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Effect of Soaking Temperature on the Physical Properties and Water Diffusion Coefficients of Selected Cowpea Varieties

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DECLARATION

I, Nancy Nelly Idun-Acquah, hereby declare that this submission is my own work towards the MPhil. Degree and that, no part of this work 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 acknowledgement has been made in the text.

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ABSTRACT

The purpose of this study was to investigate the effect of soaking temperature on the physical properties and water diffusion coefficients of three cowpea varieties (*Asontem*, *Hewale* and *Asomdwee*) grown in Ghana. 10 g of all three cowpea varieties were subjected to four soaking temperatures (30, 40, 50 and 60 ℃) for 10 h during which measurements were taken at 30 min interval. The initial values for moisture content, length, breadth, thickness, equivalent radius, and thousand seed weight of *Asontem* were 16.53% (d.b), 7.19 mm, 6.01 mm, 4.78 mm, 3.46 mm and 146.9 g, whereas the geometric mean diameter, surface area, seed volume and sphericity were 5.90 mm, 111.00 mm^2, 341.06 mm^3, and 0.83, respectively. The initial values for moisture content, length, breadth, thickness, equivalent radius, geometric mean diameter, surface area, seed volume, thousand seed weight and sphericity of *Hewale* were 12.40% (d.b), 6.88 mm, 5.54 mm, 4.45 mm, 3.26 mm, 5.53 mm, 96.44 mm^2, 281.75 mm^3, 122.27 g and 0.81, respectively. The initial average values for moisture content, length, breadth, thickness, equivalent radius, geometric mean diameter, surface area, seed volume, thousand seed weight and sphericity of *Asomdwee* were 13.63% (d.b), 7.20 mm, 5.44 mm, 4.63 mm, 3.08 mm, 5.66 mm, 100.81mm^2, 299.99 mm^3, 125.36 g and 0.79, respectively. As soaking temperature increased from 30 ℃ to 60 ℃, the values of the physical properties of the three cowpea varieties decreased linearly. The length, breadth, thickness, geometric mean diameter, surface area, seed volume and sphericity of *Asontem* decreased linearly from 9.60 mm, 7.13 mm, 5.98 mm, 7.42 mm, 173.5 mm^2, 678.2 mm^3, 0.77 to 8.85 mm, 6.61 mm, 5.56 mm, 6.91 mm, 149.9 mm^2, 542.7 mm^3 and 0.77, respectively. The length, breadth, thickness, geometric mean diameter, surface area, seed volume and sphericity of *Hewale* also decreased linearly from 9.93 mm, 6.98 mm, 5.89 mm, 7.42 mm, 173.1 mm^2, 673.6 mm^3, 0.75 to 9.64 mm, 6.59 mm, 5.50 mm, 7.06 mm, 156.1 mm^2, 576.6 mm^3 and 0.73, respectively. The length, breadth, thickness, geometric mean diameter, surface area, seed volume and sphericity of *Asomdwee* decreased linearly from 9.69 mm,

6.59 mm, 5.52 mm, 7.07 mm, 156.9 mm^2, 581.4 mm^3, 0.73 to 9.42 mm, 6.34 mm, 5.20 mm, 6.77 mm, 144.0 mm^2, 511.3 mm^3 and 0.72, respectively. The water absorption kinetics of *Asontem*, *Hewale* and *Asomdwee* cowpea varieties followed the Fick's law of diffusion during the first hours of soaking. The values of water diffusion coefficients determined for *Asontem*, *Hewale* and *Asomdwee* cowpea varieties, within the temperature variation from 30 ºC to 60 ºC during soaking ranged from 5.12 x 10^{-10} m^2/s to 6.64 x 10^{-10} m^2/s, 3.96 x 10^{-10} m^2/s to 5.12 x 10^{-10} m^2/s and 4.93 x 10^{-10} m^2/s to 6.08 x 10^{-10} m^2/s, respectively. The influence of temperature on the water diffusion coefficient was adequately described by an

Arrhenius-type equation giving activation energy values for *Asontem*, *Hewale* and *Asomdwee* cowpea varieties as 7.27 kJ/mol, 7.26 kJ/mol and 6.26 kJ/mol respectively.

KEYWORDS: Cowpea Varieties, Physical Properties, Modelling, Water Absorption, Arrhenius – type equation, Diffusion coefficient, Activation Energy

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DEDICATION

I dedicate my thesis to the Lord God Almighty and to my supportive parents, Mr. Emmanuel Idun-Acquah and Madam Gertrude Edubaa as well as my siblings, Joel Jeffery Idun-Acquah and Felicia Freda Idun-Acquah.

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CHAPTER ONE

INTRODUCTION

1.0 Background to the Study

Legumes have considerable protein and soluble fibre content making them an essential fraction of the diet in many countries (Kabagambe *et al.*, 2005). Legumes serve as chief sources of protein in many dishes prepared all over the African continent (El-Maki *et al.*, 2007). Legumes are inexpensive and excellent providers of essential nutrients needed by the human body. In contrast to animal products, legumes contain reasonably low but right amounts of the essential amino acid methionine needed to manufacture protein in humans (Shafaeia *et al.*, 2014). An essential member of the legume family Fabaceae is cowpea (*Vigna unguiculata*), which is widely consumed in many parts of the world including Ghana.

Cowpea is considered as one of the crops which have been in existence for so many years. Cowpea is grown in certain areas in all the five continents and more predominantly in the African, Asian and South American continents (Firouzi and Alizadeh, 2012). It has been indicated that cowpea on average contains 23.4%, 11%, 3.6%, 1.3% and 56.8% of protein, water, ash, fat, carbohydrate, respectively (Davies and Zibokere, 2011). Cowpea is a chief source of plant protein in the West African region, because it provides food for people, livestock and even other plants (Henshaw, 2008; Olotu *et al.*, 2013). The leaves and undeveloped pods of cowpea serve as vegetables for some consumers.

Estimation of worldwide area of production of cowpea stands at approximately 10.1 million hectares with about 4.99 million tonnes representing annual global grain production (Hamid *et al.,* 2014). This agricultural raw material is a vital source of carbohydrate, protein, iron, Vitamin B among others (Demirhan and Özbek, 2015).

In monetary terms, cowpea is also much cheaper than some grains available (Ayenlere *et al*., 2012). Therefore, anybody at all can purchase this commodity. Again, cowpea has the ability to mix well with other food ingredients (Muoneke *et al*., 2012).

In Ghana, cowpea is used in preparing foods such as cowpea fritters popularly referred to as 'koose', which is served with millet porridge; cooked beans with 'gari'(roasted grated fermented cassava) and 'tugbani' (steamed bean cake) as well as in making of stews and soup (Appiah *et al.,* 2011). In addition, cowpea, by virtue of its nutritional and functional qualities, is gradually becoming an important raw material for the production of cowpea flour for use in food formulations into other food products on industrial scale (Olotu *et al.,* 2013; Aremu *et al.,* 2014).

Generally, processing of cowpea first requires soaking of cowpea seeds in water to allow some level of water absorption for a period of time before additional processing of the cowpea seeds takes place (El-Syiad *et al.,* 2014). The rate of water absorption by the cowpea seeds largely depends on the temperature of water for soaking and soaking time (Shafaei and Masoumi, 2014). It also depends on the initial moisture content of the seeds, variety of the seeds, soaking duration, acidity level of the water and the seed physical characteristics (Demirhan and Özbek, 2015).

At the industrial level of cowpea processing, soaking of seeds is done taking into account, if not all, most of the factors that affect the rate of water absorption by the cowpea seeds. Thus, the temperature of soaking water for the cowpea seeds, for example, is usually preferred above ambient temperature because high soaking water temperature increases the rate of water absorption by the seeds (Turhan *et al.*, 2001). Consequently, the soaking time is reduced making it possible to process large quantities of cowpea seeds within the shortest possible time (Shafaei *et al.*, 2014).

Contrary to the industrial level of processing cowpea, the domestic level of cowpea processing does not necessarily consider the factors which affect the rate of water absorption. It involves soaking the cowpea seeds in water at ambient temperature overnight or for 24 h or more.

1.1 Statement of the Problem

Soaking is an integral part of processing leguminous seeds. It clearly establishes a relationship between the seed structure and water absorption by the seed (El-Syiad *et al.*, 2014). Thus, many researchers have sought to know how water moves into seeds. Many studies have further demonstrated the role of temperature in water absorption process by different seeds (Seyhan-Gürtaş *et al.*, 2001; Turhan *et al.*, 2001; Shafaei and Masoumi, 2014).

Extensive studies have been carried out by many researchers to study the water absorption patterns in a number of seeds of legumes and cereals (Tagawa *et al.*, 2003). The effects of temperature, pH, physical properties, chemical properties as well as the nutritional composition of some grains and legumes, on their water absorption capacities have also been investigated (Agarry *et al.*, 2014). In addition, some investigations conducted by researchers have revealed how temperature affects the diffusion of moisture into some legumes including soybean seeds, *Egusi* melon (*Cucumeropsis edulis*) seeds as well as cereals such as amaranth grains and maize kernels (Hsu, 1983; Addo and Bart-Plange, 2009).

However, effects of varietal variations and processing variables on the rate of water uptake and moisture diffusivity in some new varieties of legumes grown in Ghana, such as *Asontem*, *Hewale* and *Asomdwee*, all cowpea varieties have not been established. Thus, this research was undertaken to study the influence of temperature and variety on the water absorption characteristics of the three newlydeveloped cowpea varieties grown in Ghana.

1.2 Significance of the Study

From processing and engineering perspective, it is advantageous and of practical importance to first of all know how fast water can be absorbed by seeds, the effect of processing variables on the seeds and how the time spent in soaking the seeds can be estimated using specific conditions (Addo and Bart-Plange, 2009).

Consequently, for industrial purposes, whether in designing food processing equipment or determining favourable conditions under which soaking can be carried out and how these conditions change with time and temperature, it is necessary to have measurable data which describe the effect of the processing variables on agricultural materials (Bhattacharya, 1995; Abu-Ghannam and McKenna, 1997a; Taiwo *et al.*, 1998).

1.3 Aim of the Study

The aim of the study was to determine the effect of temperature on the physical properties and water diffusion coefficient of three cowpea varieties cultivated in Ghana. The specific objectives of the study were to:

1. determine the physical properties of three cowpea varieties (*Hewale, Asomdwee* and *Asontem*) prior to soaking

2. compare the physical properties of *Hewale, Asomdwee* and *Asontem* cowpea varieties after soaking under different temperature regimes

3. determine the water absorption characteristics, moisture diffusivity values and activation energy values of *Hewale*, *Asomdwee* and *Asontem* at the different soaking temperatures

CHAPTER TWO

LITERATURE REVIEW

2.0 Economic value, nutritional and chemical composition of legumes

In human nutrition, legumes play a relevant role, especially for people with low income or meagre earnings (Siddiq *et al.*, 2010). Legumes contribute significantly to meeting protein requirements in almost all parts of the world, especially in places where other protein sources are scarce and expensive (Van Heerden and Schonfelt, 2004). This is because legumes are good sources of protein, providing twice or thrice the amount of protein that cereal grains supply (Osorio-Diaz *et al.*, 2003).

Apart from being excellent sources of plant protein, legumes contain considerable amounts of minerals and vitamins (Kutos *et al.*, 2002). Processed and unprocessed legumes have high levels of resistant starch with the starch digestion rate being lower than that of some cereal products, thus a minimum supply of glucose into the blood stream and the decline in glycemic and insulinemic response (Torres *et al.*, 2004).

The inclusion of legumes in preparing meals present a great deal of advantages health-wise to the consumer by preventing certain diseases and disorders in the human body (Tharanathan *et al.*, 2003). Oomah *et al.* (2006) stated that research has shown that the disease preventing abilities of dry beans against cancer for example may be as a result of the presence of phenolics and some composites other than just dietary fiber. Dry beans contain polyphenols which inhibit the formation of reactive oxygen species, which are molecules with single unpaired electrons in their outer shells responsible for degenerative diseases like cancer (Boateng *et al.*, 2008).

2.1 Importance of Cowpea

Cowpea is considered a very important legume and for that matter, among the list of crops included in the national crop improvement program in Ghana (Oppong-Konadu *et al.*, 2005). According to Appiah *et al.* (2011), cowpea is used in preparing foods such cowpea fritters popularly referred to as 'koose', which is served with millet porridge; cooked beans with 'gari'(roasted grated fermented cassava) and 'tugbani' (steamed bean cake) as well as in making of stews and soup in Ghana.

In Nigeria, cowpea is used in preparing *Moi-moi*, a traditional food. *Moi-moi* is also an important dietary staple in some other countries in the West African region by virtue of its high protein content (Ogundele *et al.*, 2015). Another delicacy prepared with cowpea is *Ekuru*, which is a very popular food in western and southern parts of Nigeria, where *Ekuru* is used as a cultural and traditional food by the people (Adedokun *et al.*, 2014).

In Brazil, ‘akara’ is regarded as a cultural and tourism icon in Salvador (Bahia, Brazil). ‘Akara’, originally from Nigeria, is prepared from cowpea and sold on streets by the ‘baianas de acarajé’ at nearly two thousand points of sale documented by the Association of Saleswomen of Akara and Porridge (Rogério *et al.*, 2014).

Cowpea is most of the time eaten as a vegetable, usually together with cereals integrated into different kinds of recipes which are prepared into various products (Odedeji *et al.*, 2011).

2.2 Importance of Soaking

Soaking is an essential and necessary step in the processing of many legumes, especially cowpea. It is usually the first step taken in the processing of legumes. The volume of seeds during the soaking period increases with soaking time as a result of softening of the seed coat and swelling of the cotyledon due to water uptake by the seeds (El-Syiad *et al.*, 2014). The relevance of soaking cannot be over emphasized for a number of reasons.

Soaking decreases cooking time and improves food texture. This is because soaking of seeds in water for a period of time accelerates the rate of water absorption by the seeds, thus, speeding up the rate of chemical reactions, example starch gelatinization, during cooking (Zamindar *et al.*, 2013). Soaking also reduces anti-nutritional enzyme inhibitors in leguminous crops that bind useful enzymes, thereby reducing their activity. The removal of these anti-nutritional enzyme inhibitors: proteolytic enzyme inhibitors, trypsin and chymotrypsin inhibitors, oligosaccharides and lectins; enhances the accessibility of nutrients existent in these crops. A number of studies have also identified the significance of soaking in order to get rid of these anti-nutritional enzyme inhibitors in the soaking solution (Vasishtha and Srivastava, 2013).

According to Egli *et al.* (2003), soaking reduces the phytate content of foods but increases the activity of enzymes, called phytases, inherent in the seeds that breakdown the phytic acid molecule. Some studies have also reported that some amount of phytate molecules leach into the soaking water that is drained and thrown away (Egli *et al.*, 2003; Lestienne *et al.*, 2005; Vijayakumari *et al.*, 2007; Liang *et al.*, 2009; Albarracin *et al.*, 2013). Soaking also influences the concentration of phytic acid in the sense that as soaking time increases, the amount of phytic acid also reduces (Vijayakumari *et al.*, 2007).

Thomasset *et al. (*2007) indicated that polyphenols have been found to be the most ample source of antioxidants in the diet of many people. Nevertheless, these polyphenols bind themselves to positively charged mineral and protein compounds, thereby making them unobtainable for absorption and assimilation by the human body (Khandelwal *et al.*, 2010; Haslam, 1989; Reed, 1995). However, the soaking process causes reduction in the levels of polyphenols as well as tannins in legumes, thereby making mineral and protein components more accessible for absorption (Gilani *et al.*, 2005).

Zamindar *et al.* (2013) have also reported that the degree of flatulence experienced by monogastric organisms, especially human beings when they consume some legumes, is reduced when the legumes are soaked prior to cooking.

However, the soaking of a number of agricultural seeds, whether cereals or legumes, is a laborious process. Corn kernels for example, are usually soaked for more than 24 h and many times up to 72 h before the seeds undergo milling (Ji *et al.*, 2004).

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

The nutritional compositions of leguminous seeds differ from one another. Some legumes have some amount of certain constituents which are not beneficial to consumers. Therefore, certain measures are taken to reduce these unpleasant constituents within the legumes since most of the time they cannot be removed to provide wholesome grains for human consumption. As a result, several studies have been conducted to determine the most appropriate means of reducing these unwanted constituents in legumes which render them somehow unwholesome to some extent. Most of these studies have revealed that soaking of legumes in water plays a significant role in getting rid of some of these anti-nutritional substances from legumes. In addition to soaking of legumes, other studies have reported that cooking of legumes also play an important role in reducing the amounts of unwanted substances in legumes. These unwanted substances naturally present in legumes are usually referred to as anti-nutritional constituents or substances.

Red kidney bean is an example of a legume which is known to contain elevated amount of phytic acid. It also contains considerable amount of tannin. Therefore, soaking and cooking of the red kidney beans as well as other legumes causes a considerable decline in the amount of phytic acid as well as tannin present in the legumes. When the soaking medium for legumes contains some amount of sodium bicarbonate, more of the phytic acid and tannins are removed from the legumes. However, to reduce the amount of these anti-nutritional substances in legumes by using soaking and cooking as treatments, other beneficial constituents of the legumes suffer. For example, the amount of protein components of legumes decreases as a result of soaking and cooking treatments.

Minerals are also affected as they also experience the same fate as proteins during soaking and cooking of these legumes. Comparable results were reported by Lestienne *et al.* (2004) and Garcua-Pascual *et al.* (2006) when both carried out studies to evaluate the influence of soaking on some selected cereal grains and legume seeds on the amounts of iron, phytic acid and zinc in the cereals and legumes. They reported that the iron content in the cereals suffered a huge decrease, followed by the zinc content as a result of soaking. However, the amount of iron and zinc in the legumes, which were lost as a result of the soaking treatment, were much lower as compared to that of the cereals. Soaking whole seeds for 24 h led to leaching of iron and, to a lesser extent, of zinc ions into the soaking medium. They also reported that soaking of the cereals and legumes caused an impressive decline in the amount of phytic acid present in them. A study carried out by Tunde-Akintunde (2010) also revealed that temperature and time had a key role to play in the water absorption characteristics of dried bell pepper as well as the loss of nutrients by dried bell pepper. He reported that soaking of the food materials in water at elevated temperatures resulted in the loss of high quantities of ascorbic acid. Nonetheless, soaking of the food materials in water at lower temperatures resulted in the loss of high quantities of iron and calcium through leaching.

2.4 Moisture content-physical properties (of legumes) relationship

Various equipment designs for harvesting, handling, processing and storing agricultural materials like grains and legumes such as cowpea depend on the knowledge of their physical properties. The physical properties of grains for example, are essential for predicting the behaviour of grains during handling.

For agricultural materials, their physical characteristics or properties similarly influence their behaviour during transfer from one place to another by different modes of transportation (Baryeh, 2002; Karababa, 2006). In summary, the physical properties of agricultural materials are very important in performing postharvest operations (Vaishnava *et al.,* 2000).

In grading systems, the physical properties of agricultural material including the length, breadth, thickness, mass, surface area, volume and projected area are very essential. Again, the principal dimensions of agricultural materials are also relevant when constructing devices for distributing seeds into the soil. They are also important when constructing sieves for sorting agricultural materials. The design of combine harvesters, pneumatic conveying systems and planters also require knowledge of the principal dimensions of the agricultural materials for which these equipment and instrument are being designed.

One of the criteria for designing and developing effective processing and handling machines or equipment for grains and legumes is the availability of information on the variation in the physical properties with changes in their moisture contents (Tavakoli *et al.,* 2009; Lazaro *et al.,* 2005). This is so because processing equipment have specific moisture range within which they can achieve optimum performance. Thus, knowledge about these physical properties, for example, of the cereals and legumes and their variation with moisture is very important. For example, the moisture-dependent physical properties of the legumes may influence the modification and the performance of equipment for processing, storage and handling

of the legumes (Baryeh, 2001). Extensive studies have been carried out by several researchers to study the effect of moisture content on the physical properties of edible seeds and grains as well as chickpea seeds by Konak *et al.* (2002), pigeon pea by Baryeh and Mangope (2002), cocoa bean by Bart-Plange and
Baryeh (2003), lentil seed by Amin *et al.* (2004) and faba bean by Altuntas and Yildiz (2007)).

Tabatabaeefar (2003) conducted a study to determine the effect of moisture content on the physical properties of five varieties of wheat using moisture content varying from 0% to 22% on dry basis. The results showed that moisture content indeed had an influence on the physical properties of the five varieties of wheat as all the physical properties of the wheat varieties increased with increasing moisture content with the exception of their bulk and true densities which decreased as moisture content increased.

Altuntas and Demirtola (2007) also conducted a study to investigate the influence of moisture content on the physical properties of three legumes (black-eyed pea, kidney bean and dry pea seeds). They evaluated the influence of three individual moisture contents (8.21% wet basis, 8.20% wet basis, and 5.66% wet basis) on the physical properties of all the three legumes. They reported average lengths of 16.66 mm, 7.46 mm and 9.19 mm for kidney beans, dry pea and black-eyed pea, respectively. They also reported average widths of 8.86 mm, 6.02 mm and 6.96 mm for kidney beans, dry pea and black-eyed pea, respectively. The average thicknesses of seeds for each legume were 7.17 mm, 4.49 mm 6.26 mm for kidney beans, dry pea and black-eyed pea respectively. The average geometric mean diameter and unit mass of seeds for kidney beans, dry pea and black-eyed pea were

10.17 mm and 0.715 g, 5.85 mm and 0.158 g, 7.32 mm and 0.255 g, respectively. In addition, they reported increase in the seed volume, thousand seed mass, sphericity and projected area for the three legumes. However, a linear decrease in the kernel and bulk densities was obtained as the moisture content for kidney beans, dry pea and black-eyed pea seeds increased.

Furthermore, a study carried out by Al-Mahasneh and Rababah (2007) on the influence of moisture content on the physical properties of green wheat using moisture content varying from 9.3% to 41.5% wet basis showed that the physical properties of the green wheat were significantly affected by increasing moisture content.

Ahmadi *et al*. (2008) also found out that the physical properties of agricultural materials do change with increasing moisture content when they carried out a study to determine the influence of moisture content of the physical and mechanical properties of apricot fruits, pits and kernels.

Öztürk and Esen (2008) also assessed the physical properties as well as the mechanical properties of barley grains using moisture content ranging from 10% dry basis to 14% dry basis. They reported that the true density of the barley grains experienced a linear increase in value from 984.00 kg/m^3 to 1013.67 kg/m^3. However, unlike the true density of the barley grains which increased as the moisture content increased, the bulk density of the barley grains experienced a linear decline in value from 647.34 kg/m^3 to 623.00 kg/m^3.

Karimi *et al.* (2009) also confirmed results reported by other researchers, when they studied the effect moisture content had on the physical properties of wheat. They reported average values for the principal dimensions (length, breadth and thickness) of the wheat kernels at moisture content of 8% wet basis to be 6.75 mm, 3.26 mm and 2.77 mm, respectively. They also reported that at the same moisture content of 8% wet basis, the surface area, geometric mean diameter, sphericity and equivalent mean diameter of the wheat kernels were 48.68 mm^2, 3.93 mm, 0.58 and 3.94 mm respectively.

Besides Karimi *et al.* (2009), Tavakoli *et al.* (2009) also carried out a study that assessed the influence of varying moisture content (7.34% 12.11%, 16.82% and 21.58% dry basis) on selected physical properties of grains of barley. They reported that as the moisture content of the barley grains increased, the average length increased from 8.91 mm to 9.64 mm, the breadth also increased from 3.30 mm to

3.74 mm while the thickness also increased from 2.58 mm to 2.98 mm. The arithmetic mean diameter of the barley grains increased from 4.93 mm to 5.45 mm as the moisture content of the grains increased. The geometric mean diameter of the barley grains increased from 4.23 mm to 4.75 mm as the moisture content increased from 7.34% to 21.58% dry basis. They also reported an increase in the thousand grain mass from 44.48 g to 51.30 g as well as an increase in the surface area from 56.66 mm^2 to 71.09 mm^2. The sphericity of the barley grains increased from 0.475 to 0.494 while the angle of repose of the barley grains increased from 31.16 ° to 36.90 ° as the moisture content of the grains increased. The true density and porosity as well as the bulk density of the barley grains increased as the moisture content increased.

Furthermore, Ampah (2011) carried out a study to evaluate the impact of moisture addition (rewetting) and moisture removal (drying) had on physical properties of the cowpea variety *Asontem* grown in Ghana. Moisture addition to the cowpea seeds was executed using moisture content ranging from 8.07% to 22.54% wet basis while that for moisture removal used moisture content of cowpea seeds ranging from 9.58% to 19.00% wet basis. It was reported that during moisture addition, an increase was observed in the principal dimensions of the cowpea seeds as well as in other physical properties including the geometric mean diameter of the cowpea seeds, the surface area and the seed volume. Additionally, the thousand grain mass of the cowpea seeds as well as seed porosity also increased with increased moisture content. The same trend was reported for the angle of repose of the cowpea seeds as well as the static coefficient of friction of the *Asontem* cowpea seeds during the moisture addition. However, a decrease in the bulk and true density of the cowpea seeds was observed under the same moisture conditions. It was also reported that there was a decrease in seed sphericity as the seed moisture content increased. Contrary to the results reported for the physical properties of the cowpea seeds during moisture addition, the results reported during moisture removal from the seeds were different. It was reported that the removal of moisture from the seeds during drying resulted in a decrease in the principal dimensions likewise the thousand seed mass of the cowpea seeds. Furthermore, the geometric mean diameter, the surface area as well as the seed volume also experienced a decrease as a result of decreasing moisture content. On the contrary, the bulk and true density of the cowpea seeds increased with decreasing moisture content as a result of the drying process.

Firouzi and Alizadeh (2012) also carried out a study to investigate the influence moisture content had on the physical properties of cowpea seeds. They reported average values of length to be 10.77 mm, average value of breadth to be 6.39 mm and average value of thickness to be 5.91 mm thickness for the cowpea seeds at a moisture content of 15.4% dry basis. They also reported that at this same moisture content, the average value of geometric mean diameter of the cowpea seeds was 7.23 mm and the value of the unit weight of the cowpea seeds was 0.25 g while the surface area was 164.41 mm^2. The unit volume of the cowpea seeds at the said moisture content was 0.199 mm^3. They also reported that an increase in moisture content from 15.4% to 32.4% resulted in a decrease in bulk density from 679.7 kg/m^3 to 647.3 kg/m^3 as well as decrease in true density of the cowpea seeds from 1255.129 kg/m^3 to 1159.824 kg/m^3. They also reported that porosity of the cowpea seeds as well as the angle of repose also declined from 45.84% to 44.15% and 41.6 to 51.1 ° respectively as a result of the increase in moisture content of the cowpea seeds. In addition, they reported a linear increase in the value of the static coefficient of friction of cowpea seed on four different surfaces (rubber, galvanized iron, aluminium and stainless steel).

In addition, Suresh *et al*. (2013) and Marimuthu *et al.* (2013) all carried out individual studies on the influence of moisture content on physical properties. Suresh *et al*. (2013) carried out a study on the moisture dependant physical properties of sunflower seeds. They reported that geometric mean diameter of the sunflower seeds was 6.69 mm while the seed sphericity value was 0.63. Rewetting the sunflower seeds in a moisture content range of 10-18% (wet basis), the bulk density decreased from 330.7 kg/m^3 to 320.88 kg/m^3. The true density of the seed, weight of thousand kernels and porosity rose from 688.10 kg/m^3, 75.31 g and 51.94% to 725.56 kg/m, 78.86 g and 55.77%, respectively. The angle of repose varied from 18.10 ^{o} to 24.07 ^{o} and static coefficient of friction also varied from 0.51 to 0.61, respectively under the same moisture range for different surfaces. The initial cracking force for sunflower seed and hardness of the seeds decreased with increasing moisture content. Marimuthu *et al.* (2013) also studied the influence of moisture content on the physical properties of Lima beans. They reported an increase in the principal dimensions of the Lima bean seeds. The length of the seeds increased from 15.32 mm to16.16 mm. An increase from 7.92 mm to 9.02 mm was reported for the breadth of Lima bean seeds while there was an increase from 4.94 mm to 5.68 mm for the seed thickness as the seed moisture content increased. They also reported a linear increase in seed sphericity, bulk density and thousand seed weight from 0.548 to 0.579, 0.662 to 0.583 g/cm and 423 to 532 g, respectively.

Akinoso and Lasisi (2013) also studied the effect cooking time had on the properties (physical and mechanical) of dried pigeon pea. They reported that using cooking time range of 1 to 6 h at a constant temperature of 100 °C resulted in variation in the principal dimensions of the pigeon pea. The length of the pigeon pea ranged from 6.29 mm to 8.18 mm, while the breadth ranged from 5.59 mm to 6.95 mm and thickness of the pigeon pea ranged from 4.18 mm to 5.40 mm. As the time for cooking the pigeon pea seeds increased, so also did other properties of the pigeon pea seeds such as mass of seeds, the seed density, the seed sphericty, seed moisture content and aspect ratio increase.

Khanbarad *et al.* (2014) also conducted a study to evaluate the variations in the physical properties of BDN-2, a variety of pigeon pea, with changes in moisture content. They reported increase in seed moisture content from 6.2% (wet basis.) to 10.3%, 14.3%, 18.1%, 22.2%, 26.3% and 30.2% (wet basis), with corresponding spontaneous variations in the physical properties of the seeds. The initial principal dimensions of the seeds: length (5.38 mm), width (4.98 mm) and thickness (4.06), increased to 6.24 mm, 5.67 mm and 4.60 mm, respectively. They attributed the changes in the linear dimensions of the seeds to the swelling of the seeds. The mean geometrical diameter and equivalent diameters experienced an increase from 4.77 to

5.45 mm and 4.78 to 5.48 mm, respectively upon exposure to high moisture contents. The seed sphericity decreased from 0.88 to 0.87 and rose to 0.89 for the seed moisture range under consideration, with minimum sphericity occurring at a moisture content of 22% (wet basis) and an almost linear variation between moisture content of 6.2% and 22.2% (wet basis). The seed volume and seed surface area surged as the moisture contents of the seeds increased.

2.5 Water absorption characteristics of agricultural materials

During soaking process, water absorption by the seed largely depends on soaking time and the soaking medium temperature. Water slowly diffuses into the seeds until the seeds eventually reach a constant level of moisture content throughout the period of seed immersion (Ranjbari *et al.*, 2011).

The amount of water that seeds can imbibe in soaking process depends on factors such as the original amount of moisture in the seeds, variety of seeds, soaking duration, temperature of soaking medium as well as acidity level of the soaking medium (Hsu, 1983; Karapantsios *et al.*, 2002; Laria *et al.*, 2005). However, seeds of legumes and cereals do not exhibit the same physical and chemical characteristics even though they all have three main parts: the seed coat, the endosperm and an embryo. Virtually all seeds have their endosperm dominate the the major part of the seed, thus, a seed is generally regarded as a uniform entity in many studies involving moisture transfer (Gaston *et al.*, 2004; Bakalis *et al.*, 2009).

There have been considerable studies to investigate water absorption characteristics of many agricultural seeds and other biological materials. Seyhan-Gürtas *et al.* (2001) studied the water absorption characteristics of three legumes (lentils, beans and chickpeas) during soaking at three different temperatures. They reported water diffusion coefficient values which range from 3.53×10^{-10} m^2/s to 1.33×10^{-9} m^2/s, 4.35×10^{-11} m^2/s to 3.79×10^{-9} m^2/s and 3.53×10^{-10} m^2/s to 1.33×10^{-9} m^2/s for lentils, beans and chickpeas, respectively. They also reported activation energy values of 39.7 J/gmol, 33.6 to 50.8 J/gmol and 48.6 to 49.8 J/gmol for lentils, beans and chickpeas, respectively.

Badau *et al.* (2005) used Peleg's model to investigate the water absorption characteristics of two varieties of millet and one variety of sorghum. They reported activation energy values varying from 1.405 kJ/ mol to 6.572 kJ/ mol.

Białobrzewski *et al.* (2005) also determined the effective moisture diffusion coefficient of Faba beans (at initial moisture content of 0.240 kg/kg) during drying at five different drying temperatures. They reported that in a range of temperatures from 15 °C and 35 °C, during drying by convection, there exists a relationship between the range of moisture content and the effective water diffusion coefficient. However, using temperatures of 20 °C and 30 °C drying by convection had little influence on the effective water diffusion coefficient of the faba bean seeds. They also reported that the Arrhenius equation was enough to illustrate the relation between moisture content of the faba beans, the drying temperature and the effective water diffusion coefficient.

Kashaninejad and Kashiri (2007) studied the water absorption characteristics of wheat kernels using five different soaking temperatures ranging from 25 ℃ to 65 ℃. They employed five models (Henderson and Padis, Exponential, Page, Twoterm exponential and Modified Page) to determine the most suitable model required for studying the behaviour of wheat kernels during soaking. They found out from the study that Page model was more useful in predicting the behaviour of wheat kernels during soaking of kernels. They also reported that the wheat kernels had effective diffusivity of water values ranging from 2.80x10^{-12} m^2/s to 1.36x10^{-11} m^2/s. They reported 34.25 kJ/mol as activation energy value needed by the wheat kernels to absorb water during the soaking process.

Addo and Bart-Plange (2009) also studied the rate at which *egusi* melon seeds absorbed water at five different soaking temperatures: 30 °C, 40 °C, 50 °C, 60 °C and 70 °C. Data from the soaking experiment was fitted to Becker's model. The seeds had water diffusion coefficient ranging from 5.18× 10^{-8} m^2/s to 20.99× 10^{-8} m^2/s. The influence of elevated temperatures on diffusion coefficient was well described using Arrhenius-type equation, from which the activation energy was 28.38 kJ/ mol.

Kashiri *et al.* (2010) also investigated the water absorption characteristics of sorghum kernels using Peleg's models at five different temperatures: 10, 20, 30, 40 and 50 °C during soaking in water. The moisture contents of the seeds were used to establish increase in weight of kernels in the course of the experiment. The Peleg rate constant, k_1, decreased from 11.8×10^{-2} to 0.95×10^{-2} h % and that of the capacity constant, k_2, also decreased from 2.46×10^{-2} % to 2.06×10^{-2} %, with increasing temperature. The sorghum kernels had varied effective diffusivity from 8.376×10^{-12} to 2.22×10^{-12} and the activation energy value of 24.21 kJ.mol^{-1} was obtained.

Mayolle *et al.* (2012) carried out a study to evaluate the relationship between the activities of enzymes and diffusion of water in the process of malting barley grains. They reported that whole barley grains had water diffusivity values ranging from

$5.28x10^{-12}$ m^2/s and $7.61x10^{-12}$ m^2/s. However, for only the endosperm of the grains, the values of the water diffusivity ranged from 35.2 x 10^{-12} m^2/s and 49.5 x 10^{-12} m^2/s, which were far higher than the former.

Moreover, Agarry *et al.* (2014) studied on the water absorption characteristics of dent corn, corn flour, popcorn and sweet corn during a soaking experiment at temperatures of 30, 40, 50 and 60 ^oC. The water absorption data obtained from the soaking experiment were fitted to the Peleg and Becker's models as to harmoniously establish the saturation moisture content also known as the hydration equilibrium moisture content and the moisture diffusivity of the maize grains as well. Each type of maize experienced a surge in their water absorption capacity as well as saturation moisture contents as the temperature of soaking water increased. The absorption kinetics of the different types of maize adhered to Fick's law of diffusion in the first hours of soaking. The values obtained for the diffusion coefficients of the maize types ranged from 10.6 to 13.5 × 10^{-11} m^2/s for sweet corn, 5.27 to 7.09 × 10^{-11} m^2/s for yellow flour, 4.44 to 5.79× 10^{-11} m^2/s for popcorn, 6.74 to 8.88 × 10^{-11} m^2/s for white flour, 4.25 to 5.69 × 10^{-11} m^2/s for dent white corn and 3.28 to 4.68 × 10^{-11} m^2/s for dent yellow corn, respectively. Moisture diffusivity or the diffusion coefficient of dent corn (white and yellow), corn flour (white and yellow), popcorn and sweet corn was determined in relation to temperature using Arrhenius–type equation. From these, the activation energies for dent corn (white and yellow) in addition to the corn flour (white and yellow), popcorn and sweet corn were estimated as follows: 8.17 kJ/mol (dent white corn), 9.59 kJ/mol (dent yellow corn), 7.83 kJ/mol (white corn flour), 8.45 kJ/mol (yellow corn flour), 6.61 kJ/mol (sweet corn) and 8.01 kJ/mol (popcorn).

Demirhan and Özbek (2015) also modelled for cowpea (*Vigna unguiculata L*.) the water uptake process by seeds using two treatments: common treatment and microwave treatment. The common treatment and microwave treatment were used as the water absorption treatments, respectively, to study the water uptake kinetics of cowpea seeds in order to assess the influence of rehydration temperatures and microwave output powers on rehydration. Temperature range of 20 – 45 ºC and microwave output powers of 180–900 W were used study water uptake by the cowpea seeds during soaking process. An increase in the rehydration temperature and microwave output power caused a likewise increase the water uptake of cowpea seeds and a corresponding decrease in the rehydration time. The Peleg and Richards' models were able to predict water uptake of cowpea seeds going through common treatment and microwave treatment, respectively. The absorption data obtained from the experiment under the two treatments were fitted to the Fick's second law of diffusion to determine the effective diffusivity values. The diffusivity coefficients for cowpea seeds for common treatment ranged from 7.75×10^{-11} to 1.99×10^{-10} m^2/s and that of microwave treatment 2.23×10^{-9} to 9.78×10^{-9} m^2/s.

Ueno *et al.* (2015) also carried out a study to investigate water absorption of adzuki beans under the influence of high hydrostatic pressure. They reported that the effective water diffusion coefficient for adzuki beans experienced a significant increase from 8.6×10^{-13} m^2/s to 6.7×10^{-10} m^2/s as a result of high hydrostatic pressure.

CHAPTER THREE

MATERIALS AND METHODS

3.0 Study Area

The study was carried out at the Food and Postharvest Engineering laboratory of the Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

3.1 Materials

3.1.1 Preparation of seeds samples

Samples of three local cowpea varieties: *Asomdwee*, *Asontem* and *Hewale*, were obtained from the Council for Scientific and Industrial Research - Crops Research Institute (CSIR - CRI) at Fumesua, Kumasi, Ghana. The seeds were cleaned manually to remove all foreign matter viz. dirt, stones fragments, weevil contaminated seeds and broken seeds. The cleaned seeds were sealed in labelled transparent low density polyethylene bags.

Figure 3.1: *Asomdwee*

Figure 3.2: *Asontem*

Figure 3.3: *Hewale*

3.2 Methods

3.2.1 Determination of seed moisture content

The initial moisture contents of the samples of three cowpea varieties were determined in triplicate by oven drying method. 15 g of each sample was heated in an oven at 103 ℃ for 72 h according to ASAE S352.2 APR1988 R, 2012 and expressed as kg/kg (dry basis). The following equation was used in determining the initial moisture content:

$$M_d = \frac{100M_w}{100 - M_w} \quad (1)$$

where,

M_d = Moisture content (dry basis)

M_w = Moisture content (wet basis)

3.2.2 Determination of 1000 seed weight of cowpea

The 1000 seed weight of the three cowpea varieties was determined according to the method used by Varnamkhasti *et al.* (2008). Thousand seeds were randomly selected from each cowpea variety, placed on flat plates and carefully weighed using a precision electronic balance (Model XY110002C, Micromed UK) with an accuracy of 0.01 g. The method was replicated thrice for each cowpea variety under consideration prior to the soaking experiment. The following equation was used in determining the average thousand seed weight of each cowpea variety:

$$1000sw = \frac{\sum_{i=1}^{i=n} sw_1 + sw_2 + \ldots + sw_n}{n} \quad (2)$$

where,

$1000sw$=Average thousand seed weight (g)

sw_1= Weight of first sample replicate (g)

sw_2= Weight of second sample replicate (g)

sw_n = Weight of nth sample replicate (g) n =

Number of samples (in this study n=3)

The weight of the seed was thus determined by dividing the 1000-seed weight by 1000.

3.2.3 Determination of seed dimensions

The basic dimensions length (L), breadth (B) and thickness (T), expressed in millimetres, of sample seeds from each cowpea variety were determined in triplicate using a Vernier calliper with a least count of 0.02 mm for each single seed of 10 seeds sampling before and after soaking. A seed each was placed within the Vernier calliper measuring unit and the nob adjusted until the seed was just closely held before taking its reading (Addo *et al*., 2006). Mohsenin's (1980) methods were used in calculating the geometric mean diameter and sphericity for each seed with the seed dimensions (L, B and T).

3.2.4 Geometric mean diameter:

The geometric mean diameter of the seeds was determined using the following equation:

$$Dg = \left(LBT\right)^{\frac{1}{3}} \qquad (3)$$

where,

$Dg =$ Geometric Mean Diameter (mm)

$L =$ Length (Major diameter, mm)

$B =$ Breadth (Minor diameter, mm)

$T =$ Thickness (Intermediate diameter, mm)

3.2.5 Sphericity:

The sphericity of the seeds was determined using the following equation:

$$\Phi = \frac{\left(LBT\right)^{\frac{1}{3}}}{L} \qquad (4)$$

where,

$\Phi =$ Spericity

$L =$ Length (Major diameter, mm)

$B =$ Breadth (Minor diameter, mm)

$T =$ Thickness (Intermediate diameter, mm)

3.2.6 Determination of equivalent radius (R)

The average equivalent radius (R) was determined for 50 seeds from each cowpea variety. The assumption was that the volume of the cowpea seed can be approximated by calculating the volume of a sphere with radius equal to half diameters of the seed. To determine the volume of the seed, 50 ml of distilled water was transferred into a measuring cylinder of 100-ml capacity. Afterward, 50 seeds of each cowpea variety were separately immersed in the water one variety at a time. The amount of water displaced was read on the measuring cylinder and recorded accordingly. The procedure was replicated five times and the true volume was calculated $(4\pi R^3/3)$ and equivalent radius, *R*, is given by equation (5)

$$R = \sqrt[3]{\frac{3V}{4\pi}} \qquad (5)$$

V = Volume of seed (mm^3)

3.2.7 Cowpea seed volume

The volume (V) of the cowpea seeds was calculated from the expression presented by Mohsenin (1980):

$$V = \phi^3 \frac{\pi}{6} L^3 \qquad (6)$$

where,

V = Volume of cowpea seeds (mm^3)

ϕ = Spericity

L = Length (Major diameter, mm)

$\frac{\pi}{6} L^3$ = Volume of circumscribed sphere (mm^3)

3.2.8 Surface area of cowpea seeds

The surface area of the cowpea seeds was calculated using the equation used by Demirhan and Özbek (2015):

$$A = \pi Dg^2 \qquad (7)$$

where,

$A =$ Surface area of cowpea seeds (mm^2)

$Dg =$ Geometric Mean Diameter (mm)

3.3 Soaking experiment

10 g of cowpea seed samples was weighed using a precision electronic balance. The sample was placed in a net, tied and subjected to soaking in a water bath with distilled water at different water temperatures (30, 40, 50 and 60 ℃) for twenty levels of soaking durations from 30 to 600 min at 30 min interval. The procedure was replicated three times for each cowpea variety.

3.3.1 Experimental design

A factorial experiment with two factors: temperature (30, 40, 50 and 60℃) and soaking time (30 to 600min at 30 min interval) arranged in a completely randomized design with three replications was used. 10 g cowpea seeds of each variety were used for each replication.

3.3.2 Water absorption capacity of cowpea

During the soaking experiment, the samples were removed from the water bath at specified duration. The samples were placed on soft moisture absorbing tissues after untying the nets. The seeds were blotted with tissue paper to absorb remaining water on the surface of the seeds before the seed samples were reweighed (SeyhanGurtas *et al*.,2001, as cited by Addo *et al*., 2006). The water absorption capacity was determined using the following equation by McWatters *et al*.(2002):

$$W_{ac} = \frac{W_f - W_i}{W_i} \times 100 \qquad (8)$$

where,

W_{ac} = Water absorption capacity (d. b. %) of the seeds

W_f = Weight of seeds after immersion (g) into water

W_i = Weight of seeds before immersion (g) into water

3.4 Modelling of rehydration kinetics

Many studies on water absorption and drying use the moisture ratio (MR) as the basis for achieving water absorption and drying models as a result of few data dispersion and optimize data (Akpinar *et al*.,2003).

Normally, when a diffusion process takes place at a temperature, which is constant, that process is believed to exhibit Fick's second law of diffusion. As stated by Fick, a diffusion process which is axisymmetric in nature can be expressed using an equation that is three-dimensional given by:

$$\frac{\partial M}{\partial t} = D\left(\frac{\partial^2 M}{\partial x^2} + \frac{\partial^2 M}{\partial y^2} + \frac{\partial^2 M}{\partial z^2}\right) \qquad (9)$$

where,

M = Instantaneous moisture content at a specified time t (kg/kg)

D = Diffusion coefficient $\left(m^2/s \right)$

t = Time (s)

Becker (1959) proposed a model to determine the diffusion coefficient, D. The model is an equation which shows the relationship between moisture concentration and time for particles of random shape as well as relative short immersion times. The equation is given as:

$$1 - \frac{U - U_s}{U_o - U_s} = \frac{2}{\pi^{1/2}} F_o^{1/2} \qquad (10)$$

$$F_o = \frac{D\theta}{R^2} \qquad (11)$$

where,

U = Mean moisture concentration in dry weight $\left(g/g \right)$

U_s = Saturation moisture concentration in dry weight $\left(g/g \right)$

U_o = Initial moisture concentration in dry weight $\left(g/g \right)$

D =Diffusion coefficient $\left(m^2/s \right)$

R =Equivalent radius of the sphere with the same volume as that of the particle under consideration $\left(m \right)$

θ = Soaking or immersion time $\left(s \right)$

Equation (10) clearly shows that for the diffusion to be rational, the increase in moisture during absorption of water must adhere to a linear relation with $\theta^{1/2}$.

To illustrate the temperature dependency of diffusion coefficient (D), an equation (an Arrhenius type) was used:

$$D = D_o e^{-E/RT} \quad (12)$$

where,

D_o = Diffusion constant (m^2/s)

E = Activation energy (kJ/mol)

R = Gas constant $(8.314 kJ/molK)$

T = Absolute temperature (K)

A linear regression analysis of (D vs. $1/T$) was used to find activation energy values for the different cowpea varieties under consideration. The linear regression analysis gave slope value indicating (E/R). A product of the slope (E/R) value and gas constant, R , produced the activation energy values for ***Asontem***, ***Hewale*** and ***Asomdwee*** cowpea seeds.

3.5 Data Analyses

All data were subjected to the analysis of variance (ANOVA) using Minitab software and were presented as mean values with standard deviations. Differences between mean values were established using T-test and Least Significant Difference (LSD) at confidence level of 95%. All experiments were performed in triplicate.

CHAPTER FOUR

RESULTS AND DISCUSSION

Table 4.1: Initial physical properties of *Asontem*, *Hewale* and *Asomdwee* cowpea varieties

Parameter	Cowpea Variety		
	Asontem	**Hewale**	**Asomdwee**
Moisture content (%db)	16.53±0.00	12.40±0.01	13.63±0.00
Length (mm)	7.19±0.75	6.88±0.72	7.20±0.46
Breadth (mm)	6.01±0.42	5.54±0.43	5.44±0.32
Thickness (mm)	4.78±0.28	4.45±0.34	4.63±0.24
Radius (mm)	3.46± 0.38	3.26± 0.37	3.08± 0.64
Geometric mean diameter (mm)	5.90±0.33	5.53±0.38	5.66±0.26
Surface area (mm^2)	111.00±18.30	96.44±13.34	100.81±9.32
Seed volume (mm^3)	341.06±56.92	281.75±58.55	299.99±41.69
Thousand seed weight (g)	146.9±2.22	122.27±1.39	125.36±1.94
Sphericity	0.83±0.06	0.81±0.046	0.79±0.03

The initial physical properties of the three cowpea varieties (***Asontem***, ***Hewale*** and ***Asomdwee***) studied were determined before soaking at different temperatures and they are given in **Table 4.1**. The initial moisture content for *Asontem* cowpea was higher than that of *Asomdwee* and *Hewale* cowpea varieties. The data presented in Table 4.1 generally agree with those reported by Kaptso *et al*. (2008), who reported values ranging from 0.73 cm – 0.92 cm for length, 0.55 cm – 0.73 cm for breadth and 0.38 cm – 0.58 cm for thickness of cowpea seeds. Furthermore, Olapade *et al*. (2002) reported similar range of values for length, breadth and thickness of cowpea seeds. *Asontem* also exhibited generally higher values for its principal dimensions with the exception of its average length which was slightly lower than that of *Asomdwee*. However, the values for equivalent radius, the surface area, the geometric mean diameter, the seed volume, the thousand seed mass and the sphericity of *Asontem* were highest in comparison to *Asomdwee* and *Hewale*.

4.0 Effect of different soaking temperature regimes on seed length for *Asontem*, *Hewale* and *Asomdwee*

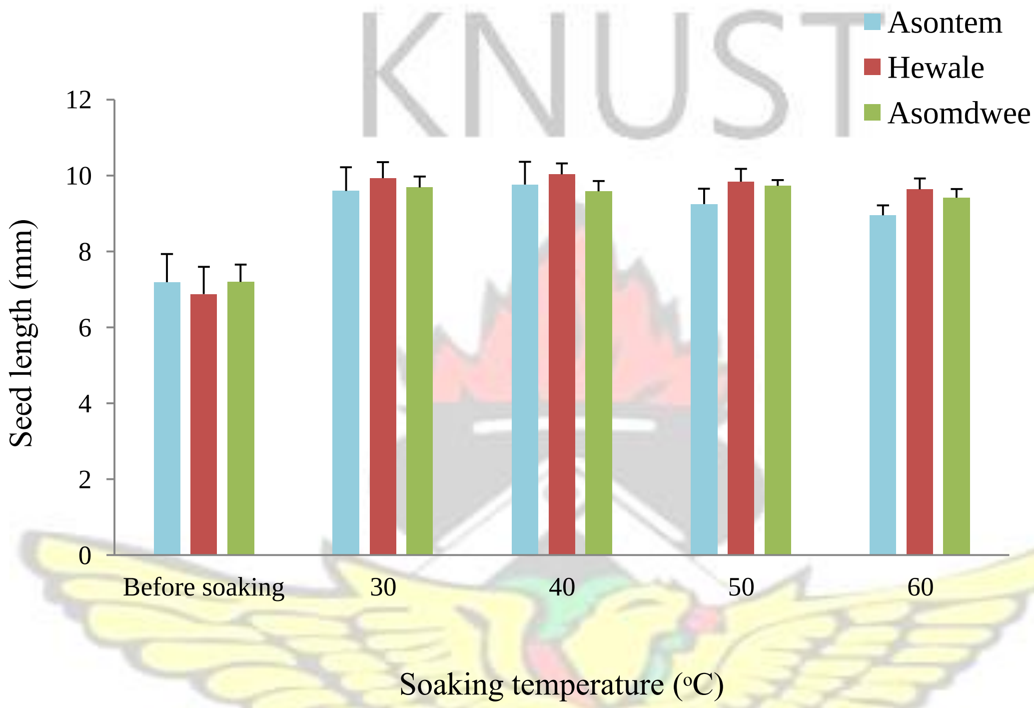

Figure 4.1: Seed length at different soaking temperatures

During soaking at four different temperatures: 30 °C, 40 °C, 50 °C and 60 °C, the average initial length for each of the three cowpea varieties (*Asontem*, *Hewale* and *Asomdwee*) showed significant increase ($p<0.05$). The length of *Asontem* cowpea variety increased from 7.19 mm to 9.60 mm, 9.77 mm, 9.25 mm and 8.95 mm after undergoing soaking treatment at temperatures of 30 °C, 40 °C, 50 °C and 60 °C respectively due to swelling of the seeds as a result of continuous imbibition of water. It can be seen from Figure 4.1 that the maximum increase in length of *Asontem* cowpea seeds, occurred under soaking temperature of 40 °C. At 40 °C, *Hewale* cowpea variety showed rapid absorption of water which resulted in its highest

increase in length (6.88 mm to 10.04 mm) as compared to the increase in seed length of *Asontem* (7.19 mm to 9.77 mm) and *Asomdwee* (7.20 mm to 9.59 mm) cowpea varieties during soaking of seeds at 40 ℃. In contrast to *Asontem* and *Hewale* cowpea varieties, *Asomdwee* cowpea variety behaved differently under the four different soaking temperature regimes. *Asomdwee* cowpea variety rather exhibited highest increase in length during soaking at temperature of 50 ℃ (7.20 mm to 9.73 mm) followed by soaking at 30 ℃ (7.20 mm to 9.69 mm), soaking at
40 ℃ (7.20 mm to 9.59 mm) and finally soaking at 60 ℃ (7.20 mm to 9.42 mm). Soaking of seeds of all three cowpea varieties at 60℃ resulted in the least increase in seed length with *Hewale* cowpea variety having the highest increase in seed length, followed by *Asomdwee* and *Asontem* cowpea varieties. The general decrease in seed length from 40 ℃ could be attributed to the seeds reaching saturation moisture concentration within a short period because of the faster rate of moisture absorption by the seeds triggered by high temperatures, thus creating equilibrium moisture concentration between the moisture surrounding the seeds and that within the seeds. Therefore, further expansion of the seeds lengthwise as a result of moisture ingress is reduced.

4.1 Effect of different soaking temperature regimes on seed breadth for *Asontem*, *Hewale* and *Asomdwee*

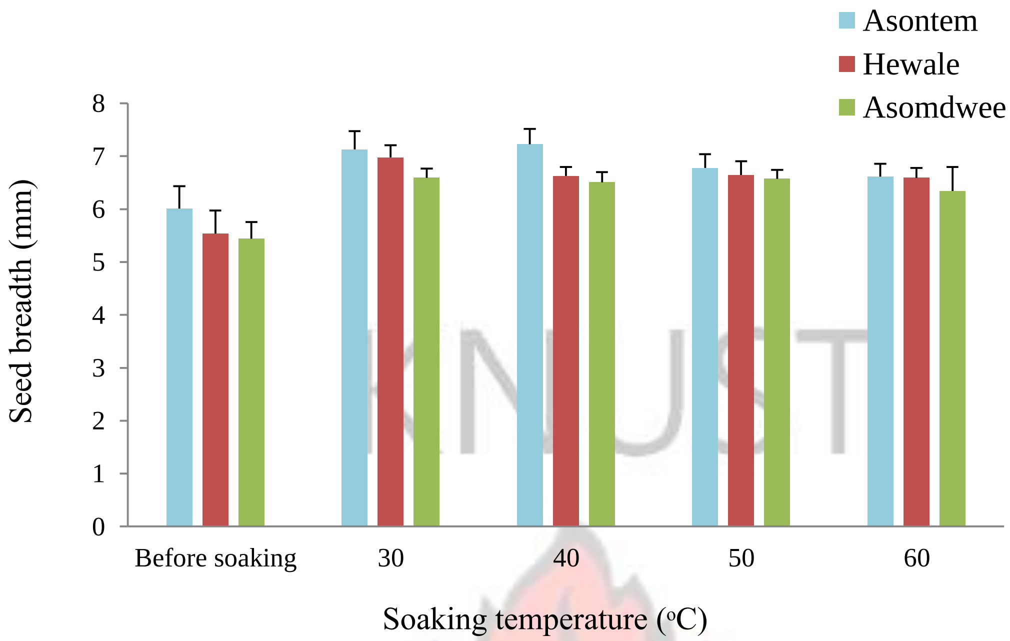

Figure 4.2: Seed breadth at different soaking temperatures

The seed breadth for all the three cowpea varieties shown in Figure 4.2 experienced a significant increase ($p<0.05$) during soaking at four different temperature regimes: 30 °C, 40 °C, 50 °C and 60 °C. It was observed that *Asontem* cowpea variety had the highest increase in seed breadth under all the four temperature treatments used during soaking of the seeds as compared to *Hewale* and *Asomdwee* cowpea varieties. Soaking of seeds of each cowpea variety at 30 °C resulted in the highest increase in seed breadth (6.01 mm to 7.13 mm) for *Asontem* cowpea variety, the second highest seed breadth (5.54 mm to 6.98 mm) for *Hewale* cowpea variety and the lowest seed breadth (5.44 mm to 6.59 mm) for *Asomdwee* cowpea variety. Furthermore, soaking of seeds of each cowpea variety at temperature of 40 °C followed the same trend observed in the three cowpea varieties when soaking was carried out at 30 °C. Thus, *Asontem* cowpea variety once again experienced the highest increase in seed breadth (from 6.01 mm to 7.23 mm), followed by *Hewale* (from 5.54 mm to 6.63 mm) and *Asomdwee* (from 5.44 mm to 6.51 mm) respectively. The seed breadth values for all the three cowpea varieties increased up to at soaking at 30 ℃ and 40 ℃ but decreased with further increase in soaking temperature.

4.2 Effect of different soaking temperature regimes on seed thickness for *Asontem*, *Hewale* and *Asomdwee*

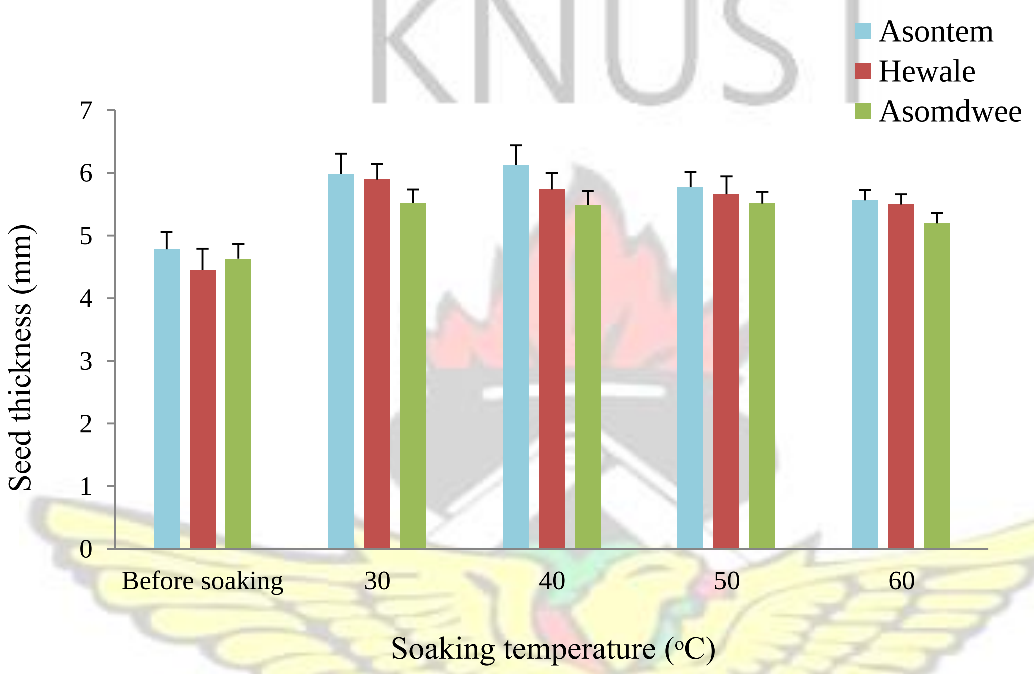

Figure 4.3: Seed thickness at different soaking temperatures

The initial seed thickness for *Asontem, Hewale* and *Asomdwee* cowpea varieties increased significantly ($p<0.05$) under the four soaking temperature regimes. Soaking of seeds of the three cowpea varieties at 30 ℃ saw an increase in their seed thickness with *Asontem* cowpea variety leading with the highest increase in thickness (from 4.78 mm to 5.98 mm), afterwards *Hewale* cowpea variety (from 4.45 mm to 5.89 mm) and lastly *Asomdwee* cowpea variety (from 4.63 mm to 5.52 mm). Again, *Hewale* and *Asomdwee* cowpea varieties experienced their highest values in seed thickness from 4.45 mm to 5.89 mm and 4.63 mm to 5.52 mm respectively at 30 ℃. Soaking of seeds at 40 ℃ resulted in the highest increase in seed thickness for *Asontem* cowpea variety from 4.78 mm to 6.12 mm in comparison to the other three soaking temperatures (30 °C, 50 °C and 60 °C) used in the study, while *Hewale* and *Asomdwee* cowpea seeds experienced an increase from 4.45 mm to 5.73 mm and 4.63 mm to 5.49 mm respectively. Soaking of seeds for all three cowpea varieties at 60 °C resulted in the least increase in seed thickness of the various cowpea varieties with *Asontem*, *Hewale* and *Asomdwee* increasing from 4.78 mm to 5.56 mm, 4.45 mm to 5.50 mm and 4.63 mm to 5.20 mm, correspondingly.

4.3 Effect of different soaking temperature regimes on seed geometric mean diameter for *Asontem*, *Hewale* and *Asomdwee*

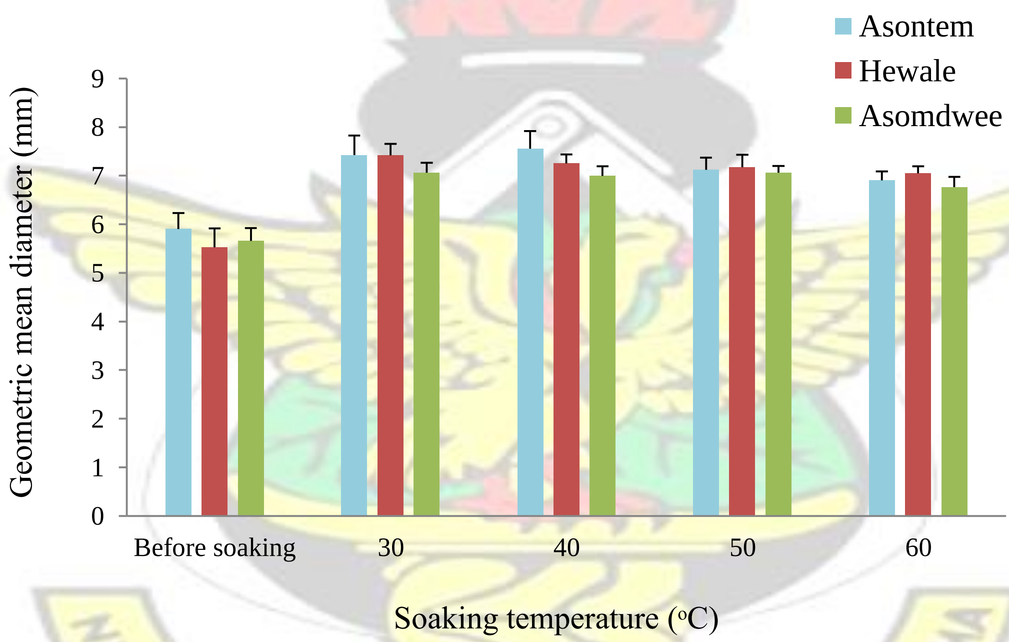

Figure 4.4: Seed geometric mean diameter at different soaking temperatures

The initial geometric mean diameter values for each cowpea variety increased significantly ($p<0.05$) as soaking temperature increased. On soaking of seeds at 30 °C, the geometric mean diameter increased significantly for all the cowpea varieties. *Asontem* and *Asomdwee* cowpea varieties increased in geometric mean diameter from initial values of 5.91 mm to 7.42 mm and 5.66 mm to 7.07 mm, respectively. *Hewale* cowpea variety experienced its highest increase in geometric mean diameter

from 5.54 mm to 7.42 mm on soaking at 30 ℃. In addition, *Asomdwee* cowpea variety also experienced its highest increase in geometric mean diameter from 5.66 mm to 7.07 mm after soaking seeds at 30 ℃. Soaking of seeds at 40 ℃ yielded the highest increase in geometric mean diameter for *Asontem* cowpea variety from 5.91 mm to 7.56 mm in comparison to the other three soaking temperatures: 30 ℃, 50 ℃ and 60 ℃. On the other hand, soaking of seeds of all three cowpea varieties at 60 ℃ resulted in the least increase in their geometric mean diameter values: *Asontem*, *Hewale* and *Asomdwee* cowpea varieties increased from 5.91 mm to 6.91 mm, 5.54 mm to 7.05 mm and 5.66 mm to 6.77 mm,
respectively.

4.4 Effect of different soaking temperature regimes on seed surface area for *Asontem*, *Hewale* and *Asomdwee*

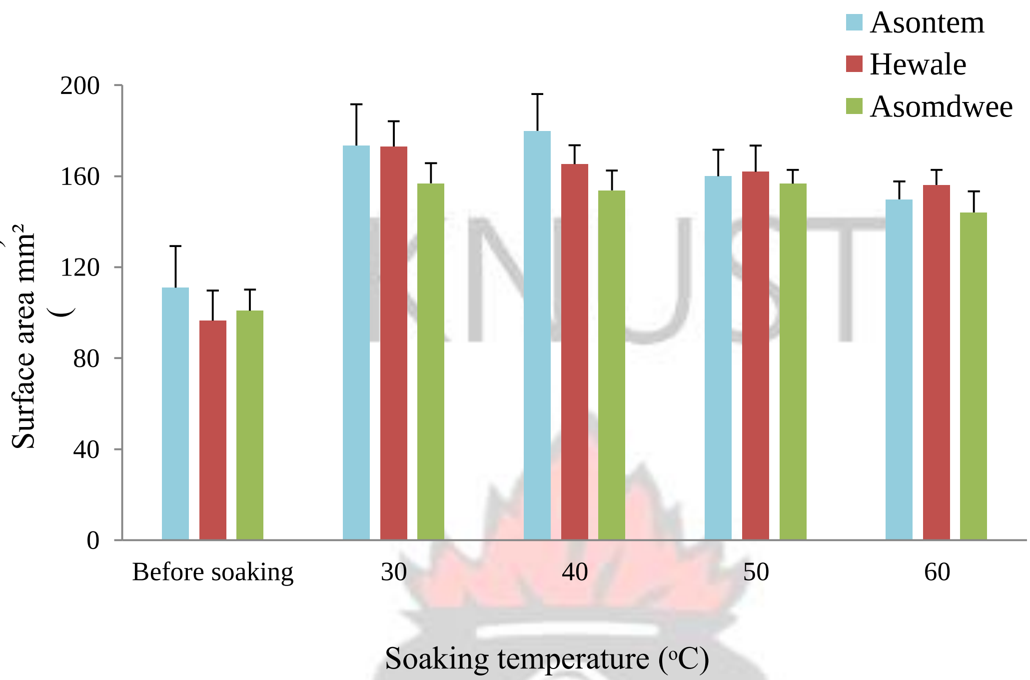

Figure 4.5: Seed surface area at different soaking temperatures

The initial surface area of seeds of all the three cowpea varieties under study increased significantly ($p<0.05$) after being subjected to soaking treatments at four different temperature regimes. Soaking of seeds of all three cowpea varieties at 30 °C led to *Asontem* cowpea variety experiencing the highest increase in surface area (from 109.71 mm^2 to 173.50 mm^2), followed by *Hewale* cowpea seeds which experienced an increase in surface area from 96.25 mm^2 to 173.10 mm^2 and lastly the surface area of *Asomdwee* cowpea seeds increasing from 100.73 mm^2 to 156.90 mm^2. The surface area for *Asontem* cowpea seeds increased sharply from 109.71 mm^2 to 179.90 mm^2 after the seeds were subjected to soaking at 40 °C. This increase in surface area for *Asontem* cowpea seeds was the highest value recorded in comparison to the other three temperatures used in the study. *Hewale* and

Asomdwee cowpea seeds also underwent increase in seed surface area, with the surface area of *Hewale* cowpea seeds increasing from 96.25 mm^2 to 165.30 mm^2 and that of *Asomdwee* cowpea seeds increasing from 100.73 mm^2 to 153.80 mm^2 after soaking at 40 °C. *Asomdwee* cowpea seeds recorded the highest increase in seed surface area after soaking at 50 °C in comparison to the other three soaking temperatures.

4.5 Effect of different soaking temperature regimes on seed volume for *Asontem*, *Hewale* and *Asomdwee*

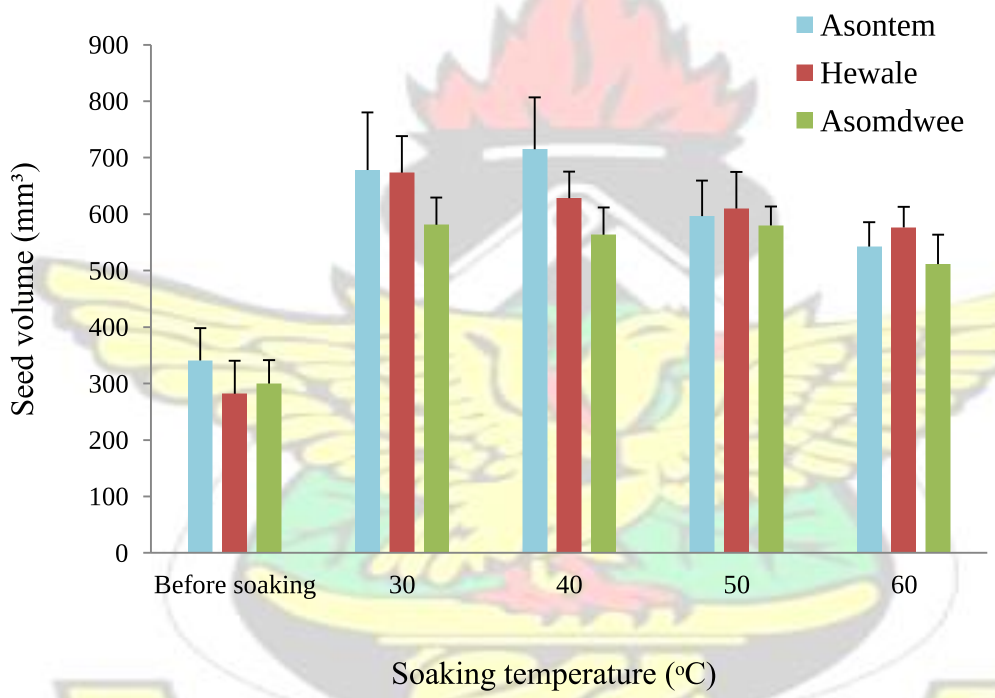

Figure 4.6: Seed volume at different soaking temperatures

The seed volume of all the three cowpea varieties increased significantly ($p<0.05$) during soaking under all the four temperature treatments. During soaking of seeds of each cowpea variety at 30 °C, the seed volume of *Asontem*, *Hewale* and *Asomdwee* cowpea variety increased from 339.49 mm^3 to 678.20 mm^3, 278.96 mm^3 to 673.60 mm^3 and 298.64 mm^3 to 581.40 mm^3, respectively. Additionally, *Hewale* and *Asomdwee* cowpea both experienced their highest increase in seed volume after soaking at the temperature of 30 °C. During soaking of cowpea seeds of each variety at 40 °C, *Asontem* cowpea seeds increased rapidly in seed volume (from 339.49 mm^3 to 715.00 mm^3) in comparison to the other three soaking temperatures and the other two cowpea varieties (*Hewale* and *Asomdwee* cowpea varieties). Soaking of cowpea seeds at 50 °C and 60 °C resulted in *Hewale* leading *Asontem* and *Asomdwee* cowpea varieties in terms of the highest increase in seed volume under the two soaking temperatures given.

4.6 Effect of different soaking temperature regimes on seed sphericity for *Asontem*, *Hewale* and *Asomdwee*

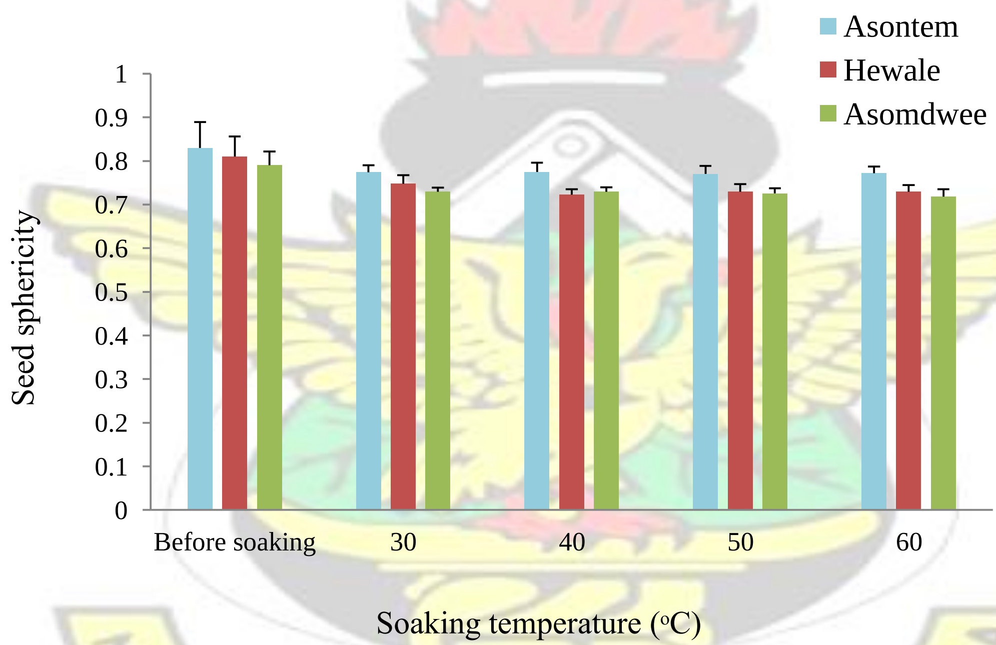

Figure 4.7: Seed sphericity at different soaking temperatures

The seeds of all the three cowpea varieties experienced significant ($p<0.05$) reduction in their sphericity when the seeds from these varieties were subjected to soaking at four temperature treatments. The sphericity of *Asontem* cowpea seeds reduced from 0.82 to 0.77 during soaking at 30 °C. The same result was again recorded for *Asontem* cowpea seeds when they were subjected to soaking at 40 °C, 50 °C and 60 °C. *Hewale* and *Asomdwee* cowpea seeds also experienced a reduction in their sphericities. During soaking of *Hewale* cowpea seeds at 30 °C, the sphericity of the seeds decreased from 0.80 to 0.75. When soaking of the seeds was carried out at 40 °C, the sphericity of the seeds further decreased from 0.80 to 0.72. Moreover, soaking of *Hewale* cowpea seeds at 50 °C gave the same result for seed sphericity (from 0.80 to 0.73) as soaking the seeds at 60 °C. The sphericity of *Asomdwee* cowpea seeds decreased from 0.79 to 0.73 at soaking temperatures of 30 °C, 40 °C and 50 °C. Soaking of *Asomdwee* cowpea seeds at 60 °C resulted in decrease in seed sphercity from 0.79 to 0.72.

4.7 Water absorption curves of *Asontem*, *Hewale* and *Asomdwee* cowpea varieties

The water absorption curves of *Asontem*, *Hewale* and *Asomdwee* cowpea varieties are shown in Figures 4.8, 4.9 and 4.10.

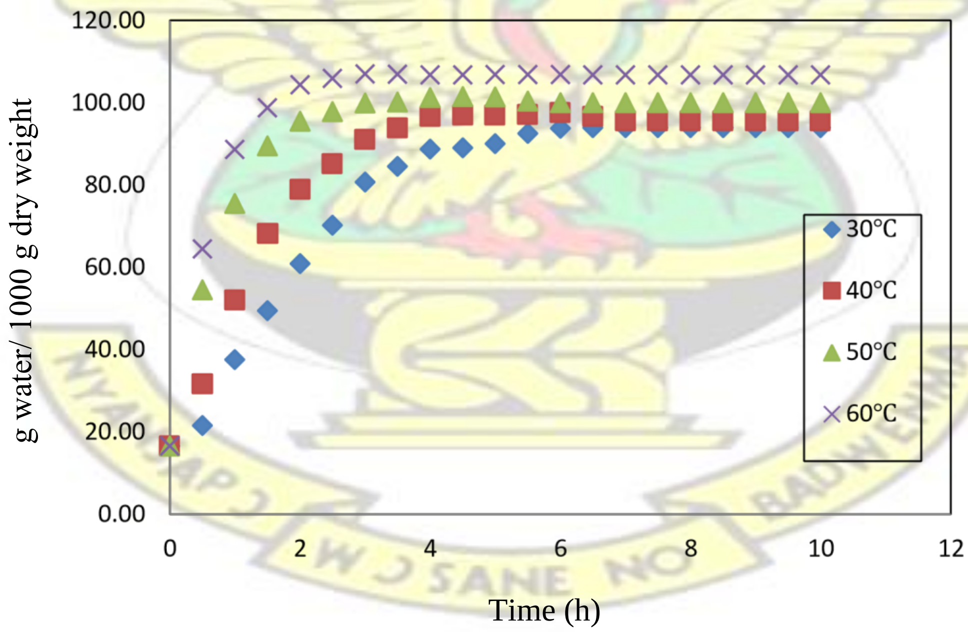

Figure 4.8: Water absorption characteristics of *Asontem*

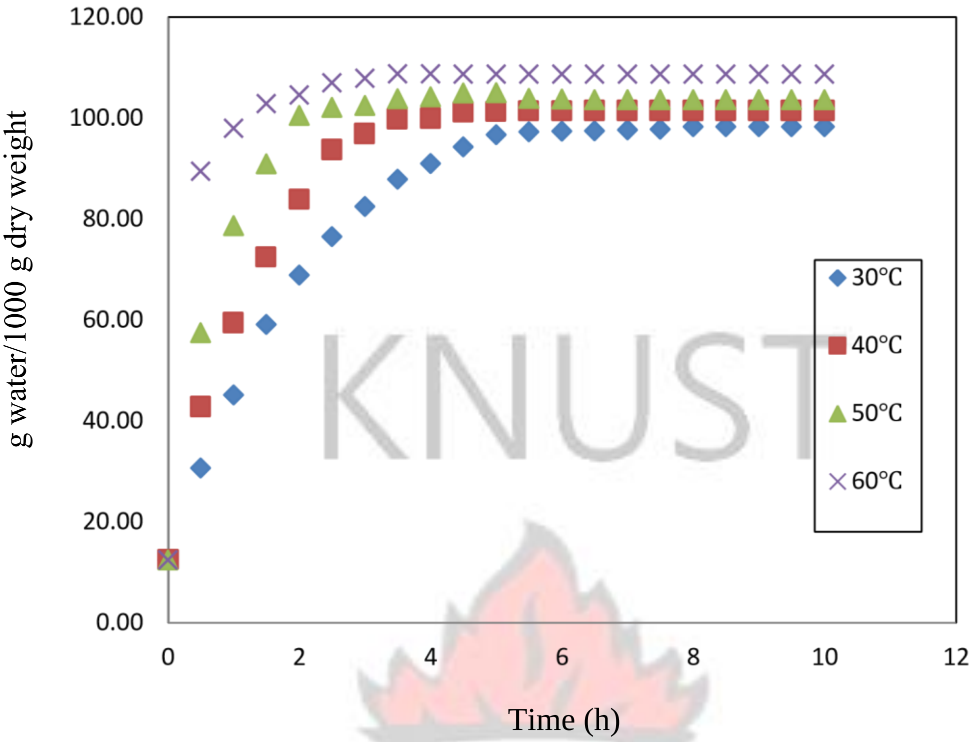

Figure 4.9: Water absorption characteristics of *Hewale*

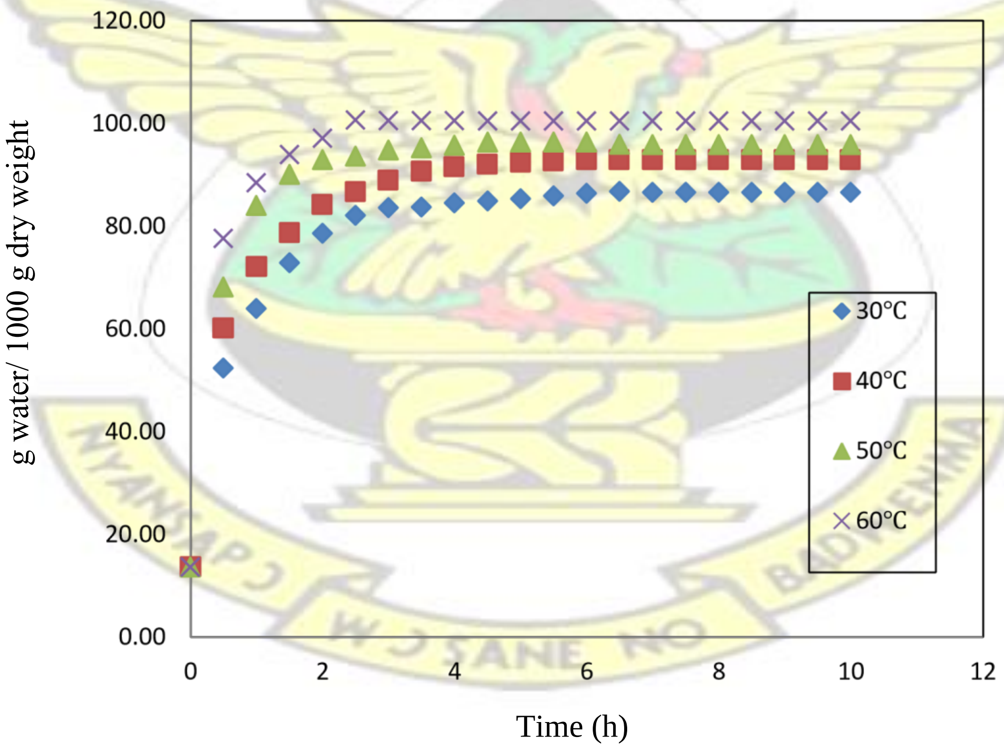

Figure 4.10: Water absorption characteristics of *Asomdwee*

It is clearly seen from figures 4.8, 4.9 and 4.10 that the rate of water absorption by cowpea seeds increased as the soaking temperatures increased. Sopade and Obekpa (1990), Turhan *et al*. (2001) and Shafaei *et al.* (2014) reported similar results from their studies on the water absorption characteristics of soybean and chickpea. Pan and Tangratanavalee (2003) also made comparable observation when they studied on the water absorption characteristics of soybean seeds.

During the soaking process, an initial instant rate of water absorption was observed after which the rate of water absorption gradually slowed down as the saturation moisture content was approached at all four temperatures. This was because the force driving the water absorption into the seeds decreased as the rate of water absorption neared saturation moisture content (Kashiri *et al.,* 2010). The time taken for saturation moisture content for all the cowpea varieties to be reached was longer during soaking at 30 ºC but decreased with increasing temperatures. This is because the higher the temperature, the higher the rate of water diffusion into the seeds. Again higher temperatures mean faster gelatinization of starch content of seeds and faster denatured protein resulting in faster rate of water absorption. The time taken for saturation moisture content for *Asontem* cowpea to be reached was at 8 hours during soaking at 30 ℃, but it reduced to 6 h, 4.5 h and 3 h when soaking was carried out at 40 ℃, 50 ℃ and 60 ℃, respectively. The time taken for saturation moisture content to be achieved for *Hewale* cowpea during soaking at 30℃ was also 8 hours but it also reduced to 6.5 h, 5 h and 3.5 h as the soaking temperature of the water was increased to 40 ℃, 50 ℃ and 60 ℃ respectively. Similar results were obtained for *Asomdwee* cowpea variety whose saturation moisture content was reached at 6.5 h, 6 h, 4.5 h and 2.5 h during soaking at 30 ℃, 40 ℃, 50 ℃ and 60 ℃ respectively. Similar results were reported by Addo *et al.* (2006) when they studied the water absorption characteristics of two maize varieties: *Obatanpa* and *Mamaba*.

4.8 Water Absorption Rates of *Asontem*, *Hewale* and *Asomdwee* cowpea varieties

Table 4.2: Saturation moisture contents and diffusion coefficients of *Asontem* cowpea variety

	Temp(℃)			
Parameter	**30**	**40**	**50**	**60**
U_s	93.9	97.6	101.5	106.9
$D (x\ 10^{-10} m^2/s)$	5.12	5.69	6.19	6.64
R^2	0.93	0.89	0.88	0.87

Table 4.3: Saturation moisture contents and diffusion coefficients of *Hewale* cowpea variety

	Temp(℃)			
Parameter	**30**	**40**	**50**	**60**
U_s	98.3	101.5	104.9	108.7
$D (x\ 10^{-10} m^2/s)$	3.96	4.38	4.85	5.12
R^2	0.95	0.91	0.84	0.96

Table 4.4: Saturation moisture contents and diffusion coefficients of *Asomdwee* cowpea variety

	Temp(℃)			
Parameter	**30**	**40**	**50**	**60**
U_s	86.8	92.9	96.4	100.7

D(x 10^{-10}m^2/s)	4.93	5.16	5.80	6.08
R^2	0.80	0.87	0.82	0.97

The diffusion coefficients of the three cowpea varieties (*Asontem*, *Hewale* and *Asomdwee*) during water absorption were determined using Equation 10 and Equation 11. The factors from the linear regression analyses: the diffusion coefficient, saturation moisture content and the coefficient of determination are shown in Tables 4.2, 4.3 and 4.4. The saturation moisture content of all the three cowpea varieties increased as the soaking temperatures increased**,** although the rates of increment in the saturation moisture contents between the initial and final soaking temperatures were not the same for the three different cowpea varieties. The values obtained for the coefficient of determination ranged from 0.80 to 0.97 indicating an extremely good fit to the data obtained from the experiment. The water absorption rates for *Asontem*, *Hewale* and *Asomdwee* cowpea varieties are shown in Figures 4.11, 4.12 and 4.13.

From Table 4.2, the diffusion coefficient values of *Asontem* cowpea seeds ranged from 5.12x 10^{-10} m^2/s to 6.64 x 10^{-10} m^2/s which were higher than those of *Asomdwee* cowpea seeds in Table 4.4 ranging from 4.93 x 10^{-10} m^2/s to 6.08 x 10^{-10} m^2/s and *Hewale* cowpea in Table 4.3 ranging from 3.96 x 10^{-10} m^2/s to 5.12 x 10^{-10} m^2/s, respectively. This outcome could be as a result of the variations in their seed characteristics since they are different varieties of cowpea (Haros *et al.*, 1995). According to Agarry *et al*. (2014), proteins and carbohydrates are the main constituents of seeds, which have the ability to absorb so much water, with proteins having a higher water absorption power than carbohydrates. Thus, the differences in the nutritional compositions of *Asontem*, *Hewale* and *Asomdwee* cowpea seeds could also be another reason for the diffusion coefficient values of *Asontem* cowpea seeds being higher than that of the other two cowpea varieties. It is therefore possible that *Asontem* cowpea seeds have higher protein content than that of *Hewale* and *Asomdwee*, making *Asontem* cowpea seeds absorb more water than the other two cowpea varieties under the same temperature treatments and the same soaking time. In contrast to the diffusion coefficient values (common treatment: 7.75×10^{-11} to 1.99×10^{-10} m^2/s and microwave treatment: 2.23×10^{-9} to 9.78×10^{-9} m^2/s) reported by Demirhan and Özbek (2015), the diffusion values reported in this study were lower but similar to the values of 4.35x 10^{-11} to 3.79 x 10^{-9} m^2/s and 1.99 x 10^{-10} to 39.16 x 10^{-10} m^2/s reported by Seyhan-Curtas *et al*. (2001) and

Thakur and Gupta (2006).

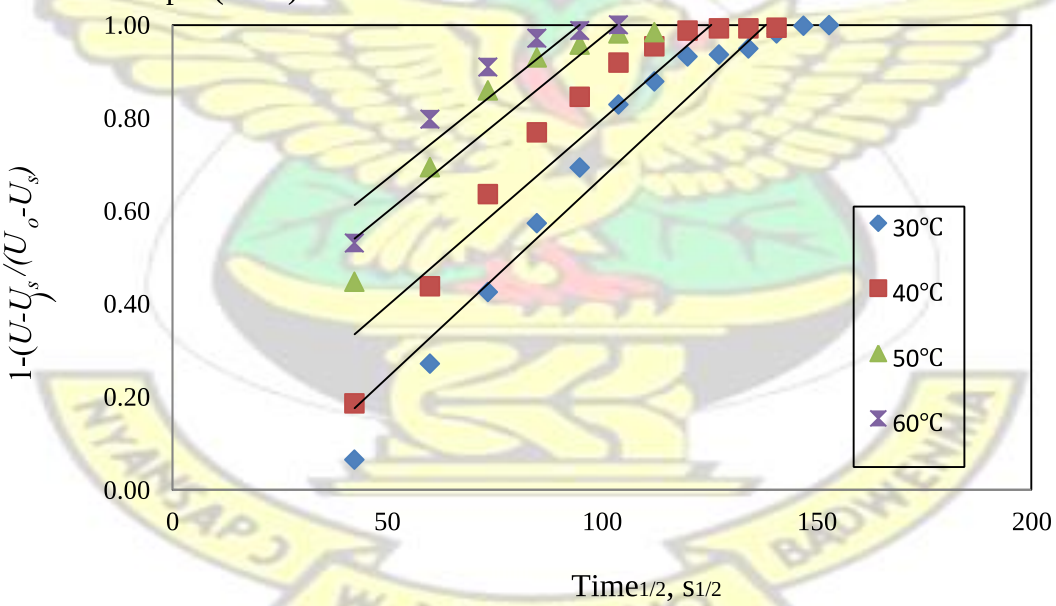

Figure 4.11: Water absorption rate for *Asontem*

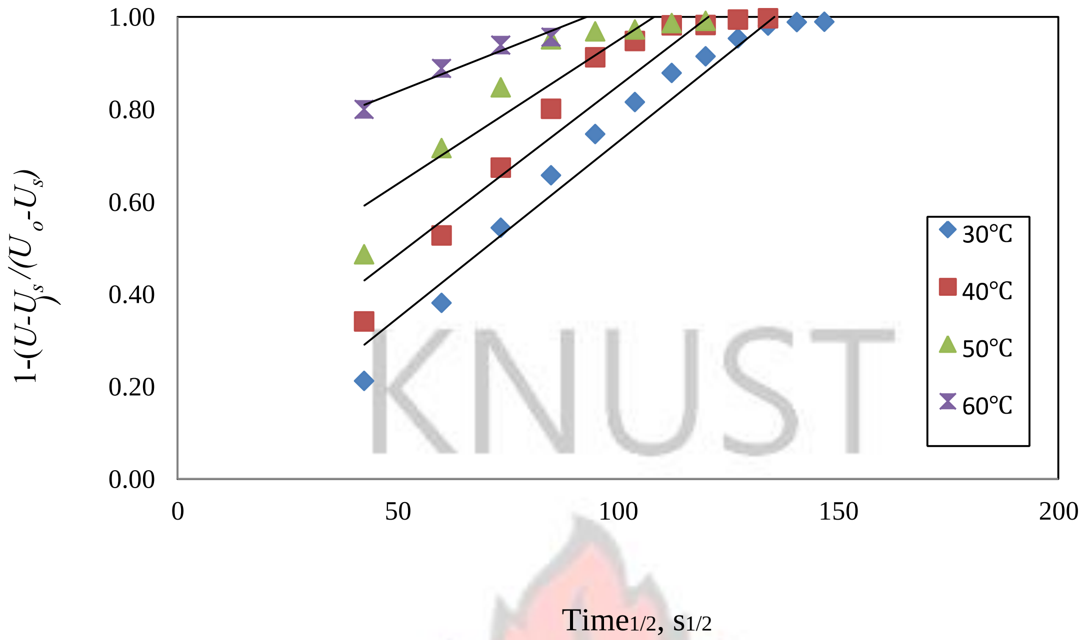

Figure 4.12: Water absorption rate for *Hewale*

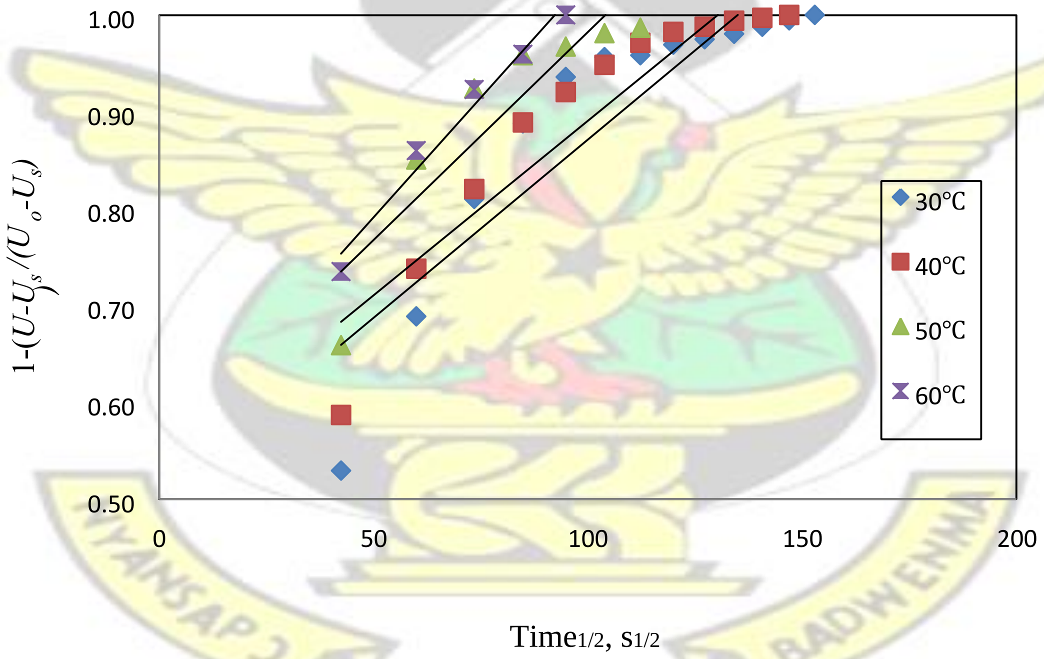

Figure 4.13: Water absorption rate for *Asomdwee*

The values of the diffusion coefficients of *Asontem*, *Asomdwee* and *Hewale* cowpea varieties were fitted to an Arrhenius equation (Equation 12) in order to describe the temperature effect on the moisture diffusivity of the three cowpea varieties, with the coefficient of determination, R^2, which ranged from 0.96 to 0.99.

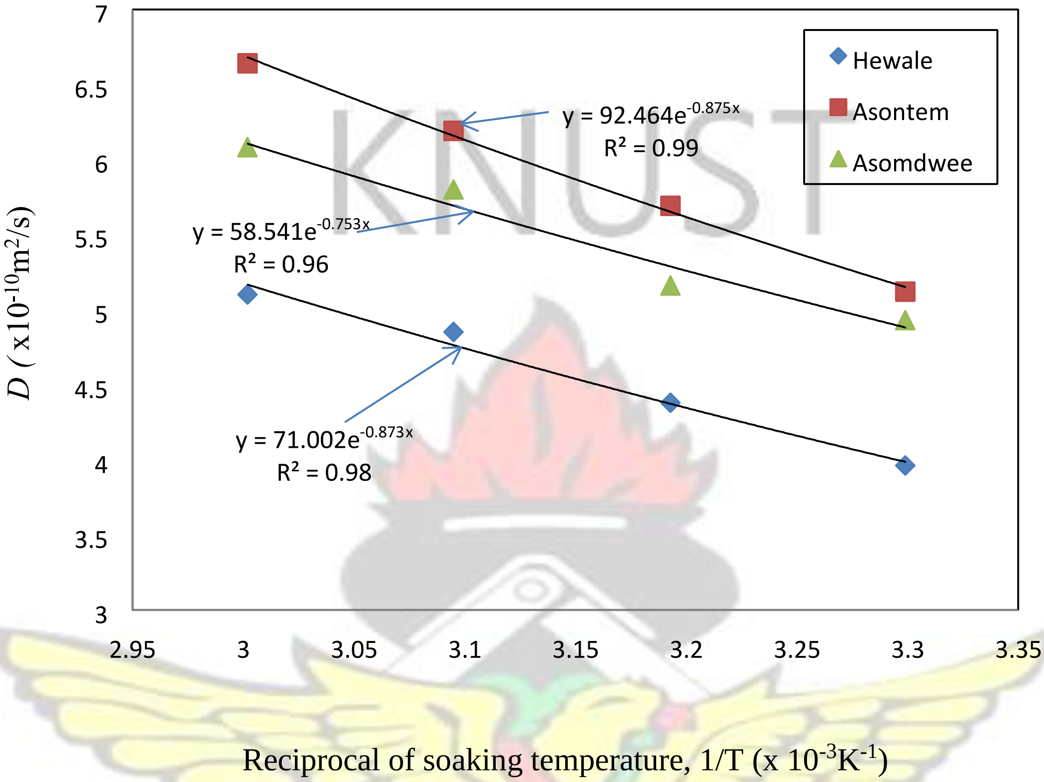

Figure 4.14: Relationship between diffusion coefficients and temperature of *Asontem*, *Hewale* and *Asomdwee*

Figure 4.14 shows the Arrhenius relation for the diffusion coefficients and temperature of *Asontem, Hewale and Asomdwee* cowpea varieties. It shows the existence of a linear relationship between the diffusion coefficients and the reciprocal of absolute temperatures used in the soaking experiment. In addition, the Arrhenius equation (Equation 11) was extremely adequate in describing the effect or influence of temperature on the absorption of moisture by the seeds of all the three cowpea varieties.

Table 4.5 presents the activation energy values for diffusion of water in *Asontem*, *Hewale* and *Asomdwee* cowpea varieties.

Table 4.5: Activation energy, E, of water diffusion during soaking of three cowpea varieties grown in Ghana

Cowpea variety	E (kJ/mol)	R_2
Asontem	7.27	0.99
Hewale	7.26	0.98
Asomdwee	6.26	0.96

From Table 4.5, the temperature sensitivity of the diffusion coefficient, D, was highest for *Asontem* cowpea variety with activation energy of 7.27 kJ/mol, the second highest being *Hewale* cowpea variety with activation energy of 7.26 kJ/mol and lowest for *Asomdwee* cowpea variety with activation energy of 6.26 kJ/mol. The values of activation energy obtained for the three cowpea varieties were similar to those reported by Addo *et al*. (2006) for two maize varieties: *Obatanpa* and *Mamaba*. Obatanpa maize variety had activation energy value of 6.54 kJ/mol while Mamaba maize variety had activation energy of 6.82 kJ/mol. However, in comparison to other studies, the activation energy values obtained for the three cowpea varieties were significantly smaller. Kaptso (2008) reported activation energy value of 11.20 kJ/mol for white bambara groundnut. Addo and Bart-Plange (2009) also reported an activation energy value of 28.38 kJ/mol for *egusi* melon seeds, whereas Seyhan-Curtas *et al*. (2001) reported higher activation energy values for soybean.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.0 CONCLUSIONS

The study was carried out to determine the effect of temperature on some selected physical properties and water diffusion coefficient of three cowpea varieties: *Asontem*, *Hewale* and *Asomdwee*. From the results obtained during the study, the following conclusions are drawn:

1. The initial physical properties of the three cowpea varieties differed as a result of differences in the initial moisture contents of each of the three cowpea varieties. It was observed that the higher the moisture content of a variety, the higher the values of its corresponding physical properties.
2. *Asontem* cowpea variety with initial moisture content of 16.53% dry basis had average length, breadth, thickness, equivalent radius, geometric mean diameter, surface area, seed volume, thousand seed weight and sphericity as 7.19 mm, 6.01 mm, 4.78 mm, 3.46 mm, 5.90 mm, 111.00 mm^2, 341.06 mm^3, 146.9 g and 0.83, respectively.
3. *Hewale* cowpea variety at initial moisture content of 12.40% dry basis had average length, breadth, thickness, equivalent radius, geometric mean diameter, surface area, seed volume, thousand seed weight and sphericity as 6.88 mm, 5.54 mm, 4.45 mm, 3.26 mm, 5.53 mm, 96.44 mm^2, 281.75 mm^3, 122.27 g and 0.81, respectively.
4. *Asomdwee* cowpea variety at initial moisture content of 13.63% dry basis had average length, breadth, thickness, equivalent radius, geometric mean diameter, surface area, seed volume, thousand seed weight and sphericity as 7.20 mm, 5.44 mm, 4.63 mm, 3.08 mm, 5.66 mm, 100.81 mm^2, 299.99 mm^3, 125.36 g and 0.79, respectively.

5. The selected physical properties (length, breadth, thickness, geometric mean diameter, surface area and seed volume excluding sphericity) of all three cowpea varieties which were used in the study increased significantly after undergoing soaking at the temperature range 30 ℃ - 60 ℃.
6. The results obtained for the physical properties of the three cowpea varieties after soaking provided evidence that suggested that temperature had an effect on the physical properties of the three cowpea varieties.
7. The physical properties (length, breadth, thickness, geometric mean diameter, surface area, seed volume and sphericity) of *Asontem* cowpea variety after soaking at the temperature range 30 ℃ - 60 ℃ ranged from 9.60 mm-8.85 mm, 7.13 mm-6.61 mm, 5.98 mm-5.56 mm, 7.42 mm-6.91 mm, 173.5 mm^2–149.9 mm^2, 678.2 mm^3–542.7 mm^3 and 0.77–0.77,

   respectively.
8. The length, breadth, thickness, geometric mean diameter, surface area, seed volume and sphericity of *Hewale* cowpea variety after soaking at the temperature range 30 ℃ - 60 ℃ ranged from 9.93 mm–9.64 mm, 6.98 mm–6.59 mm, 5.89 mm-5.50 mm, 7.42 mm–7.06 mm, 173.1 mm^2–156.1 mm^2, 673.6 mm^3–576.6 mm^3 and 0.75–0.73, respectively.
9. The length, breadth, thickness, geometric mean diameter, surface area, seed volume and sphericity of *Asomdwee* cowpea variety after undergoing soaking treatment at the temperature range 30 ℃ - 60℃ ranged from 9.69 mm– 9.42 mm, 6.59 mm–6.34 mm, 5.52 mm–5.20 mm, 7.07 mm–6.77 mm, 156.9 mm^2–144.0 mm^2, 581.4 mm^3–511.3 mm^3 and 0.73–0.72,

   respectively.

10. The physical properties of *Asontem* cowpea variety were fairly higher than those of *Hewale* and *Asomdwee* cowpea varieties with the exception of its average length which was lower than that of *Hewale* cowpea variety but higher than that of *Asomdwee* cowpea variety after soaking within temperature range of 30 ºC to 60 ºC.
11. The time taken for *Asontem*, *Hewale* and *Asomdwee* cowpea varieties to reach saturation moisture content during soaking was decreased from 8 h to 3 h, 8 h to 3.5 h and 6 h to 2.5 h respectively by the increase in soaking temperature from 30 ºC through to 60 ºC.
12. A reasonable forecast of water absorption by *Asontem*, *Hewale* and *Asomdwee* cowpea varieties during soaking was achievable by fitting of the experimental data to diffusion law according to Fick.
13. The water diffusion coefficients for *Asontem*, *Hewale* and *Asomdwee* cowpea varieties, within temperature variation from 30 ºC to 60 ºC, ranged from 5.12×10^{-10} m^2/s to 6.64×10^{-10} m^2/s, 3.96×10^{-10} m^2/s to 5.12×10^{-10} m^2/s and 4.93×10^{-10} m^2/s to 6.08×10^{-10} m^2/s, respectively.
14. The influence of temperature on the water diffusion coefficient was adequately described by an Arrhenius-type equation giving activation energy values of *Asontem*, *Hewale* and *Asomdwee* cowpea varieties as 7.27 kJ/mol, 7.26 kJ/mol and 6.26 kJ/mol, respectively.

5.1 RECOMMENDATIONS

1. Additional studies should be carried out to determine the effect of temperature on the physical properties of other legumes.

2. Research should be conducted to study the influence of temperature on the chemical and nutritional properties of *Asontem*, *Hewale* and *Asomdwee* cowpea varieties as well as other widely consumed legumes in Ghana and other countries.

3. Research should be conducted to study the influence of temperature on the chemical and nutritional properties of cereals cultivated locally in Ghana.

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APPENDICES

APPENDIX A: Materials, instrument and equipment used in the soaking experiment

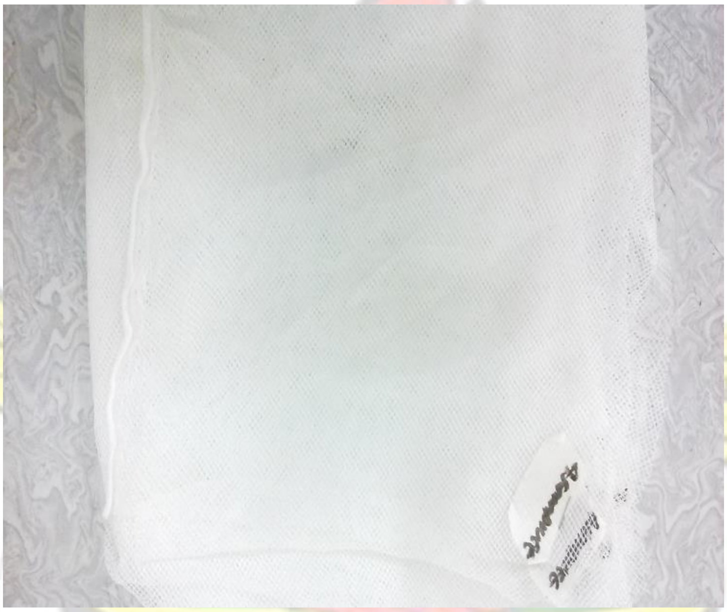

Figure 6.1: Soaking nets

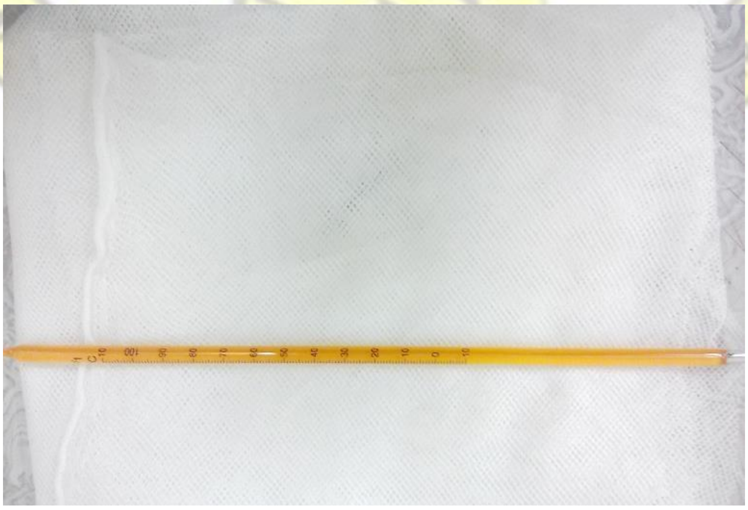

Figure 6.2: Liquid-in-glass Thermometer

Figure 6.3: Digital Vernier calliper

Figure 6.4: Electronic Precision balance

Figure 6.5: Water bath

APPENDIX B: Summary of mean values for various physical properties of *Asontem*, *Hewale* and *Asomdwee* cowpea varieties during soaking at 30 ℃, 40 ℃, 50 ℃ and 60 ℃

Table 6.1: Mean values with standard deviation (Std. Deviation) of selected physical properties of *Asontem* cowpea variety during soaking at 30 ℃, 40 ℃, 50 ℃ and 60 ℃

Physical Property	Temperature (℃)				
	30	**40**	**50**	**60**	**Standard Deviation**
Length (mm)	9.60	9.77	9.25	8.95	0.23
Breadth (mm)	7.13	7.23	6.78	6.61	0.16
Thickness (mm)	5.98	6.12	5.77	5.56	0.13
Geometric mean diameter (mm)	7.42	7.56	7.12	6.91	0.12
Surface area (mm^2)	173.5	179.9	160.0	149.9	5.49
Seed volume (mm^3)	678.2	715.0	596.7	542.7	31.16
Sphericity	0.77	0.77	0.77	0.77	0.01

Table 6.2: Mean values with standard deviation (Std. Deaviation) of selected physical properties of *Hewale* cowpea variety during soaking at 30 ℃, 40 ℃, 50 ℃ and 60 ℃

Physical Property	Temperature (℃)				
	30	**40**	**50**	**60**	**Standard Deviation**
Length (mm)	9.93	10.04	9.84	9.64	0.29
Breadth (mm)	6.98	6.83	6.64	6.59	0.17
Thickness (mm)	5.89	5.73	5.66	5.50	0.17
Geometric mean diameter (mm)	7.42	7.25	7.18	7.06	0.14
Surface area (mm^2)	173.1	165.3	162.0	156.1	6.55
Seed volume(mm^3)	673.6	628.3	610.1	576.6	37.34
Sphericity	0.75	0.72	0.73	0.73	0.01

Table 6.3: Mean values with standard deviation (Std. Deviation) of selected physical properties of *Asomdwee* cowpea variety during soaking at 30 ℃, 40 ℃, 50 ℃ and 60 ℃

Physical Property	Temperature (℃)				
	30	**40**	**50**	**60**	**Standard Deviation**
Length (mm)	9.69	9.59	9.73	9.42	0.15
Breadth (mm)	6.59	6.51	6.57	6.34	0.25
Thickness (mm)	5.52	5.49	5.51	5.20	0.12
Geometric mean diameter (mm)	7.07	6.99	7.06	6.77	0.12
Surface area (mm^2)	156.9	153.8	156.7	144.0	5.35
Seed volume (mm^3)	581.4	563.9	579.9	511.3	30.01
Sphericity	0.73	0.73	0.73	0.72	0.01

APPENDIX C: Moisture content (dry basis) of three cowpea varieties during 10 h soaking at 30 ℃, 40 ℃, 50℃ and 60 ℃

Table 6.4: Moisture content (dry basis) of *Asontem* cowpea variety during 10 h soaking at 30 ℃, 40 ℃, 50 ℃ and 60 ℃

	Temperature(℃)			
Soaking Time (h)	**30**	**40**	**50**	**60**
0.0	16.53	16.53	16.53	16.53
0.5	21.55	31.57	54.54	64.49
1.0	37.54	52.03	75.47	88.62
1.5	49.46	68.08	89.47	98.75
2.0	60.91	78.88	95.50	104.35
2.5	70.21	85.03	97.84	105.88
3.0	80.70	91.02	99.93	106.97
3.5	84.52	93.89	100.13	106.96
4.0	88.68	96.59	101.28	106.80
4.5	89.03	96.99	101.47	106.79
5.0	90.02	97.00	101.37	106.87
5.5	92.54	97.09	100.36	106.85
6.0	93.81	97.59	100.03	106.84
6.5	93.91	96.59	100.02	106.80
7.0	93.93	95.59	100.01	106.77
7.5	93.95	95.47	100.00	106.75
8.0	93.94	95.45	100.00	106.75
8.5	93.94	95.45	100.00	106.75
9.0	93.94	95.45	100.00	106.75
9.5	93.94	95.45	100.00	106.75
10.0	93.94	95.45	100.00	106.74

Table 6.5: Moisture content (dry basis) of *Hewale* cowpea variety during 10 h soaking at 30 ℃, 40 ℃, 50 ℃ and 60 ℃

	Temperature(℃)			
Soaking Time (h)	**30**	**40**	**50**	**60**
0.0	12.40	12.40	12.40	12.40
0.5	30.63	42.79	57.42	89.46
1.0	45.12	59.41	78.68	97.99
1.5	59.12	72.43	90.90	102.84
2.0	68.87	83.79	100.49	104.55
2.5	76.50	93.72	102.09	106.99
3.0	82.49	96.88	102.45	107.87
3.5	87.89	99.88	103.79	108.74
4.0	90.99	99.99	104.18	108.74
4.5	94.26	101.05	104.95	108.72
5.0	96.69	101.25	104.99	108.72
5.5	97.29	101.38	103.85	108.72
6.0	97.38	101.43	103.77	108.72
6.5	97.46	101.53	103.65	108.72
7.0	97.62	101.52	103.64	108.72
7.5	97.79	101.52	103.64	108.72
8.0	98.28	101.52	103.64	108.72
8.5	98.26	101.52	103.64	108.72
9.0	98.26	101.52	103.64	108.72
9.5	98.26	101.52	103.64	108.72

10.0	98.26	101.52	103.64	108.72

Table 6.6: Moisture content (dry basis) of *Asomdwee* cowpea variety during 10 h soaking at 30 ℃, 40 ℃, 50 ℃ and 60 ℃

Soaking Time (h)	Temperature(℃)			
	30	**40**	**50**	**60**
0.0	13.63	13.63	13.63	13.63
0.5	52.35	60.19	68.15	77.60
1.0	63.99	72.15	84.01	88.47
1.5	72.88	78.68	90.08	93.98
2.0	78.59	84.14	92.93	97.14
2.5	82.10	86.64	93.67	100.68
3.0	83.58	88.87	94.81	100.57
3.5	83.73	90.67	95.27	100.55
4.0	84.54	91.57	95.77	100.52
4.5	84.94	91.99	96.37	100.52
5.0	85.35	92.47	96.37	100.52
5.5	85.89	92.72	96.36	100.50
6.0	86.38	92.95	96.36	100.49
6.5	86.78	92.95	95.92	100.49
7.0	86.59	92.95	95.91	100.49
7.5	86.58	92.95	95.91	100.49
8.0	86.58	92.95	95.91	100.49
8.5	86.58	92.95	95.91	100.49
9.0	86.58	92.95	95.91	100.49
9.5	86.58	92.95	95.91	100.49

10.0	86.58	92.95	95.91	100.49

APPENDIX D: Water absorption rate of three cowpea varieties

Table 6.7: Water absorption rate of *Asontem* cowpea variety

		Temperature (℃)			
Time(h)	**Time(s)1/2**	**30**	**40**	**50**	**60**
0.5	42	0.06	0.19	0.45	0.53
1.0	60	0.27	0.44	0.69	0.80
1.5	73	0.43	0.64	0.86	0.91
2.0	85	0.57	0.77	0.93	0.97
2.5	95	0.69	0.85	0.96	0.99
3.0	104	0.83	0.92	0.98	1.00
3.5	112	0.88	0.95	0.98	
4.0	120	0.93	0.99		
4.5	127	0.94	0.99		
5.0	134	0.95	0.99		
5.5	141	0.98	0.99		
6.0	147	1.00			
6.5	153	1.00			

Table 6.8: Water absorption rate of *Hewale* cowpea variety

		Temperature (℃)			
Time(h)	**Time(s)1/2**	**30**	**40**	**50**	**60**
0.5	42	0.21	0.34	0.49	0.80
1.0	60	0.38	0.53	0.72	0.89
1.5	73	0.54	0.67	0.85	0.94
2.0	85	0.66	0.80	0.95	0.96
2.5	95	0.75	0.91	0.97	
3.0	104	0.82	0.95	0.97	
3.5	112	0.88	0.98	0.99	
4.0	120	0.92	0.98	0.99	
4.5	127	0.95	0.99		
5.0	134	0.98	1.00		
5.5	141	0.99			
6.0	147	0.99			

Table 6.9: Water absorption rate of *Asomdwee* cowpea variety

Time(h)	Time(s)1/2	Temperature (℃)			
		30	40	50	60
0.5	42	0.53	0.587	0.659	0.735
1.0	60	0.69	0.738	0.851	0.860
1.5	73	0.81	0.820	0.924	0.923
2.0	85	0.89	0.889	0.958	0.959
2.5	95	0.94	0.920	0.967	1.000
3.0	104	0.96	0.949	0.981	
3.5	112	0.96	0.971	0.987	
4.0	120	0.97	0.983		
4.5	127	0.97	0.988		
5.0	134	0.98	0.994		
5.5	141	0.99	0.997		
6.0	147	0.99	1.000		
6.5	153	1.00			

APPENDIX E

Table 6.10: Relationship between water diffusion coefficient and temperature for *Asontem*, *Hewale* and *Asomdwee* cowpea varieties

1/T ($x\ 10^{-3}K^{-1}$)	D ($x10^{-10}m^2/s$)		
	Asontem	Hewale	Asomdwee
3.30	5.12	3.96	4.93
3.19	5.69	4.38	5.16
3.10	6.19	4.85	5.80
3.00	6.64	5.12	6.08

APPENDIX F: Analyses of variance tables

I. ASONTEM

General Linear Model: Length (mm) versus Time (min), Temp (^oC)

```
Factor       Type   Levels  Values
Time (min)   fixed      20  30, 60, 90, 120, 150, 180, 210, 240, 270, 300,
330,
                            360, 390, 420, 450, 480, 510, 540, 570, 600
Temp (°C)    fixed       4  30, 40, 50, 60

Analysis of Variance for Length (mm), using Adjusted SS for Tests
Source                  DF    Seq SS    Adj SS   Adj MS       F      P
Time (min)              19  22.94312  22.94312  1.20753   23.48  0.000
Temp (°C)                3  23.81304  23.81304  7.93768  154.34  0.000
Time (min)*Temp (°C)    57  26.55342  26.55342  0.46585    9.06  0.000
Error                  160   8.22896   8.22896  0.05143
Total                  239  81.53854

S = 0.226784   R-Sq = 89.91%   R-Sq(adj) = 84.92%
```

General Linear Model: Breadth (mm) versus Time (min), Temp (^oC)

```
Factor       Type   Levels  Values
Time (min)   fixed      20  30, 60, 90, 120, 150, 180, 210, 240, 270, 300,
330,
                            360, 390, 420, 450, 480, 510, 540, 570, 600
Temp (°C)    fixed       4  30, 40, 50, 60

Analysis of Variance for Breadth (mm), using Adjusted SS for Tests
Source                  DF    Seq SS    Adj SS   Adj MS       F      P
Time (min)              19   3.59945   3.59945  0.18944    7.62  0.000
Temp (°C)                3  15.01370  15.01370  5.00457  201.28  0.000
Time (min)*Temp (°C)    57  11.95209  11.95209  0.20969    8.43  0.000
Error                  160   3.97822   3.97822  0.02486
Total                  239  34.54346

S = 0.157683   R-Sq = 88.48%   R-Sq(adj) = 82.80%
```

General Linear Model: Thickness (mm) versus Time (min), Temp (^oC)

```
Factor       Type   Levels  Values
Time (min)   fixed      20  30, 60, 90, 120, 150, 180, 210, 240, 270, 300,
330,
                            360, 390, 420, 450, 480, 510, 540, 570, 600
Temp (°C)    fixed       4  30, 40, 50, 60

Analysis of Variance for Thickness (mm), using Adjusted SS for Tests
Source                  DF    Seq SS    Adj SS   Adj MS       F      P
Time (min)              19   5.85781   5.85781  0.30831   18.70  0.000
Temp (°C)                3  10.77105  10.77105  3.59035  217.75  0.000
Time (min)*Temp (°C)    57   9.00951   9.00951  0.15806    9.59  0.000
Error                  160   2.63816   2.63816  0.01649
Total                  239  28.27654


S = 0.128408   R-Sq = 90.67%   R-Sq(adj) = 86.06%
```

General Linear Model: Geometric Mean D versus Time(m), Temp(°C)

```
Factor     Type   Levels  Values
Time(m)    fixed      20  30, 60, 90, 120, 150, 180, 210, 240, 270, 300,
330,
                          360, 390, 420, 450, 480, 510, 540, 570, 600
Temp(°C)   fixed       4  30, 40, 50, 60


Analysis of Variance for Geometric Mean Diameter(mm), using Adjusted SS for
     Tests
Source              DF    Seq SS    Adj SS   Adj MS       F      P
Time(m)             19   7.62786   7.62786  0.40147   29.51  0.000
Temp(°C)             3  15.60445  15.60445  5.20148  382.37  0.000
Time(m)*Temp(°C)    57  12.98488  12.98488  0.22780   16.75  0.000
Error              160   2.17650   2.17650  0.01360
Total              239  38.39370

S = 0.116632   R-Sq = 94.33%   R-Sq(adj) = 91.53%
```

General Linear Model: Surface Area (mm²) versus Time (min), Temp (°C)

```
Factor      Type   Levels  Values
Time (min)  fixed      20  30, 60, 90, 120, 150, 180, 210, 240, 270, 300,
330,
                           360, 390, 420, 450, 480, 510, 540, 570, 600
Temp (°C)   fixed       4  30, 40, 50, 60


Analysis of Variance for Surface Area (mm²), using Adjusted SS for Tests
Source                  DF    Seq SS    Adj SS    Adj MS       F      P
Time (min)              19  15238.52  15238.52    802.03   26.60  0.000
Temp (°C)                3  32715.93  32715.93  10905.31  361.65  0.000
Time (min)*Temp (°C)    57  26353.23  26353.23    462.34   15.33  0.000
Error                  160   4824.67   4824.67     30.15
Total                  239  79132.35



S = 5.49128   R-Sq = 93.90%   R-Sq(adj) = 90.89%
```

General Linear Model: Seed Volume versus Time (min), Temp (°C)

```
Factor      Type   Levels  Values
Time (min)  fixed      20  30, 60, 90, 120, 150, 180, 210, 240, 270, 300,
330,
                           360, 390, 420, 450, 480, 510, 540, 570, 600
Temp (°C)   fixed       4  30, 40, 50, 60


Analysis of Variance for Seed Volume, using Adjusted SS for Tests
Source                  DF   Seq SS   Adj SS  Adj MS       F      P
Time (min)              19   465135   465135   24481   25.21  0.000
Temp (°C)                3  1094660  1094660  364887  375.78  0.000
Time (min)*Temp (°C)    57   834824   834824   14646   15.08  0.000
Error                  160   155363   155363     971
Total                  239  2549982

S = 31.1612   R-Sq = 93.91%   R-Sq(adj) = 90.90%
```

General Linear Model: Sphericity versus Time (min), Temp (^oC)

```
Factor      Type   Levels  Values
Time (min)  fixed      20  30, 60, 90, 120, 150, 180, 210, 240, 270, 300,
330,
                           360, 390, 420, 450, 480, 510, 540, 570, 600
Temp (°C)   fixed       4  30, 40, 50, 60

Analysis of Variance for Sphericity, using Adjusted SS for Tests
Source                DF     Seq SS     Adj SS     Adj MS     F      P
Time (min)            19  0.0228338  0.0228338  0.0012018  5.96  0.000
Temp (°C)              3  0.0007268  0.0007268  0.0002423  1.20  0.311
Time (min)*Temp (°C)  57  0.0210127  0.0210127  0.0003686  1.83  0.002
Error                160  0.0322785  0.0322785  0.0002017
Total                239  0.0768518

S = 0.0142035   R-Sq = 58.00%   R-Sq(adj) = 37.26%
```

II. HEWALE

General Linear Model: Length (mm) versus Time (min), Temp (^oC)

```
Factor      Type   Levels  Values
Time (min)  fixed      20  30, 60, 90, 120, 150, 180, 210, 240, 270, 300,
330,
                           360, 390, 420, 450, 480, 510, 540, 570, 600
Temp (°C)   fixed       4  30, 40, 50, 60


Analysis of Variance for Length (mm), using Adjusted SS for Tests
Source                DF    Seq SS    Adj SS   Adj MS      F      P
Time (min)            19   3.45728   3.45728  0.18196   2.14  0.006
Temp (°C)              3   5.08870   5.08870  1.69623  19.91  0.000
Time (min)*Temp (°C)  57   9.73420   9.73420  0.17078   2.00  0.000
Error                160  13.62989  13.62989  0.08519
Total                239  31.91007


S = 0.291868   R-Sq = 57.29%   R-Sq(adj) = 36.20%
```

General Linear Model: Breadth (mm) versus Time (min), Temp(^oC)

```
Factor      Type   Levels  Values
Time (min)  fixed      20  30, 60, 90, 120, 150, 180, 210, 240, 270, 300,
330,
                           360, 390, 420, 450, 480, 510, 540, 570, 600
Temp(°C)    fixed       4  30, 40, 50, 60
```

Analysis of Variance for Breadth (mm), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time (min)	19	0.97503	0.97503	0.05132	1.70	0.042
Temp(°C)	3	5.76324	5.76324	1.92108	63.49	0.000
Time (min)*Temp(°C)	57	5.26674	5.26674	0.09240	3.05	0.000
Error	160	4.84138	4.84138	0.03026		
Total	239	16.84639				

S = 0.173950   R-Sq = 71.26%   R-Sq(adj) = 57.07%

General Linear Model: Thickness (mm) versus Time (min), Temp (°C)

Factor	Type	Levels	Values
Time (min)	fixed	20	30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 360, 390, 420, 450, 480, 510, 540, 570, 600
Temp (°C)	fixed	4	30, 40, 50, 60

Analysis of Variance for Thickness (mm), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time (min)	19	2.67158	2.67158	0.14061	5.16	0.000
Temp (°C)	3	4.91211	4.91211	1.63737	60.05	0.000
Time (min)*Temp (°C)	57	7.28719	7.28719	0.12785	4.69	0.000
Error	160	4.36256	4.36256	0.02727		
Total	239	19.23343				

S = 0.165124   R-Sq = 77.32%   R-Sq(adj) = 66.12%

General Linear Model: Geometric Mean D versus Time(m), Temp(°C)

Factor	Type	Levels	Values
Time(m)	fixed	20	30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 360, 390, 420, 450, 480, 510, 540, 570, 600
Temp(°C)	fixed	4	30, 40, 50, 60

Analysis of Variance for Geometric Mean Diameter(mm), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time(m)	19	1.58303	1.58303	0.08332	4.00	0.000
Temp(°C)	3	4.33778	4.33778	1.44593	69.39	0.000
Time(m)*Temp(°C)	57	5.64500	5.64500	0.09904	4.75	0.000
Error	160	3.33401	3.33401	0.02084		
Total	239	14.89982				

S = 0.144352   R-Sq = 77.62%   R-Sq(adj) = 66.58%

General Linear Model: Surface Area (mm²) versus Time (min), Temp (°C)

Factor	Type	Levels	Values
Time (min)	fixed	20	30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 360, 390, 420, 450, 480, 510, 540, 570, 600

Factor	Type	Levels	Values
Temp (°C)	fixed	4	30, 40, 50, 60

Analysis of Variance for Surface Area (mm^2), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time (min)	19	3246.74	3246.74	170.88	3.98	0.000
Temp (°C)	3	9051.36	9051.36	3017.12	70.25	0.000
Time (min)*Temp (°C)	57	11567.32	11567.32	202.94	4.73	0.000
Error	160	6871.30	6871.30	42.95		
Total	239	30736.72				

S = 6.55329   R-Sq = 77.64%   R-Sq(adj) = 66.61%

General Linear Model: Seed Volume versus Time (min), Temp (^{o}C)

Factor	Type	Levels	Values
Time (min)	fixed	20	30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 360, 390, 420, 450, 480, 510, 540, 570, 600
Temp (°C)	fixed	4	30, 40, 50, 60

Analysis of Variance for Seed Volume, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time (min)	19	104086	104086	5478	3.93	0.000
Temp (°C)	3	294517	294517	98172	70.43	0.000
Time (min)*Temp (°C)	57	370763	370763	6505	4.67	0.000
Error	160	223026	223026	1394		
Total	239	992393				

S = 37.3352   R-Sq = 77.53%   R-Sq(adj) = 66.43%

General Linear Model: Sphericity versus Time (min), Temp (^{o}C)

Factor	Type	Levels	Values
Time (min)	fixed	20	30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 360, 390, 420, 450, 480, 510, 540, 570, 600
Temp (°C)	fixed	4	30, 40, 50, 60

Analysis of Variance for Sphericity, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time (min)	19	0.0035931	0.0035931	0.0001891	0.81	0.691
Temp (°C)	3	0.0204879	0.0204879	0.0068293	29.32	0.000
Time (min)*Temp (°C)	57	0.0247695	0.0247695	0.0004346	1.87	0.001
Error	160	0.0372679	0.0372679	0.0002329		
Total	239	0.0861184				

S = 0.0152619   R-Sq = 56.72%   R-Sq(adj) = 35.36%

III. ASOMDWEE

General Linear Model: Length (mm) versus Time(min), Temp (^{o}C)

Factor	Type	Levels	Values

Factor	Type	Levels	Values
Time(min)	fixed	20	30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 360, 390, 420, 450, 480, 510, 540, 570, 600
Temp (°C)	fixed	4	30, 40, 50, 60

Analysis of Variance for Length (mm), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time(min)	19	2.91793	2.91793	0.15358	6.42	0.000
Temp (°C)	3	3.39952	3.39952	1.13317	47.40	0.000
Time(min)*Temp (°C)	57	6.23252	6.23252	0.10934	4.57	0.000
Error	160	3.82511	3.82511	0.02391		
Total	239	16.37508				

S = 0.154619   R-Sq = 76.64%   R-Sq(adj) = 65.11%

General Linear Model: Breadth (mm) versus Time (min), Temp(°C)

Factor	Type	Levels	Values
Time (min)	fixed	20	30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 360, 390, 420, 450, 480, 510, 540, 570, 600
Temp(°C)	fixed	4	30, 40, 50, 60

Analysis of Variance for Breadth (mm), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time (min)	19	2.13148	2.13148	0.11218	1.82	0.025
Temp(°C)	3	2.36115	2.36115	0.78705	12.75	0.000
Time (min)*Temp(°C)	57	6.01607	6.01607	0.10555	1.71	0.005
Error	160	9.87810	9.87810	0.06174		
Total	239	20.38681				

S = 0.248472   R-Sq = 51.55%   R-Sq(adj) = 27.62%

General Linear Model: Thickness (mm) versus Time (min), Temp(°C)

Factor	Type	Levels	Values
Time (min)	fixed	20	30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 360, 390, 420, 450, 480, 510, 540, 570, 600
Temp(°C)	fixed	4	30, 40, 50, 60

Analysis of Variance for Thickness (mm), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time (min)	19	2.48055	2.48055	0.13056	9.51	0.000
Temp(°C)	3	4.42985	4.42985	1.47662	107.51	0.000
Time (min)*Temp(°C)	57	4.60330	4.60330	0.08076	5.88	0.000
Error	160	2.19754	2.19754	0.01373		
Total	239	13.71124				

S = 0.117195   R-Sq = 83.97%   R-Sq(adj) = 76.06%

General Linear Model: Geometric Mean D versus Time (min), Temp (°C)

Factor	Type	Levels	Values
Time (min)	fixed	20	30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 360, 390, 420, 450, 480, 510, 540, 570, 600
Temp (°C)	fixed	4	30, 40, 50, 60

Analysis of Variance for Geometric Mean Diameter (mm), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time (min)	19	1.89207	1.89207	0.09958	6.98	0.000
Temp (°C)	3	3.54164	3.54164	1.18055	82.75	0.000
Time (min)*Temp (°C)	57	4.31339	4.31339	0.07567	5.30	0.000
Error	160	2.28269	2.28269	0.01427		
Total	239	12.02980				

S = 0.119444 R-Sq = 81.02% R-Sq(adj) = 71.66%

General Linear Model: Surface Area (mm²) versus Time (min), Temp (°C)

Factor	Type	Levels	Values
Time (min)	fixed	20	30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 360, 390, 420, 450, 480, 510, 540, 570, 600
Temp (°C)	fixed	4	30, 40, 50, 60

Analysis of Variance for Surface Area (mm²), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time (min)	19	3605.83	3605.83	189.78	6.64	0.000
Temp (°C)	3	6633.23	6633.23	2211.08	77.32	0.000
Time (min)*Temp (°C)	57	8263.38	8263.38	144.97	5.07	0.000
Error	160	4575.42	4575.42	28.60		
Total	239	23077.86				

S = 5.34756 R-Sq = 80.17% R-Sq(adj) = 70.38%

General Linear Model: Seed Volume versus Time (min), Temp (°C)

Factor	Type	Levels	Values
Time (min)	fixed	20	30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 360, 390, 420, 450, 480, 510, 540, 570, 600
Temp (°C)	fixed	4	30, 40, 50, 60

Analysis of Variance for Seed Volume, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time (min)	19	107645.8	107645.8	5665.6	6.29	0.000
Temp (°C)	3	194237.9	194237.9	64746.0	71.91	0.000
Time (min)*Temp (°C)	57	248167.5	248167.5	4353.8	4.84	0.000

Error	160	144058.8	144058.8	900.4		
Total	239	694110.0				

S = 30.0061   R-Sq = 79.25%   R-Sq(adj) = 69.00%

General Linear Model: Sphericity versus Time (min), Temp (°C)

Factor	Type	Levels	Values
Time (min)	fixed	20	30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330, 360, 390, 420, 450, 480, 510, 540, 570, 600
Temp (°C)	fixed	4	30, 40, 50, 60

Analysis of Variance for Sphericity, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Time (min)	19	0.0041162	0.0041162	0.0002166	1.59	0.063
Temp (°C)	3	0.0047337	0.0047337	0.0015779	11.60	0.000
Time (min)*Temp (°C)	57	0.0112817	0.0112817	0.0001979	1.46	0.036
Error	160	0.0217558	0.0217558	0.0001360		
Total	239	0.0418874				

S = 0.0116608   R-Sq = 48.06%   R-Sq(adj) = 22.42%