.90	0.99	143.9
Nhyira	4.74	0.99	97.6	5.38	0.98	102.8	5.79	0.96	106.2	6.28	0.87	110.4
Nagbaar	5.05	0.97	140.2	5.81	0.96	141.1	6.39	0.95	142.7	6.75	0.86	143.0
Anidso	2.90	0.99	118.0	3.12	0.96	124.0	3.25	0.92	126.2	3.56	0.92	128.7

*x10^{-10} m^2/s

The typical hydration curves of selected local legumes are shown in Fig. 4.4. The pattern of moisture ingression generally follows an exponential growth pattern. The rate of moisture migration was dependent on the temperature of soaking. The higher the soaking temperature, the higher was the rate of moisture absorption. The sudden jump in the moisture absorption pattern as the soaking temperature increased from 30°C to 60°C might be due to some microstructure details that are yet to be studied for the different legume varieties. At the beginning of the soaking period, a higher rate of absorption was observed in all the varieties over the entire temperature range followed by a slower absorption in later stages. This slower absorption may eventually be such that the increase in reconstitution ability becomes very small at higher soaking times.

The water absorption rates for *Tona, Nhyira, Nagbaar and Anidaso* are shown in Figures 4.4a, 4.4b, 4.4c and 4.4d

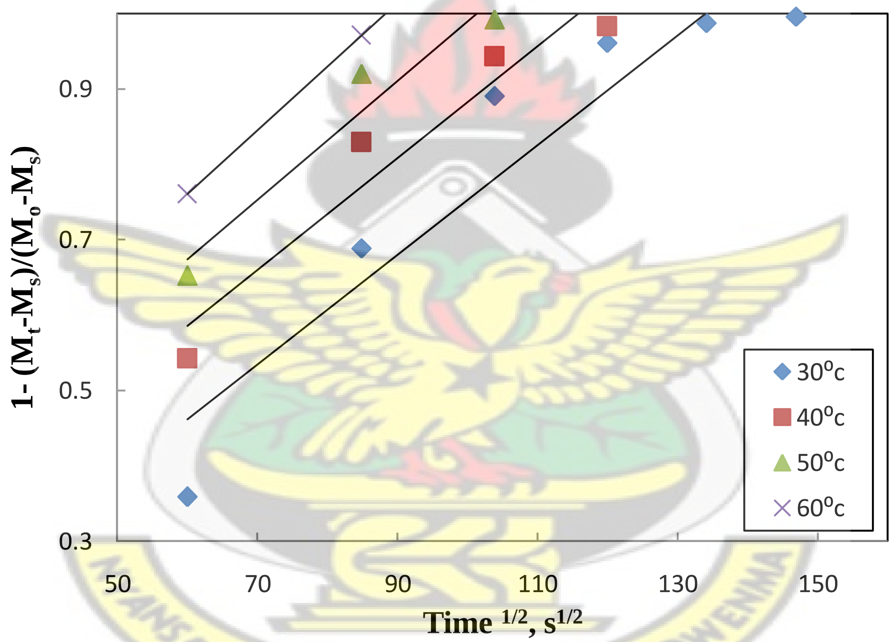

Fig. 4.4a: Water absorption rate for *Tona*

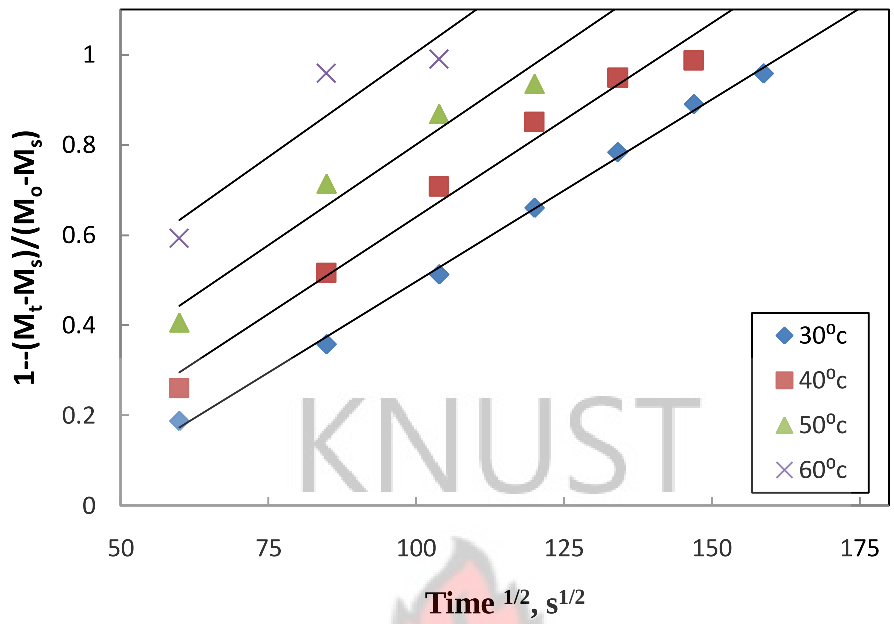

Fig. 4.4b Water absorption rate for *Nhyira*

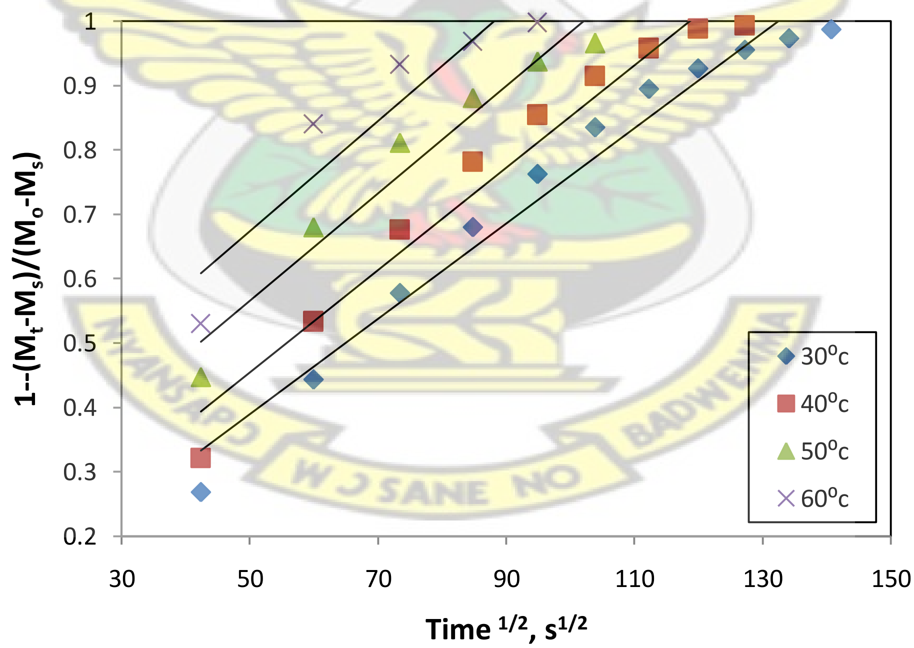

Figure 4.4c Water absorption rate for *Nagbaar*

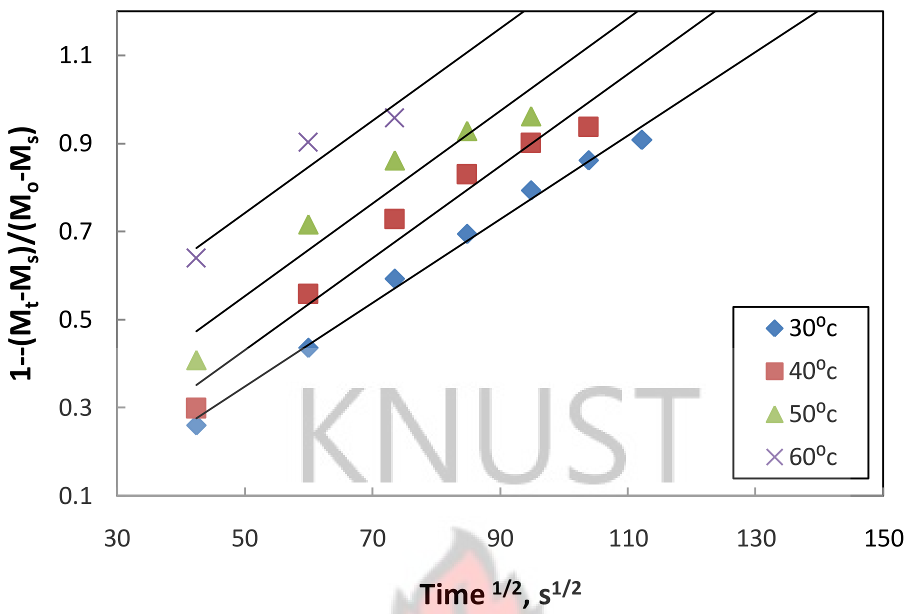

Fig. 4.4d Water absorption rate for *Anidaso*

The effective water diffusion coefficients of the legumes obtained by the root finding procedure are presented in Table 4.4. From Table 4.2 and Table 4.4 for dry beans, it is clear that no relation exist between the diffusivity (D_{ff}), and the surface area (SA). Diffusion coefficient values were 2.90 to 3.56 x 10^{-10} m^2/s; 4.36 to 5.90 x 10^{-10} m^2/s; 4.74 to 6.28 x 10^{-10} m^2/s; and 5.05 to 6.75 x 10^{-10} m^2/s for *Anidaso*, *Tona; Nhyira* and *Nagbaar* respectively.*Nhyira* with smaller surface area recorded higher diffusion coefficient than *Tona*as expected. A similar observation has also been reported for soybean varieties (Hsu et al., 1983). On the other hand, *Nagbaar* variety recorded the higher diffusion coefficient than *Anidaso* even though their surface areas (seed size) are almost the same. Hung et al. (1993) calculated higher water absorption rates for large-seed (i.e. smaller SSA) cultivars of chickpeas. It is important to note that *Nagbaar* and *Anidaso* of the soybean variety have similar surface area, however, there was a large difference in their diffusion coefficients (Table 4.4). Therefore, the relation between diffusion coefficient and surface area appears to be valid only for some legumes (cowpea) rather than being a general rule for all legumes.Moreover, surface area seems to be one of several factors controlling the rate of water absorption in legumes but not a dominant one (e.g. soybean).This implies that other factors might have contribution toward the slower rate observed for *Anidaso* hybrid. These factors might include the higher viscosities and lower water activities associated with the more concentrated bicarbonate solutions. This observation did not agree with results reported by Snyder (1936), which showed that lower pH slows water uptake. Because soy protein is quite soluble between pH 7 and 9, a faster rate of water uptake rather than a slower one can be expected with this range.

Since there was no published report on absorption characteristics of soybean variety grown in Ghana, direct comparison of the results of this study cannot be provided. However, diffusivity values reported in this study were lower than those obtained by Addo and Bart-Plange (2009) for egusi melon seed. On the other hand, these values compared favourably with the results published by Seyhan-Gurtas et al., (2001) for legumes grown in Turkey.

4.5 Diffusion Constant and Activation energies of selected local Cereals and legumes

The values of diffusion coefficients of the selected varieties were fitted to an Arrhenius relationship of the type

$$D_{ff} = D_o x \exp^{-(Ea/RTo)} \quad (6)$$

where,

D_{ff} = diffusion coefficient (m^2/s)

D_o = diffusion constant (m^2/s)

E_a= activation energy (kJ/mol)

R = gas constant (8.314 kJ/mol$^-$K)

T_o = absolute temperature (K)

The Arrhenius equation was sufficient to describe the temperature effect on the moisture diffusivity of the selected varieties. The relationship between the diffusion coefficients and the reciprocal of the absolute temperatures is shown in Fig. 4.5 and 4.6

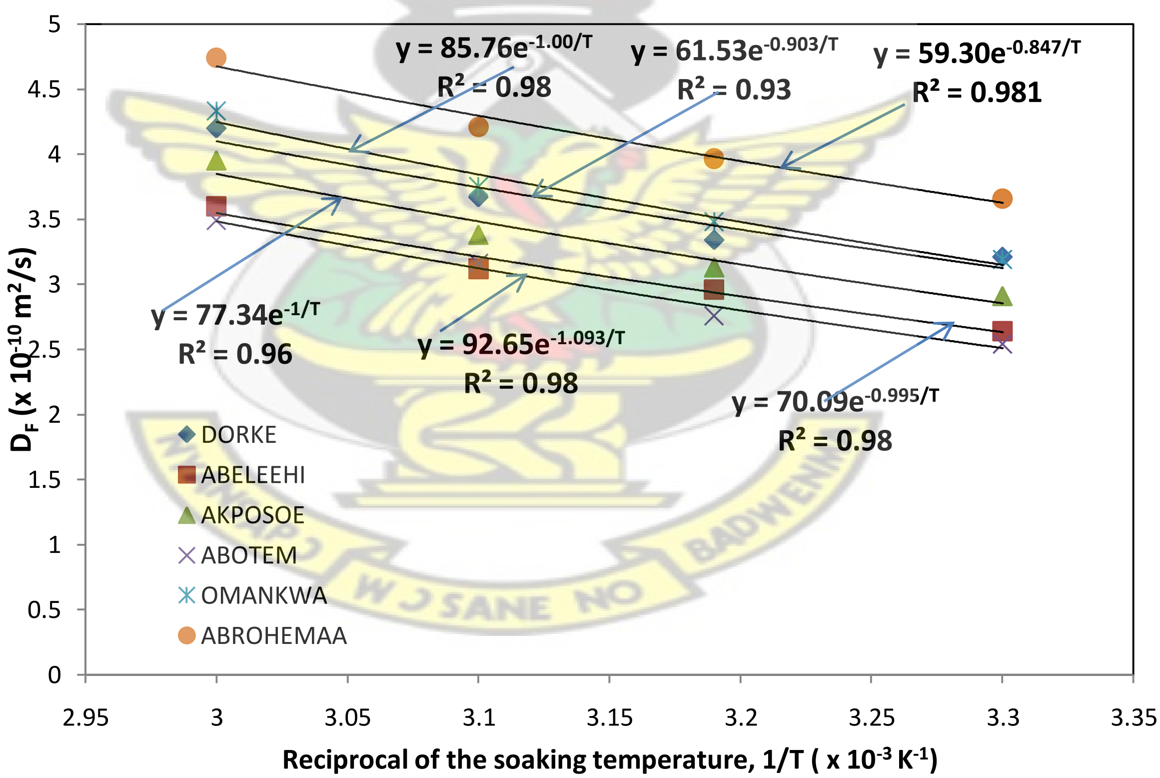

Figure 4.5 Relationship between Diffusion Coefficient and temperature for *Dorke ,Abeleehi*, *Akposoe*, *Abotem*, *Omankwa* and *Abrohemaa*

Equation (6) shows that the relationship between the diffusion coefficients and the reciprocal of the absolute temperature was linear on a semi–logarithmic plot. Figure 4.5 shows the Arrhenius relation for the diffusion coefficients and temperature for *Abotem, Dorke, Abeleehi, Akposoe, Abrohemaa* and *Omankwa.* The Arrhenius equation was sufficient to describe the temperature effect on the moisture absorption.

Table 4.5 Activation energy of water diffusion during soaking of selected local maize grown in Ghana

Legume	Ea (kJ/mol)	Coefficient of Determination (R^2)
Abotem	9.09	0.98
Dorke	7.50	0.93
Abeleehi	8.27	0.98
Akposoe	8.31	0.96
Abrohemaa	7.04	0.98
Omankwa	8.31	0.98

From Table 4.5, the activation energy values as determined from the slopes of each curve, for *Abotem, Dorke, Abeleehi, Akposoe, Abrohemaa* and *Omankwa* were 9.09; 7.50; 8.27; 8.31; 7.04 and 8.31 kJ/mol respectively.

The activation energy values obtained in this research were similar to the results obtained by Addo et al. (2006) for different varieties of maize. Reported values of energy of activation by Addo et al (2006) were 6.54 and 6.82kJ/mol for *Obatanpa* and *Mamaba* respectively. Meanwhile, there was large difference between the values obtained in this work and the values obtained by other studies.Verma and Prasad (1999) reported that, the activation energy evaluated from the same relation, varied from 33.50 to 41.56kJ/mol and 31.66 to 45.42kJ/mol for 'K6400' and 'Dekalb 547' varieties of maize respectively. Charan and Prasad (1996) and Fan et al. (1963) also reported that the activation energy values were 45.75 kJ/mol for 'Hi-starch' maize and 28.66, 31.69 and 34.15 kJ/mol for 'K4' hybrid popcorn, `K-1859' hybrid maize and `Gold Rash' sweet maize during water soaking respectively. Furthermore, Pabis and Henderson (1961) reported activation energy of 32.2kJ/mol, while Tolaba and Suarez (1988) found a value of 27.6kJ/mol for maize drying process.The difference in values could be due to varietal characteristics arising from the genetic constitution of each hybrid.

These findings show that raising the temperature of a soaking process will affect the water absorption behaviour of *Abotem*, *Dorke*, *Abeleehi*, *Akposoe*, *Abrohemaa* and *Omankwa*.

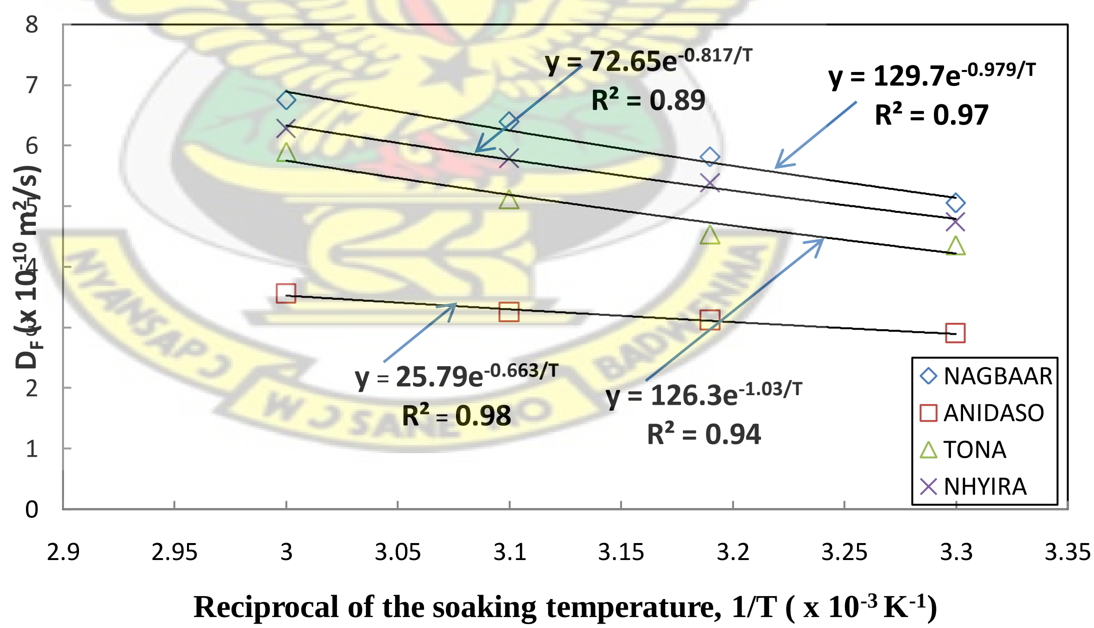

Figure 4.6 Relationship between Diffusion Coefficient and temperature for legume (*Tona*, *Nhyira*, *Anidaso* and *Nagbaar)*

Figure 4.6 shows the Arrhenius relation for the diffusion coefficients and temperature of *Anidaso, Hhyira, Tona and Nagbaar.*The variation of moisture diffusivity with the soaking temperature was consistent with the observations of Quast and DeSilva (1977) and Hung et al. (1993) for the beans, peas and soybeans, and the cultivars of chickpeas, respectively. Arrhenius equation was sufficient to describe the temperature effect on the moisture diffusivity, as the coefficient of determination (R^2) of fitting was between 0.93 and 0.98 (Table 4.5). The activation energy values for water diffusion in the legumes were also presented in Table 4.6. From Table 4.4, the values of D_{ff} were highest for the *Tona* hybrid and lowest for the *Nhyira* hybrid.

Table 4.6 Activation energy of water diffusion during soaking of selected dry legumes grown in Ghana

Legume	**Ea (kJ/mol)**	**Regression coefficient (R^2)**
Soybean		
Nagbaar	8.14	0.97
Anidaso	5.51	0.98
Cowpea		
Tona	8.56	0.94
Nhyira	7.73	0.89

From Table 4.6, the temperature sensitivity of D_{ff} was highest for *Nagbaar* with activation energy being 8.14 kJ/mol and lowest for *Anidaso* with activation energy being 5.51 kJ/mol. The activation energy values obtained in this study were quite smaller than 44.3 kJ/mol for soybean and 51.4 kJ/mol for pigeonpea, and

Turkish legumes as reported by Singh and Kulshresta (1987) and Seyhan-Gurtas et al., 2001) respectively.

CHAPTER FIVE

CONCLUSION

1. The duration of reaching equilibrium moisture content during soaking for *Abrohema*, *Abotem*, *Omankwa*, *Abeleehi*, *Akposoe* and *Dorke* was reduced from 12 h to 8 h by the increase in soaking temperature from 30 to 60ºC.
2. A satisfactory prediction of water absorption during soaking of *Abrohema*, *Abotem*, *Omankwa*, *Abeleehi*, *Akposoe* and *Dorke* hybrids was possible by fitting experimental data to Fick's law of diffusion.
3. The water diffusion coefficients for *Abrohema*, *Abotem*, *Omankwa*, *Abeleehi*, *Akposoe*, *Dorke* varied from 3.66 – 4.74 x 10^{-10} m^2/s; 2.54- 3.49 x 10^{-10} m^2/s; 3.19-4.33 x 10^{-10} m^2/s; 2.64-3.59 x 10^{-10} m^2/s; 2.91-3.95 x 10^{-10} m^2/s; 3.21-4.2 x 10^{-10} m^2/s respectively within the temperature range of 30 - 60ºC.
4. An Arrhenius-type equation described the strong temperature effect on the diffusion coefficient with activation energy values of 9.09 kJ/mol; 7.50 kJ/mol; 8.27kJ/mol; 8.31 kJ/mol; 7.04 kJ/mol and 8.31 kJ/mol for *Abotem*, *Dorke*, *Abeleehi*, *Akposoe*, *Abrohemaa* and *Omankwa*respectively.
5. The duration of soaking for selected dry legumes grown in Ghana was reduced from 8 h to 3.5h by increasing the temperature of the soaking water from 30 to 60^0 C.
6. The simple Fick's diffusion equation successfully simulated the water absorption kinetics of the soybean and cowpea hybrids at all temperatures. The effective water diffusivity values of the selected legumes varied from 2.90 x 10^{-10} m^2/s to 6.75 x 10^{-10} m^2/s.

7. The temperature dependency of D_{ff} of cowpea and soybean was adequately described by an Arrhenius equation with the activation energies ranging from 5.51 to 8.56kJ/mol.
8. Surface area seems to be one of several factors controlling the rate of water absorption in legumes. However, the relation between Diffusion Coefficient and surface area is valid only for some legumes rather than being a general rule for all legumes.
9. Increment in water absorption rate between the initial and final soaking temperatures was not the same for the varieties and this could be attributed to the difference in the physiochemical and nutrient composition of the varieties because of the difference in severity of disorderliness arising from the different levels of temperatures used.
10. Data presented in this study on D_{ff} and the temperature dependence of D_{ff} for the selected legumes can help in better design of sorption process and equipment.

Recommendation

Further studies should be carried out to determine how physiochemical, microstructure and nutritional compositionaffect the rate of water absorption in cereal and legume hybrids

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APPENDENCES

Appendix A Table showing moisture contents in g water/1000 g dry weight with respect totime at 30, 40, 50 and 60^oC for selected cereal grown in Ghana

ABOROHEMAA

Time(h)	30^{o}C	40^{o}C	50^{o}C	60^{o}C
0	11.86	11.86	11.86	11.86
1	20.67	22.8	27.29	31.54
2	26.4	29.38	36.01	43.28
3	30.53	35.23	43	52.01
4	34.23	39.2	48	58.5
5	37.41	43.03	51.68	63.4
6	39.99	45.31	55.36	67.23
7	42	48.19	58.38	70.02
8	44.01	50	61	72.26
9	45.52	51.14	64.07	73.15
10	46.64	52.35	64.5	73.27
11	47.94	53.47	64.5	73.27
12	48.95	53.47	64.5	73.27
13	48.95	53.47	64.5	73.27
14	48.95	53.47	64.5	73.27
15	48.95	53.47	64.5	73.27

ABOTEM

Time(h)	30^{o}C	40^{o}C	50^{o}C	60^{o}C
0	12.13	12.13	12.13	12.13
1	20.3	23.14	26.23	29.63
2	26.6	30.42	34.78	40.8
3	31.02	35.78	40.8	48.83
4	35.01	39.67	45.8	55.6
5	38.06	42.6	49.8	60.8
6	40.5	45.1	53.2	64.16
7	42.3	47	55.73	66.07
8	44.2	48.69	57.95	67.75
9	45.77	50.82	59.83	68.09
10	47.34	52	61.8	68.2
11	48.35	52.91	62.53	68.2
12	49.36	53.73	63.21	68.2
13	50.17	55.09	63.21	68.2
14	50.17	55.09	63.21	68.2
15	50.17	55.09	63.21	68.2

OMANKWA				
Time(h)	**30^{o}C**	**40^{o}C**	**50^{o}C**	**60^{o}C**
0	11.76	11.76	11.76	11.76
1	20.93	23.17	25.4	28.97
2	26.06	30.31	34.44	40
3	30.08	35.335	40.5	48.63
4	33.33	39.36	45.7	55
5	36.23	42.155	50.2	60
6	39.14	44.95	53.2	63.72
7	41.2	46.935	55.32	65.29
8	43.27	48.92	56.78	65.96
9	44.78	50.87	58.12	66.18
10	46.29	52.28	59.2	66.41
11	47.74	53.22	59.9	66.41
12	49.02	54	60.27	66.41
13	50.02	54	60.27	66.41
14	50.02	54	60.27	66.41
15	50.02	54	60.27	66.41

ABELEEHI				
Time(h)	**30^{o}C**	**40^{o}C**	**50^{o}C**	**60^{o}C**
0	13.57	13.57	13.57	13.57
1	24.16	27.62	30.69	34.97
2	30.38	34.53	39.69	45.79
3	35.26	38.33	44.92	52.64
4	38.9	42.82	49.01	57.41
5	41.74	47.25	51.62	60.87
6	44.24	50.09	54.66	63.32
7	46.39	52.07	56.27	65.22
8	48.32	53.72	59.57	67.06
9	49.12	55.03	61.1	67.06
10	50.26	56.45	61.1	67.06
11	51.05	57.52	61.1	67.06
12	51.25	57.52	61.1	67.06
13	51.85	57.52	61.1	67.06
14	51.85	57.52	61.1	67.06
15	51.85	57.52	61.1	67.06

AKPOSOE

T(h)	30^oC	40^oC	50^oC	60^oC
0	13.57	13.57	13.57	13.57
1	24.09	27.4	32.27	37.05
2	30.88	34.81	42.76	49.46
3	36.76	40.69	49.52	57.98
4	41.51	45.24	54.86	64.4
5	44.8	48.87	59.17	68.68
6	47.98	52.37	62.63	71.44
7	49.57	54.96	65.42	72.12
8	51.5	57	67.86	72.74
9	52.64	59.42	70.19	72.74
10	53.66	60.96	70.19	72.74
11	54.46	61.1	70.19	72.74
12	55.37	61.1	70.19	72.74
13	55.37	61.1	70.19	72.74
14	55.37	61.1	70.19	72.74
15	55.37	61.1	70.19	72.74

DORKE SR

T(h)	30^oC	40^oC	50^oC	60^oC
0	13.57	13.57	13.57	13.57
1	25.06	28	31.4	35.17
2	31.63	34.81	39.41	45.85
3	36.29	39.69	45.37	53.74
4	39.81	44.24	50.54	61.16
5	42.42	47.47	54.12	66.78
6	45.14	50.37	56.9	68.88
7	47.53	52.36	59.51	70.76
8	49.23	54	61.95	71.44
9	50.26	55.42	63.66	71.44
10	51.5	56.96	63.66	71.44
11	52.41	56.96	63.66	71.44
12	52.41	56.96	63.66	71.44
13	52.41	56.96	63.66	71.44
14	52.41	56.96	63.66	71.44
15	52.41	56.96	63.66	71.44

Appendix B Table showing moisture contents in g water/1000 g dry weigh with respect to time at 30, 40, 50 and 60°C for selected legumes grown in Ghana

TONA

Time	**30°C**	**40°C**	**50°C**	**60°C**
0	10.9	10.9	10.9	10.0
1	51.5	74.3	91	112
2	89	108	124	140
3	112	121.3	132.8	143.9
4	120	126	132.8	143.9
5	123	128	132.8	143.9
6	124	128	132.8	143.9
7	124.5	128	132.8	143.9
8	124.5	128	132.8	143.9
9	124.5	128	132.8	143.9
10	124.5	128	132.8	143.9
11	124.5	128	132.8	143.9
12	124.5	128	132.8	143.9
13	124.5	128	132.8	143.9

NHYIRA

Time	**30°C**	**40°C**	**50°C**	**60°C**
0	10.4	10.4	10.4	10.4
1	26.8	34.43	49.37	69.69
2	41.6	58.1	78.8	106.2
3	55.1	75.8	93.7	109.3
4	68	89	100	110.4
5	78.8	98	103.8	110.4
6	88	101.6	106.2	110.4
7	94	102.8	106.2	110.4
8	97.6	102.8	106.2	110.4
9	97.6	102.8	106.2	110.4
10	97.6	102.8	106.2	110.4
11	97.6	102.8	106.2	110.4
12	97.6	102.8	106.2	110.4
13	97.6	102.8	106.2	110.4

NAGBAAR

Time	**30°C**	**40°C**	50°C	**60°C**
0	10.4	10.4	10.4	10.4
30	45.2	52.4	69.6	80.7
60	67.9	80.1	100.4	121.8
90	85.4	98.8	117.7	134.1
120	98.7	112.5	126.9	138.8
150	109	122.1	134.4	142.7
180	119	130	138.2	143
210	127	135.6	142.7	143
240	131	139.6	142.7	143
270	134	140.2	142.7	143
300	137	141.1	142.7	143
330	139	141.1	142.7	143
360	140	141.1	142.7	143
390	140	141.1	142.7	143

ANIDASO

Time	30°C	40°C	50°C	60°C
0	9.9	9.9	9.9	9.9
30	38	44	59.34	85.8
60	57	73.63	93.19	117.1
90	73	93	110.1	123.6
120	85	104.5	117.8	126.6
150	95.6	112.6	121.8	127.7
180	103	116.8	123.8	128.7
210	108	118.8	125	128.7
240	112	121.3	125.5	
270	114.6	122	125.7	
300	115.4	123	126.2	
330	115.8	123.5	126.2	
360	116.2	123.6		
390	116.8	124		
420	117	124		

Appendix C Water absorption rate of selected cereals grown in Ghana

Abrohemaa

T/h	√T/S	30°C	40°C	50°C	60°C
1	60	0.2375	0.2629	0.2931	0.3205
2	84.8528	0.392	0.4211	0.4588	0.5116
3	103.923	0.5034	0.5616	0.5916	0.6538
4	120	0.6031	0.6571	0.6866	0.7595
5	134.164	0.6889	0.7491	0.7565	0.8393
6	146.969	0.7584	0.8039	0.8264	0.9016
7	158.745	0.8126	0.8731	0.8837	0.9471
8	169.706	0.8668	0.9166	0.9335	0.9836
9	180	0.9075	0.944	0.9688	
10	189.737	0.9377	0.9731		
11	198.997	0.9728			
12	207.846				
13	216.333				
14	224.499				
15	232.379				

Abotem

T/h	√T/S	30°C	40°C	50°C	60°C
1	60	0.2149	0.2563	0.276	0.3121
2	84.8528	0.3806	0.4257	0.4434	0.5113
3	103.923	0.4968	0.5505	0.5613	0.6545
4	120	0.6018	0.6411	0.6592	0.7753
5	134.164	0.682	0.7093	0.7375	0.868
6	146.969	0.7462	0.7675	0.804	0.9279
7	158.745	0.7935	0.8117	0.8536	0.962
8	169.706	0.8435	0.851	0.897	0.992
9	180	0.8848	0.9006	0.9338	0.998
10	189.737	0.8998	0.9281	0.9724	0.9982
11	198.997	0.9264	0.9493	0.9867	
12	207.846	0.9529			
13	216.333	0.9661			
14	224.499				
15	232.379				

Omankwa

T/h	√T/S	30 °C	40 °C	50 °C	60 °C
1	60	0.2397	0.2701	0.2812	0.3149
2	84.8528	0.3738	0.4392	0.4675	0.5167
3	103.923	0.4788	0.5581	0.5925	0.6747
4	120	0.5638	0.6534	0.6996	0.7912
5	134.164	0.6396	0.7196	0.7924	0.8827
6	146.969	0.7156	0.7857	0.8543	0.9508
7	158.745	0.7695	0.8327	0.898	0.9795
8	169.706	0.8236	0.8797	0.9281	0.9918
9	180	0.863	0.9259	0.9557	0.9958
10	189.737	0.9025	0.9593	0.9924	
11	198.997	0.9404			
12	207.846	0.9739			

Abeleehi

T/h	**√T/S**	**30**°C	**40**°C	**50**°C	**60**°C
1	60	0.2766	0.3197	0.3602	0.4001
2	84.8528	0.4391	0.4769	0.5495	0.6024
3	103.923	0.5666	0.5634	0.6596	0.7304
4	120	0.6617	0.6655	0.7456	0.8196
5	134.164	0.7359	0.7663	0.8005	0.8843
6	146.969	0.8012	0.8309	0.8645	0.9301
7	158.745	0.8574	0.876	0.8984	0.9656
8	169.706	0.9078	0.9135	0.9678	
9	180	0.9287	0.9433		
10	189.737	0.9585	0.9757		
11	198.997	0.9791	0.9932		
12	207.846	0.9843			
13	216.333				
14	224.499				
15	232.379				

Akposoe

T/h	√T/S	30°C	40°C	50°C	60°C
1	60	0.2517	0.291	0.3303	0.3968
2	84.8528	0.4141	0.4469	0.5155	0.6066
3	103.923	0.5548	0.5706	0.6349	0.7505
4	120	0.6684	0.6663	0.7292	0.8591
5	134.164	0.7471	0.7427	0.8054	0.9314
6	146.969	0.8232	0.8163	0.8665	0.978
7	158.745	0.8612	0.8708	0.9158	0.9882
8	169.706	0.9074	0.9137	0.9588	
9	180	0.9347	0.9647		
10	189.737	0.9591	0.9971		
11	198.997	0.9782			
12	207.846				
13	216.333				
14	224.499				
15	232.379				

Dorke SR

T/h	√T/s	30°C	40°C	50°C	60°C
1	60	0.2958	0.3326	0.356	0.3733
2	84.8528	0.465	0.4895	0.5159	0.5578
3	103.923	0.585	0.602	0.6349	0.6941
4	120	0.6756	0.7068	0.7381	0.8224
5	134.164	0.7428	0.7813	0.8095	0.9195
6	146.969	0.8128	0.8481	0.865	0.9558
7	158.745	0.8744	0.894	0.9171	0.9882
8	169.706	0.9181	0.9318	0.9659	
9	180	0.9446	0.9645		
10	189.737	0.9766			
11	198.997				
12	207.846				
13	216.333				
14	224.499				
15	232.379				

Appendix D Water absorption rate of selected legumes grown in Ghana

Tona

T/h	√T/S	30°C	40°C	50°C.	60°C
1	60	0.3585	0.5422	0.6523	0.7605
2	84.8528	0.688	0.8295	0.9204	0.9707
3	103.923	0.8902	0.9429	0.9919	
4	120	0.9605	0.9829		
5	134.164	0.9868			
6	146.969	0.9956			
7	158.745				
8	169.706				
9	180				
10	189.737				
11	198.997				
12	207.846				
13	216.333				

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Nhyira

√T/S	√T/S	30°C	40°C	50°C	60°C
1	60	0.1881	0.2424	0.4019	0.599
2	84.8528	0.3578	0.5162	0.714	0.958
3	103.923	0.5126	0.7078	0.8695	0.989
4	120	0.6606	0.8506	0.9353	
5	134.164	0.7833	0.9481		
6	146.969	0.8899	0.987		
7	158.745	0.9587			
8	169.706				
9	180				
10	189.737				
11	198.997				
12	207.846				
13	216.333				

Nagbaar

√T/S	√T/S	30°C	40°C	50°C	60°C
30	42.4264	0.2681	0.3213	0.4475	0.5302
60	60	0.443	0.5333	0.6803	0.8401
90	73.4847	0.5778	0.6764	0.811	0.9329
120	84.8528	0.6803	0.7812	0.8806	0.9683
150	94.8683	0.7627	0.8546	0.9373	0.9977
180	103.923	0.8351	0.9151	0.966	
210	112.25	0.8952	0.9579		
240	120	0.9268	0.9885		
270	127.279	0.9553	0.9931		
300	134.164	0.973			
330	140.712	0.9877			
360	146.969				
390	152.971				
420	158.745				
450	164.317				
480	169.706				

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Anidaso

√T/S	√T/S	30°C	40°C	50°C	60°C
30	42.4264	0.2599	0.2989	0.4079	0.6389
60	60	0.4357	0.5585	0.7162	0.9024
90	73.4847	0.593	0.7283	0.8616	0.9571
120	84.8528	0.6947	0.8291	0.9278	
150	94.8683	0.7928	0.9001	0.9618	
180	103.923	0.8612	0.9369		
210	112.25	0.9075			
240	120				
270	127.279				
300	134.164				
330	140.712				
360	146.969				
390	152.971				
420	158.745				

Appendix E Relationship between Diffusion Coefficient and temperature for *Dorke, Abeleehi*, *Akposoe*, *Abotem, Omankwa* and *Abrohemaa*

1/T (x $10^{-3}K^{-3}$)	D_{ff} (x $10^{-10}m^2/s$)					
	DORKE	ABELEEHI	AKPOSOE	ABOTEM	OMANKWA	ABROHEMAA
3.3	3.21	2.64	2.91	2.542	3.19	3.656
3.19	3.34	2.96	3.13	2.756	3.48	3.964
3.1	3.67	3.12	3.38	3.161	3.75	4.21
3	4.2	3.6	3.95	3.49	4.33	4.74

Appendix F Relationship between Diffusion Coefficient and temperature for legume (*Tona*, *Nhyira*, *Anidaso* and *Nagbaar)*

$1/T (x\ 10^{-3}K^{-3})$	D_{ff} (x $10^{-10}m^2/s$)			
	NAGBAAR	ANIDASO	TONA	NHYIRA
3.3	5.05	2.9	4.36	4.74
3.19	5.81	3.12	4.54	5.38
3.1	6.39	3.25	5.12	5.79
3	6.75	3.56	5.9	6.28