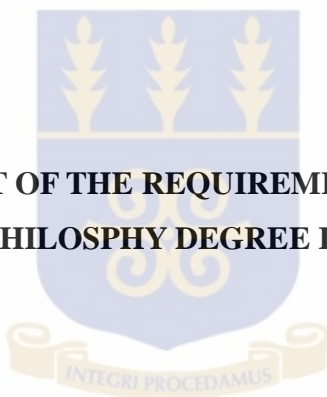


**PHYSICO-FUNCTIONAL PROPERTIES OF WHEAT-MORAMA BEAN  
COMPOSITE FLOUR AND ITS PERFORMANCE IN FOOD SYSTEMS**

**A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES, UNIVERSITY  
OF GHANA**

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MASTER OF PHILOSOPHY DEGREE IN FOOD SCIENCE**



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## DECLARATION

This is to certify that this thesis is the result of research undertaken by Lesego Buddy Phuthego towards the award of the Masters of Philosophy in Food Science in the Department of Nutrition and Food Science, University of Ghana

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## ABSTRACT

There is an increasing demand for variety in food products, mankind rely on very limited number of crops to meet the needs of staple diets on a very limited number of major non-food crops to meet the associated needs, the functionality of wheat-morama bean composite flour for food applications was thus investigated. Morama bean (*Tylosema esculentum*) was shelled and milled into flour. Part of the morama bean flour was defatted using n-hexane. Wheat flour (both hard and soft) was substituted with defatted and full fat morama bean flour at varying levels and their physico-functional and pasting properties determined. The design of the study followed a 2 X 2 X 4 factorial design for morama bean flour (full fat and defatted), wheat flour type (soft and hard) and morama bean flour substitution level in composite flour (10, 20, 30 and 40%).

The least gelation concentrations of the wheat-morama composites were quite low with some composites gelling at 4%. The functionality of the composite flours was significantly influenced by the particles size distribution of the morama bean flour. Defatted morama bean flour had a similar particle size distribution as the soft wheat flour. Full fat morama bean flour generally had larger particle sizes due to the presence of fat. At 70°C, water absorption capacity of the composite flours decreased with increasing morama bean flour (full fat or defatted) concentration. The functionality of the composite flours was more influenced by morama bean flour (defatted or full fat) level than by wheat type (soft or hard wheat). Incorporation of morama bean flour (both defatted and full fat) to wheat reduced the pasting indices of peak viscosity, breakdown and setback even when as little as 5% of full fat morama bean flour was added. At 40% morama level of substitution the composite flour did not show meaningful pasting profile.

At 30°C the water sorption behavior of the composite flours was influenced by the amount and type of morama bean flour. The equilibrium moisture content of composite flour with

defatted morama bean flour was more sensitive to increasing water activity, indicating the possibility of it being less stable due to moisture absorption during storage than full –fat morama flour composites. Monolayer values of the composite flour were influenced by the level of morama bean flour (full fat and defatted). The GAB model was the better model in describing the relationship between water activity and moisture content of soft wheat-morama bean flour, as compared to the BET model.

Consumer preference tests data showed that twenty (20) percent substitution of soft wheat with full fat morama bean flour was the preferred composite flour for making biscuits.

The successful application of morama bean flour in food systems will enhance its utilization and improve food and nutrition security.



## DEDICATION

Glory be to God Almighty.

This is dedicated to my lovely mother Gerita Dikhai, beloved sister Pinkie and my brother  
Bashen.



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**LIST OF ABBREVIATIONS**

FC = Foam capacity

FS= Foam Stability

SW= Soft wheat

HW= Hard wheat

FFM= Full fat morama bean flour

DFM= Defatted morama bean flour

## 1.0 INTRODUCTION

### 1.1 Background

In spite of growing threats to food and nutritional security due to climate change and associated factors, there are still many under-utilized food crops indigenous to the developing world, particularly in Africa. For such crops, rigorous research work is needed to determine their potential and applications in foods in order to derive their full benefits. Morama bean is one of such many under exploited crops that have been shown to have exceptionally high nutritional value (Hartley *et al.*, 2002) and holds promise in helping to strengthen the food and nutritional security in areas where it grows.

Morama bean, [*Tylosemaesculentum* (Burchell) Schreiber] (Family Fabaceae) is a drought-tolerant wild perennial legume (Nepolo *et.al* 2009) which is currently not cultivated but harvested from the wild for human consumption (Amarteifio and Moholo, 1998). It is adapted to the harsh conditions of Botswana and Namibia, which are characterized by low rainfall and nutritionally poor soils (Hartley *et al.*, 2002). In those regions the seeds are an important component of the diet among the nomadic people in remote settlements where few conventional crops can survive (Mosele *et al.*, 2011). The mature seeds have been reported to be exceptional as they contain high amounts of lipid (35-43%), protein (30-39%) and some carbohydrates (18-25%) (Mpotokwame *et al*, 2013) but does not contain starch (Mosele *et al.*, 2011). Consequently the roasted mature seeds can be ground into butter, similar to peanuts. They could also be blended with cereals to improve the nutritional value (Van der Maesen, 2006).

The diet of an average Motswana consists of foods that are mostly carbohydrate based. There is therefore a need for strategic use of inexpensive high protein resources that complement the amino acid profile of the staple diet in order to enhance their nutritive value. The proteins

of morama beans have been shown to have an impressive profile of essential amino acids, which include tyrosine, arginine, leucine and lysine (Mosele *et al.*, 2011). The use of legumes to enrich wheat flour is not a new technique and different legumes have been used for this purpose. Incorporation of morama bean flour in composite flours can help cut down the costs of importation of wheat flour and increase the availability of protein-rich flours.

## **1.2 Problem statement**

Batswana consumers have become more aware of the benefits of healthy eating and demand healthier foods. Botswana, a country that used to rely a great deal on animal protein, is therefore in search of alternative ways to provide healthier and affordable plant protein. For economic reasons too, the increasing prices of meat and meat products is making it more and more difficult for the low income consumer to afford or acquire the required amounts of nutrients. The solution is to provide alternative sources of good nutrition by exploring available vegetable sources. The continuous increase in population and inadequate supply of protein has increased the occurrence of malnutrition in developing countries (Siddhuraju, 1996). Studies have shown that malnutrition among children in developing countries is mainly due to the consumption of cereal based porridge which is bulky, low in energy and density and high in anti-nutrients (Michaelsen and Henrik, 1998)'. Morama-enriched flour could play an important role in reducing malnutrition.

## **1.3 Rationale**

Morama bean (*Tylosemaesculentum*) occurs naturally in the drier areas of Southern Africa, including Botswana and Namibia, where it is not cultivated but grows in the wild. It is a good crop for semi-arid and arid agriculture, and like other legumes it provides inexpensive forms of proteins and oil. The application of morama bean flour in composite flours to improve the

nutritional quality of bakery products has not been exploited. As an under-utilized crop its substitution for wheat in composite flours for bakery products will cut down on the cost of importation of wheat, improve the nutritional quality of products, and increase morama bean utilization in food applications.

#### **1.4 Objectives**

The main objective of this work was to develop wheat-morama bean composite flours and assess their physical and functional properties as well as their performance in a bakery product.

#### **1.5 Specific objectives**

The specific objectives of this study were to:

1. formulate composite flours from wheat and morama bean flours
2. Assess the physical and functional properties of wheat-morama bean composite flours
3. Analyze the quality and consumer acceptance of wheat – morama bean composite flour biscuits.

## 2.0 LITERATURE REVIEW

### 2.1 Background information on the Morama bean

*Tylosemaesculentum* (Burch) A. Schreib popularly known as Morama in Setswana (Botswana), Braaiboonjie, Maramabonjie, and Elandbonjie in Afrikaans (Van Wyk and Gericke 2000) is a wild, underutilized legume in Southern Africa and is used as a food source by the rural communities of the Kalahari desert (Jackson *et. al.* 2010). It has also gained some names in the process as researchers were looking at its food potential. Some call it the magic bean of Africa and some have called it the green gold of Africa. It grows in open sand veld and open grass and bush savannah (Amarteifio and Moholo 1998). Above ground it produces seeds similar to the peanut or soybean but is actually higher in nutritional value than either. Below ground it produces a tuber that is bigger and more nutritious than potatoes, yams or sugar beet. It is dormant in winter and re-grows from the tuber in spring. The plant grows in well-drained, fine, generally calcareous sands, but also in regions of harder calcareous conglomerates, at pH 6 to 8, with very little organic matter, nitrate or phosphate (Lawlor, 2004). Hartley *et al.*, (2002) pointed that the plant is adapted to the harsh conditions of Botswana and Namibia, which are characterized by low rainfall and nutritionally poor soils. The plant thrives in the poor quality, sandy soil of the desert, withstanding blistering summer temperatures, freezing nights of the Kalahari winters, and highly erratic and often absent rainfall.

#### 2.1.1 Physical traits of morama bean

Morama beans are reported to grow in a large, flat woody pod (Plate 2.1) in groups of approximately six beans per pod. Jideane *et al.* (2009) described the morama bean as chestnut to dark brown in color, spherical and weighing 2- 3 g each (Plate 2.2). Each bean has a hard

inedible brown outer shell with edible two lobed seeds inside. The edible part is cream in color (Plate 2.3).

The most common way that local people prepare morama beans is by roasting the bean, still in shells in hot sand. The beans are never eaten raw; they have been reported to have an unpleasant slimy texture or soapy taste. However the immature beans can be boiled and eaten, whilst still green. Menninger, (1970) indicated that, after roasting, the seeds take on a nutty flavor that has been compared with roasted cashew nuts



**Plate 2.1: Morama in pods-both green and brown**

### **2.1.2 Chemical composition of morama bean**

Many researchers have compared the composition of morama beans to that of peanuts and soybeans. Mosele (2012) even concluded that morama bean is equally, if not more nutritious than well known high nutritional value legumes. Jideane *et al.*, (2009) reported that morama protein ranges between 29.9 and 41.8 %. Its protein (29–38%) and oil (32-42%) contents (Holse *et al.*, 2010) are very similar to those of soya (Mujoo *et al.*, 2003) and peanut (Venkatachalam and Sathe, 2006). Mmonatau (2005) reported morama bean to have protein content of 37%.

According to Jideane *et al.*, 2009 the oil content of morama beans ranges between 32.1 and 45.3%. They described the oil as clear golden yellow and has a nutty flavor which they associate with almond oil. Holse *et al.*, (2010) seemed to concur with Jideane *et al.* (2009). They found the morama oil content to range between 32 and 42%. Ketshajwang, Holmack and Yeboah (1998) reported oil content of 48.2% while Mmonatau (2005) reported 39% for morama beans as cited by Maruatona (2010).

This places morama beans in a good position in comparison with other oilseeds like groundnuts (45-55%), sunflower seeds (22-36%), rapeseed (22-49%), or soya bean (21%) (Salunkhe and Kadam, 1989)

Total carbohydrate content of morama has been approximated at 24% (Bower *et al.*, 1988; Amarteifio and Moholo, 1998; Mosele *et al.*, 2011a) as cited by Mosele (2012). According to Holse *et al.* (2010), also cited by Mosele (2012) mature morama beans have a high content of dietary fibre with variation between 19% and 27%. They also associated the large variation to the fact that morama bean is not a domesticated plant so some external factors cannot be controlled.

Morama beans are also reported to contain minerals and vitamins which include potassium, thiamin, calcium, iron, zinc, phosphorus, riboflavin and nicotinic acid (Mpotokwane *et.al.* 2013).



**Plate 2.2: Morama beans**



**Plate 2.3: Shelled morama beans cotyledons**

## **2.2 Defatted legume flours**

When protein rich, stable flours are required, defatting is necessary like in the case of leguminous oilseeds like morama beans. Full fat flours, though deemed to be more energy dense when compared to the partially or defatted flours, are said to be lower in protein content and are prone to hydrolytic and oxidative rancidity. The main purpose of oil

extraction is thus to reduce the oil content of oilseeds so that they can have a higher protein content and a longer shelf life.

It has been suggested that dry heating morama beans prior to dehulling disrupts oil bodies which allows oil to be readily available during the defatting stage. Maruatona *et al* (2009) said the process thus results in higher protein content than flour produced from unheated morama beans.

Singh *et al.*, (2009) cited Bongirwar *et al.* (1979) who looked at the development of high protein ready-to-eat foods from defatted groundnut and soybean blends and observed that defatted soy flour mixed products gave satisfactory structure, colour and appearance.

### **2.3 Particle size distribution of legume flours**

Milling of dry cereal or legumes is a size reduction unit operation involving a number of stages (such as grinding, reduction, sifting and purifying) used to produce flours or meals. Sieving happens in two stages: in the first stage the particles with much smaller sizes pass through the sieve; and in the second stage (which is actually the slowest) particles that are closer to that of the opening of the sieve get sieved through. 'Particle size distribution of flours influences functionality of cowpea paste and final end product quality (Ubbor and Akobundu, 2009). According to Kerret *et al.*, (2001), milling the flour to too fine particle size could result in textural quality problems in end products.

Particle size and distribution is an important characteristic contributing to product appearance. Particle size affects the overall bulk properties of the food item such as visual texture and density as well as color. Kerr *et al.*, (2001) cited that larger particle size may indicate a chewy food, whereas smaller particle size may indicate crunchy and less moist.

Determinations of particle size and its distribution in flour are important in understanding both physical and chemical properties of food ingredients as they affect their behaviour when in contact with water (Ayernor, 1976). In particular, particle size and particle size distribution affect the hydration properties of food flours. Hebrard *et al.* (2003) observed that the size of semolina particles influenced sorption kinetics: the finer the particles, the faster their sorption kinetics. The authors explain that even though the biochemical composition ultimately determines the amount of water sorbed, the particle size distribution is a determinant of the sorption rate.

#### **2.4 Composite flours**

Composite flours are considered as blends of wheat and other flours, which can be anything from tubers to cereal or legume and there have been instances where wheat flour was not in the composite.

The composite flours containing wheat and legumes are utilized in many parts of the world. The basic composite flour technology refers to the process of mixing wheat flour with cereals and legumes to produce high quality food products in an economical way. Flours produced from only either cereals, legumes or tubers will have a nutritional value inferior to those produced from a combination of cereals, legumes or tubers. For instance, composite flours produced from cereals and legumes have the advantage of improving overall nutrition (FAO, 1995) while composite flours produced from legumes and tubers will have high protein content and will also have high calorific value (Chinma *et al.*, 2007).

Several studies about the influence of the addition of legume flours on the functional properties of bread dough and final bread quality have been reported. Noor *et al.* (2012) indicated that there were significant changes in the composition, like the protein content of

chick pea cookies showed to be the highest while mung bean cookies showed high ash content and this was attributed to the high mineral content of mung bean.

Awadhesh *et al.* (2009) observed that protein content of soy-fortified mix increased and postulated it was due to the use of higher protein content of defatted soy flour. McWaters (1978) indicated that protein content was significantly affected by the addition of peanut flour to the sugar cookie- each increment raised the protein content by 1.5%-and cookies prepared from the 30% peanut flour formulation showed double the protein (8.9%) as compared with the control.

## **2.5 Nutritional composition of composite flours**

There are two reasons for making composite flours, economic and nutritional. It is for these reasons that legumes have been used extensively in composite flours; they are superior in nutrition content, compared to tubers or cereals and thus provide cheaper protein. When added to the wheat or any other flour then they are expected to help improve the nutritional status of that flour.

### **2.5.1 Protein**

The findings by Ubbor and Akobundu (2009) claimed that a blend of watermelon seed and cassava flour (90:10) showed to have more protein content than a 50:50 blend of the same flours. The protein content seemed to increase with the watermelon seed flour content. They attributed this increase to the fact that watermelon seed has a high content of protein. Saleh *et al.* (2012) reported that as the substitution of either defatted flour or chickpea was increased from 5% to 15%, the protein content of biscuits increased. A higher increase was reported in defatted soy flour.

### **2.5.2 Fat**

According to Ubbor and Akobundu, (2009) a blend of watermelon seed flour and cassava 90:10 had higher amount of fat, followed by a blend of watermelon seed flour and cassava flour 85:15. The fat content of biscuits increased from 14.6 to 24.0% with the increase in soy flour from 0 to 25% as was reported by (Banureka and Mahendran, 2009). Soy bean flour has a high amount of fat and this could have contributed to their findings.

### **2.5.3 Moisture**

In their results Saleh *et al.* (2012) showed that as wheat was substituted with defatted soy flour or chickpea flour the moisture content showed a gradual increase in biscuits. Banureka and Mahendran (2009) found that the moisture content of the control was higher than that of wheat-soy bean flour biscuits. The moisture content decreased from 2.90 to 1.53% as the soybean flour was increased from 0 to 25%. This was attributed to the fact that soy bean flour has a lot of dry matter and higher emulsifying properties than wheat.

## **2.6 Functional properties of legume flours**

The term "functional property" as applied to food ingredients, is defined as any property, aside from nutritional attributes, that influences the ingredient's usefulness in food. Most functional properties play a major role in the physical behaviour of foods or food ingredients during their preparation, processing, or storage (Fennema, 1985).

### **2.6.1 Bulk density**

The bulk density gives an indication of the relative volume of packaging material required; it is a reflection of the load a sample would carry if allowed to rest directly on one another. Ikpeme *et al.* (2010) looked at the difference between loose bulk density and packed bulk

density, the slight differences according to them indicated that the incorporation of taro did not cause a significant decrease in bulk densities of flour blends. They also pointed out that lower bulk densities are more desirable as they imply the sample would pack better during storage or distribution. High bulk density is a good physical attribute when determining the mixing quality of a particular matter.

Edema *et al.* (2005) found that their values for bulk density were generally lower (between 0.38 for commercially sold soybean flour and 0.55 for Maize soya blend) than those obtained by Amarjeet *et al.* (1993) for durum wheat blends (0.80 to 0.82). Butt and Batool, (2010) reported that the defatting process results in porous texture of the defatted product that can be attributed to low bulk density. This would be an advantage in the formulation of complementary foods (Akpata and Akubor, 1999).

### **2.6.2 Water and oil absorption**

Water absorption is the amount of water absorbed by flour to produce dough of workable consistency. Interactions of water and oil with flours are very important in food systems because of their effects on the flavor and texture of foods.

High water absorption may assure the product cohesiveness and this is a functional characteristic mostly important for ready-to-use foods but may also be important for dough making. Proteins are mainly responsible for the bulk of the water uptake and to a lesser extent the starch and cellulose at room temperature (Afoakwa, 1996). Ikpeme *et al.* (2010) claimed their results suggested that indeed addition of taro flour affected the water absorption. In their case the taro starch actually inhibited the absorption of water as the 90:10wheat: taro blend had the highest absorption of water. Uzor-Peters *et al.* (2008) suspected that the addition of defatted soy flour or defatted groundnut cake flour for kokoro (a finger-like maize-based snack food that is consumed alone or with roasted groundnuts) formulation may have

increased the oil absorption capacity of the product which resulted in a higher fat content of the products: 26.8% for defatted soya flour and 34.06% for defatted groundnut cake flour.

Olu *et al.* (2012) reported that the water absorption of yam flour reduced as the proportion of soy flour was increased.

The importance of oil absorption is in the fact that oil acts as a flavour retainer and helps increase the mouth feel of food. The main chemical component affecting the oil absorption capacity is protein which is composed of both hydrophilic and hydrophobic parts. Non polar amino acid side chain can form hydrophobic interactions with hydrocarbon chains of lipid (Jitngarmkusol *et al.*, 2008).

### **2.6.3 Emulsion capacity and stability**

Emulsion capacity and emulsion stability are critical parameters that affect the choice of a protein for use in an industrial process. Proteins can reduce tension at the water-oil interface and help prevent coalescence (McWatters and Cherry, 1981). A protein's stabilizing effect in an emulsion comes from the membrane matrix that surrounds the oil drop and prevents its coalescence.

High emulsion capacity could be an indication that the flour can make a good emulsifier with other foods. Kohajdova *et al.* (2011) associated the higher emulsion capacity of legumes with the dissociation and partial unfolding of globular proteins, leading to exposure of hydrophobic amino acid residues, which consequently increase the surface activity and adsorption at the oil and water interface. When incorporating chickpea in wheat flour, Kohajdova *et al.* (2011) concluded that the ability to form an emulsion was majorly from the chickpea flour than from the wheat flour.

Carvalho *et al.* (2006) pointed that the ability of a protein to interact with both the water and oil shows that they possess well balanced proportions of externally hydrophilic and

hydrophobic groups and could be used as thickeners, viscosity and adherence enhancers in addition to increasing flavor retention.

#### **2.6.4 Foaming capacity and stability**

Another practical application of proteins in industrial production comes from their ability to generate foam (foam capacity). Proteins must be highly soluble in water, flexible and form part of a cohesive film at the water-air interface to ensure good foam formation (Wagner and Gueguen, 1999). The film should possess sufficient viscosity to prevent rapture and subsequent coalescence (foam stability).

Researchers report that defatting markedly increases the foaming properties of flours and thus make better aerating agents. Partially defatted flaxseed flour samples were reported by Hussain *et al.* (2008) to have higher foam capacity and stability. Giami and Bekebian (1992) and Egbekun and Ehieze (1997) reported that the foam of defatted flours was more stable than that of the full fat flours.

#### **2.6.5 Least gelation concentration**

The ability of protein to form gels and provide structure matrices for holding water flavours, sugars and food ingredients is useful in food applications and in new product development, thereby providing an added dimension to protein functionality (Devi and Haripriya, 2012). The ability of seed flour to form gels is especially desirable in extended meat products. Protein gelation is vital in the preparation and acceptability of many foods, including vegetables and other products (Lawal *et al.*, 2007). Lower least-gelation concentration enhances the swelling capacity of the flour. According to (Ikpeme *et al.*, 2010), the taro blends had better gelling capacity; the least gelation concentration of wheat and taro blends ranged from 6-8% while the control had a high gelation concentration of 10%. Complete gelation of instant chickpea incorporated in wheat flour was reported to be 6% by (Kohajdova

*et al.*, 2011). The gelation concentration is said to be interrelated to water absorption capacities, the lower the water absorption could mean low gel formation. It readily takes place at higher protein concentration because the intermolecular contact during heating is high.

## 2.7 Sorption isotherms

The shelf life of packaged food materials has been shown to be influenced greatly by the temperature, relative humidity and moisture content and thus the water activity of the material. The knowledge and understanding of sorption isotherms is highly important in food science and technology for the design and optimization of drying equipment, designing of packages, predicting of quality, stability, shelf life, and calculating moisture changes that may occur during storage (Abramovic and Klofutar, 2006).

Several different isotherm models have been proposed and compared in the literature to fit the moisture sorption behavior of different food powders at different storage temperatures. Some of these models have theoretical basis while others are semi -empirical or fully empirical. Staudt *et al.*, (2013) reported that these models are necessary to predict the moisture content at a given water activity and are used to evaluate thermodynamic functions of water in foods.

The most common equations that are used for describing sorption in food products are the Langmuir equation, the BET equation, the Oswin model, the Smith model, the Halsey model, the Henderson model, the Iglesias-Chirife equation, the GAB model, and the Peleg model. Nikolay D. Menkov and Albena G. Durakov (2006) used the five models (modified Oswin, modified Halsey, modified Chung -Pfof, modified Henderson and Guggenheim-Anderson-de Boer (GAB) to determine the moisture equilibrium (adsorption and desorption) of sesame flour. The GAB model was found to be the most suitable for describing the sorption data and

the monolayer moisture content was estimated using the Brunauer- Emmertt- Teller (BET). Saad *et al.*, (2007) modelled the experimental water adsorption isotherms of wheat flour based on the two parameter model (BET), the three parameter model (GAB) and the four parameter model (TSS).

### 2.7.1 Brunauer-Emmett-Teller (BET) equation.

The BET equation (1938), which is the most widely used model in food systems, was first proposed by Brunauer, Emmett and Teller and it represents a fundamental milestone in the interpretation of multi-layer sorption isotherms, particularly the types II and III. It is reported to be an effective method for estimating the amount of bound water in specific polar sites of dehydrated food systems. The BET model is usually presented as follows:

$$M = \frac{X_m C \cdot a_w}{(1 - a_w)(1 - a_w + C \cdot a_w)}$$

Where:

$M$  = water content on a dry basis at equilibrium

$X_m$  = water content when each sorption site contains one water molecule (monolayer)

$a_w$  = water activity

$C$  = sorption constant which is related to the energy interaction between the first and further sorbed molecules at the individual sorption site.

An important issue regarding BET model is that its assumptions are expected to hold only for small values of  $a_w$ , up to 0.4–0.5. However, for some food materials the BET model has been shown to produce reasonable agreement with experimental data over the whole range of water activity (Cassini *et al.*, 2006; Mulet *et al.*, 1999; Thys *et al.*, 2010). Another interesting feature of the BET model is the fact that it includes the monolayer moisture content ( $X_m$ ),

which is a parameter of interest in dried foods. The value of the monolayer is of particular importance because it indicates the amount of water that is strongly adsorbed in specific sites, and it is considered to be the value at which a food product is the most stable (Andrape *et. al* 2011)

### 2.7.2 Guggenheim-Anderson-de Boer (GAB) model:

The term GAB model comes from the names Guggenheim, Anderson and De Boer, who independently derived the equation in 1966, 1946 and 1953, respectively (cited by Andrape *et. al* 2011). The model can be stated as follows:

$$M = \frac{X_m C K a_w}{(1 - K a_w) (1 - K a_w + C K a_w)}$$

Where:

$X_m$  = water content when each sorption site contains one molecule (monolayer)

$a_w$  = water activity

$M$  = water content on a dry basis at equilibrium

$C$  and  $K$  = sorption constants that are related to the energy interaction between the first and further sorbed molecules at the individual sorption site.

The GAB model has been used due to its theoretical bases, it describes the sorption behavior in a wide range of  $a_w$  (0 - 0.9). The major advantages of the GAB model are reported to be that it has a viable theoretical background since it is a further refinement of Langmuir and BET theories of physical adsorption and also it provides a good description of the sorption behaviour of almost every food product ( $a_w$ -0.9) (Andrape *et al* 2011).

## **2.8 Rheological properties of composite flour**

Mechanical and rheological properties of dough play an important part in governing the quality of baked products. Wheat flour contains the viscoelastic gluten which gives specific rheological properties to the dough and in turn influences the final quality of the baked product. Addition of another component which lacks the gluten to wheat, like in composition of composite flours is expected to affect or influence the rheological properties of the resultant dough. This is majorly from the dilution effect of partially replacing some of the wheat component. In a study on wheat-cassava composite flours, Khalil *et al.* (2000) reported that there was a progressive reduction in water absorption of flours with an increase in substitution with cassava flour, possibly due to reduced protein content of the composite flours. Mixing time, stability, and strength of the composite doughs also increased as the proportion of cassava flour increased. From the results obtained by (Saleh *et al.*, 2012) it was observed that increasing the substitution levels in the blends from 5 to 15% of either the defatted soy flour or the chickpea flour, the water absorption was found to be increased in all blends as compared to the control, (100%) wheat flour. The dough development time on the other hand was observed to decrease as the level of defatted soy flour was increased in the blend from 5 to 15%, the dough development time was not different for all the blends of the chickpea flour from 5 to 15%.

### **2.8.1 Pasting properties**

Adunni and Olaposi (2010) observed soybean substitution to reduce the peak value and holding strength values in a blend of banana flour with defatted soybean flour. Banana flour was reported to have higher binding capacities and could better form viscous gel in hot condition than the substituted samples. Many studies have confirmed that protein and hydrolyzed protein can also influence the pasting properties of starch by affecting thermal

transition, the network of gel, and competition of available water. Ikegwu *et al.* (2010) attributed the interaction of starch with protein and fat as factors that influenced the pasting characteristics, which decrease peak viscosity, trough, setback and final viscosity of *Brachyegiaeaurycoma*. Devi and Haripriya (2012) observed the same behavior of reduced pasting potentiality of wheat when replaced by soy that was observed by Adunni and Olaposi (2010) when substituting banana with soy flour. The decreased peak and breakdown viscosity of the starch in the flours could be correlated to the high protein content (Ayo *et al.*, 2007).

## 2.9 Biscuits

In earlier times some dough products were baked twice, once to set the structure of the product and again to further reduce the moisture content so the product acquired a long shelf life. This was convenient for travelers, soldiers, and sailors. Only a few products are baked twice nowadays and these are rusks, biscotti, croutons, and Melba toast while most biscuits and cookies are baked only once (Birt, 2011). Urbanization and the increased number of women working have put the rate of snack food consumption on the rise. Biscuits hold an important position in snack foods due to variety in taste, ready-to-eat nature, crispiness and digestibility. Biscuits have become one of the most desirable snacks for both youth and elderly people due to their low manufacturing cost, convenience, long shelf-life, and ability to serve as a vehicle for important nutrients (Akubor, 2003; Honda and Jood, 2005).

The success of biscuits and cookies can be attributed to four key factors which include their relatively long shelf life, the human liking and weakness for sugar and chocolate and finally their relatively good value for money.

Aleem *et al.* (2012) found that thickness of biscuits increased with increase in concentration of defatted soy flour. The reduction of spread ratio of biscuits was attributed to better binding strength of soy protein, also resulting in increase of thickness. The defatted soy flour

incorporated biscuits were reported to have lower hardness and this may be due to high water binding capacity of defatted soy flour.

### **2.10 Physical properties of biscuits**

Aleem *et al.* (2012) reported a linear decrease in total weight, diameter, spread ratio and hardness of biscuits as the level of defatted soy flour incorporation was increased. Biscuit thickness was reported to increase with the increase of incorporation. Similarly, the authors observed a gradual decrease in weight when defatted soy flour or chickpea flour was incorporated to wheat flour and cited Yadav *et al.* (2012) and Aleem *et al.* (2012) who respectively related it to low oil absorption properties of chickpea flour or good binding properties of defatted soy flour

### **2.11 Sensory evaluation of biscuits**

Sensory analysis on biscuits is conducted in order to evaluate if some wheat may be replaced by legume flour without a significant change in the sensory profile.

Aziah *et al.* (2011) work showed that cookies prepared from chickpea and mung were rated high in flavour, crispiness, aftertaste, colour and overall acceptability with significant difference ( $p < 0.05$ ) as compared to the control. There was a pronounced aftertaste in the mung bean and chickpea cookies but these cookies were still significantly preferred over the control. They concluded that the addition of mung bean and chickpea flour did not change the functional properties but rather increased the protein content and the acceptability of cookies.

Aleem *et al.*, (2012) pointed out that the colour characteristics of biscuits became darker with the increase in concentration defatted soy flour, the grainy appearance of the biscuits from incorporated formulation was more acceptable but the excessive grainy appearance was not as accepted. A slight improvement in crispness was also noted in the biscuits from the

defatted soy flour incorporated formulation. They concluded that the incorporation of defatted soy flour to the level of 20% is superior to all other treatments including the control.

Work done by Shahzad *et al.*, (2006) on the other hand showed that increasing the level of flaxseed flour resulted in the significant decrease in the sensory attributes of the biscuits as the biscuits made from wheat flour had a better score for overall acceptability than those made from 5% full fat flaxseed flour.

This work aims at using underutilized legume to make composite flours with wheat flour, the crop is nutritious but the downside is that it grows in the wild though efforts to grow it are underway but in the meantime the source remains unreliable. The use of defatted flour is advantageous since it is regarded to have a better shelf life and defatted flour is believed to be more nutritious but at the same time the process of removing the oil could be tedious and expensive. Addition of legume to wheat flour to form composite will definitely alter the particle size distribution of the resulting flour. The particle size distribution affects the hydration properties of the flour and thus should be known so as to know which food system the flour would be more suited. Protein is responsible for the gelling properties, this is important in water holding and retaining flavours. It is thus relevant to determine the gelling properties of flours. The sorption isotherm helps determine the behavior of flours in different conditions, humidity, temperatures and can also be used to help choose the kind of package for the flour given how it behaves. The next step would be to determine the isotherms in different temperatures to see how the flour behaves in different conditions as only one temperature was used here. Finally the consumers have much say on the final product, its appearance, taste, smell and overall. The consumers are the ones that are going to utilize the product so should be given chance to decide if it is something that they would be interested in.

### 3.0 MATERIALS AND METHODS

#### 3.1 Experimental design

A 2x2x4 factorial experimental design was used and the principal factors were:

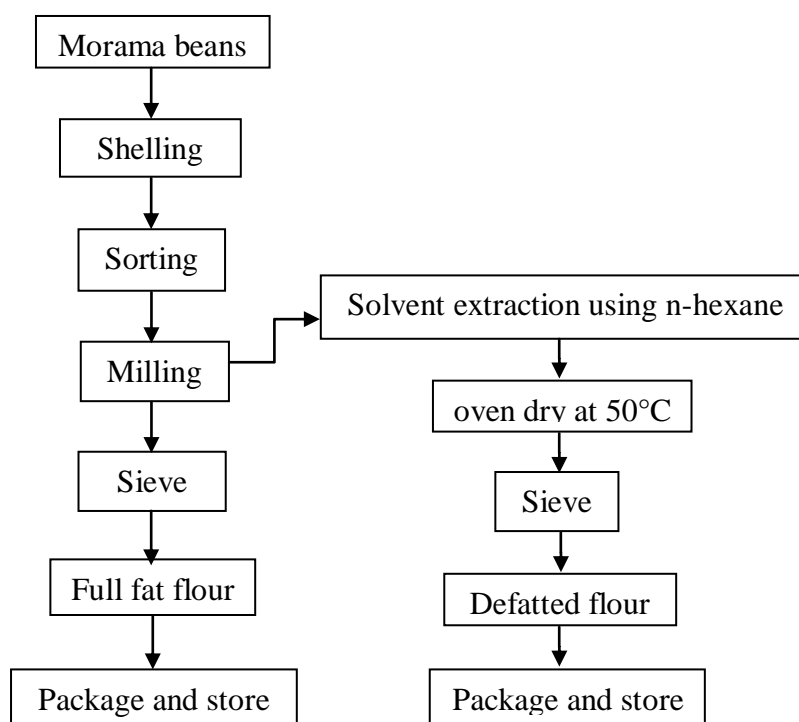
1. Type of wheat; soft and hard
2. Pre treatment of morama; full fat and defatted
3. Substitution level of morama; 10%, 20%, 30% and 40%.

#### 3.2 Material acquisition

Morama beans were acquired from National Food Technology Research Center (Kanye) in Botswana. They were kept in a cool dry place at 25-30°C.

#### 3.3 Production of full fat and defatted morama flour

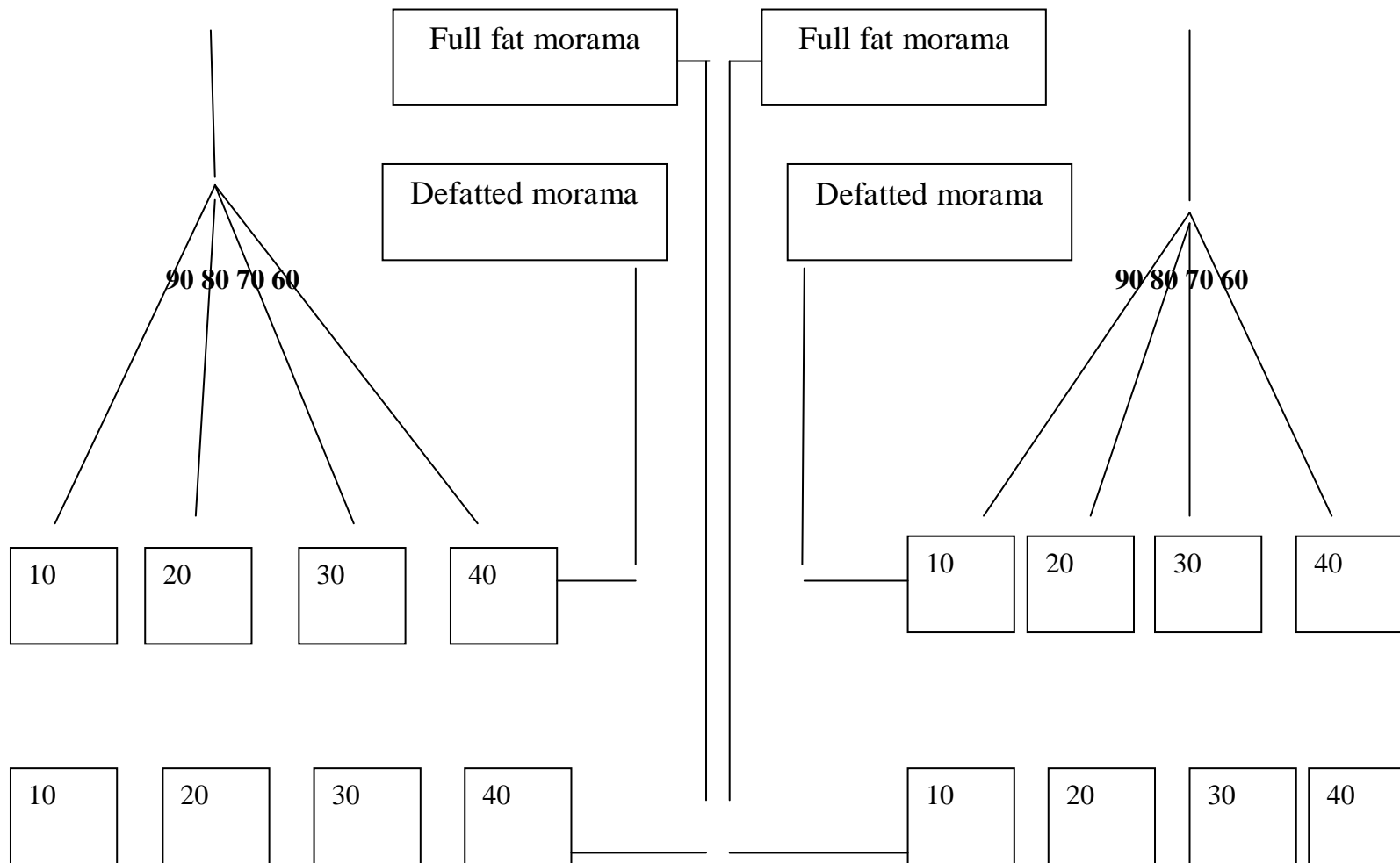
The process for obtaining full fat and defatted morama bean flour is as outlined in Figure 3.1.



**Figure 3.1 Flow chart of sample preparation of full fat and defatted morama bean flour**

### **3.4 Production of composite flours**

Both soft and hard wheat flours were purchased from a local flour milling company (Irani Brothers Ltd) in Tema near Accra. Sixteen composite flours were prepared according to the design of the study, by substituting soft and hard wheat flour with full fat and defatted morama bean flour in the percentage proportions of 0:100, 10:90, 20:80, 30:70 and 40:60% respectively.



**Figure 3.2: Flow diagrams of composite flour blends**

### **3.5 Proximate Analysis**

#### **3.5.1 Determination of protein content**

Protein content was determined using the Kjeldahl procedure as described in AOAC (2000). The nitrogen content obtained was multiplied by a factor of 6.25 to obtain protein content in the sample.

#### **3.5.2 Determination of fat content**

Crude fat was extracted in a Soxhlet extractor with petroleum ether as described in AOAC (2000).

#### **3.5.3 Determination of ash content**

Ash content was determined according to AOAC (2000).

#### **3.5.4 Determination of moisture content**

Moisture content was determined following the procedure (AOAC, 2000) using the air-oven at 105°C for 3hours.

### **3.6 Determination of particle size distribution**

The particle size distribution of flour samples obtained from the blends of wheat and morama bean flour was carried out using a sieve analysis technique with the aid of Endecotts Test Sieve Shaker (model 1 MK11-11381, London, UK) as described by Bolade and Buraimoh (2006). Different sieves with varying apertures (that is 35, 50,106,150 and 300 µm) were arranged on top of each other with the one having the biggest aperture on the topmost level and then arranged in decreasing order of aperture. The sieves were fastened into a rigid

position using a fastening screw after a standard quantity of the flour sample (50g) was already placed inside the topmost sieve. The sieve shaker was then switched on for 10 min after which the quantity of flour retained on each sieve was collected and weighed.

Calculation:

$$\% \text{ recovered} = \frac{W \text{ sieve} \times 100}{W \text{ total}}$$

Where: W sieve is the weight of the aggregate in the sieve

W total is the weight of the total aggregate.

### **3.7 Functional Properties**

#### **3.7.1 Determination of Bulk density**

Bulk density was followed according to the method of Asoegwu *et al.* (2006) with slight modifications. Fifty grams (50g) samples were placed in a 100 ml graduated cylinder and packed by gently tapping the cylinder on the bench top to attain a constant volume and the volume of the sample was recorded. The procedure was repeated three times for each sample and the bulk density was computed as g/ml of the sample.

$$\text{Bulk density} = \frac{\text{Weight of sample (g)}}{\text{Volume of sample (ml)}}$$

#### **3.7.2 Determination of Water absorption and oil absorption**

Water absorption capacity was determined using the method of Sathe and Salunkhe, (1981) as modified by Adebawale *et al.* (2005), with some modifications. Twenty milliliters of

deionized water was added to 5.0 g of the sample in a centrifuge tube. The suspension was stirred using a magnetic stirrer for 5min. The suspension obtained was thereafter centrifuged at 3000 rpm for 30 min and the supernatant measured in a 20mL graduated cylinder. The density of water was taken as  $1.0\text{gcm}^{-3}$ . Water absorbed was calculated as the difference between the initial volumes of water added to the sample and the volume of the supernatant.

### 3.7.3 Determination of emulsifying properties

The method modified by Yasumatu *et al* (1992) was followed where 3.0g of flour was suspended in 50mL of Viking (vegetable oil) oil. The mixture was emulsified in a blender at high speed for 1min. Emulsion obtained was put into 15mL centrifuge tubes and centrifuged at 1500 rrpm for 5 minutes.

$$\text{Emulsifying capacity} = \frac{\text{Volume of emulsified layer} \times 100}{\text{Volume of total sample in tube}}$$

The emulsion stability was also determined following the methods described by Okecie and Bello (1988). The same type of mixture was employed but heated at 80C for 30 minutes in a water bath. The mixture was cooled under running tap water for 15 minutes and centrifuged at 1500rrpm for 5 minutes. The emulsion stability was calculated using the same method used for emulsion activity. Triplicate determinations were carried out and the mean results taken.

### 3.7.4 Determination of Least gelation concentration

Least gelation concentration was determined using the method described by Coffman and Gracia (1977). Sample suspensions of 2-20% were prepared in distilled water. Ten milliliter of each of the prepared dispersions was transferred into a test tube. It was heated in a boiling

water bath for 1 h, followed by rapid cooling in a bath of cold water. The test tubes were further cooled at 4°C for 2 h and then left to stay at 4°C overnight. The least gelation concentration was determined as the concentration when the sample from the inverted test tube did not slip or fall. All the results were mean of triplicate determinations.

### 3.7.5 Determination of foaming properties

The Foam capacity (FC) and foam stability (FS) were determined according to the method of Lawhon *et al.* (1972). Sample (3 g) was dispersed in 100 ml of distilled water and pH adjusted to 7.0 using either 1M HCL or NaOH. The contents were transferred to a mixer blender whipped at high speed for 5 min. The contents, along with the foam, were poured into a 250 ml measuring cylinder and the foam volume was recorded after 30 seconds. FC was expressed as percentage increase in volume. After 30 min, the volume of foam was measured and expressed as FS.

$$FC = \frac{\text{Volume after homogenization} - \text{Volume before homogenization} \times 100}{\text{Volume before Homogenization}}$$

$$FS = \frac{\text{Volume after time (t)} \times 100}{\text{Initial foam volume}}$$

### 3.8 Sorption Isotherm analysis

A static gravimetric method was used for the experiment (Greenspan, 1977). Duplicate samples of one gram each of wheat-moroma bean flour were placed in small dishes inside

bottles containing saturated salts solutions (LiCl, CH<sub>3</sub>COOK, MgCl<sub>2</sub>, K<sub>2</sub>CO<sub>2</sub>, NaCl and KCl) which provided constant relative humidity environments ranging from 11 to 85%. The bottles were kept in a controlled oven at a constant temperature of 30°C. The samples were weighed at intervals of two days using a digital balance until constant weight was obtained after three consecutive recordings, when the samples were assumed to be at equilibrium.

The dry mass was determined by the oven drying method for 6- 10 hours at 105°C (AOAC 2000).

The time to reach equilibrium ranged from 15 to 20 days depending on the water activity in each bottle. Those at higher water activities reached equilibrium faster than those with lower water activities. The equilibrium moisture contents were calculated as averages of the triplicates from which the moisture sorption isotherms were determined.

The data for the water adsorption were fitted to the GAB and BET equations to describe their moisture sorption behavior.

### **3.9 Determination of pasting properties**

Pasting characteristics were determined using the Brabender Visco-Amylograph. For each flour sample, slurry containing 8% solids (w/v) was prepared. The weight of flour to achieve the 8% solids was calculated on the dry matter basis. The slurry was heated at a rate of 1.5 °C/min from 50 to 90°C with a holding time of two minutes, and then cooled at a rate of -1.5°C / min to 50°C.

### 3.10 Biscuits production

Biscuits were prepared using the traditional creamy method described by Whitley (1970) with modifications. The ingredients used were margarine (25%), sugar (25%), baking powder and composite flour (50%).

The margarine and sugar were creamed in a Kenwood mixer for 15 minutes until light and fluffy. After sieving the flour with baking powder, they were slowly introduced into the mixture. The flour and margarine and sugar were mixed at a high speed until the mixture did not stick to the sides of the mixer anymore. The dough obtained was then rolled out on a flat pastry board using a wooden rolling pin. Flour was sprinkled on the dough during rolling to aid in obtaining a uniform thickness.

A biscuit cutter was used to cut the dough into shapes which were placed on a well greased baking tray.

Biscuits were baked in an electric oven at 150°C for 15 minutes. The cooked biscuits were pale brown in colour.

### 3.11 Physical parameters of biscuits

Biscuits were analyzed for width, thickness and spread ratio according to the procedure described in the AOAC (2000).

a. **Width - (W)** -six biscuits were placed horizontally (edge to edge) and their average diameter taken using the vernire calipers with 0.01 mm accuracy.

b. **Thickness** - six biscuits were placed one another and their average thickness was taken using the venire calipers

c. **Spread ratio** - the spread ratio was calculated as the average diameter/thickness.

### 3.12 Colour analysis

The colour of biscuits was measured in accordance with CIE  $L^*a^*b^*$  colour space system based on the tristimulus value. The lightness (L), redness(= +ve a), yellowness (+ve b) and the magnitude of total colour difference values were measured by placing the samples on the port of the colour measuring system (Lab Scan XE Hunter Lab instruments). A positive value of  $a^*$  indicates the magnitude of reddish component, while its negative value shows that of greenish component. A positive value for  $b^*$  shows yellowish component while its negative indicates the bluish component. The  $L^*$ ,  $a^*$ ,  $b^*$  values were recorded.

### 3.13 Sensory evaluation

The method described by Iwe (2002) was used for the sensory analysis. Biscuits samples made from soft wheat and morama bean flour were tasted by panelist of 65 students randomly selected from the students of University of Ghana, Legon, Accra, Ghana. Biscuits samples made from soft wheat flour served as the control.

The nine samples were put on trays on different coded dishes and served to the panelists. Quality attributes of appearance, colour, crispiness, texture, taste and overall acceptance of the biscuits were scored on the 9-point hedonic scale. The degree of likeness was expressed as follows, Like extremely-9, Like very much -8, Like moderately-7, Like slightly-6, Neither like nor dislike-5, Dislike slightly-4, Dislike moderately-3, Dislike very much-2, Dislike extremely-1

## 4.0 RESULTS AND DISCUSSION

### 4.1 Proximate analysis of the flours

Proximate analysis of wheat and legume flours was carried out.

#### 4.1.1 Protein content of whole flours

The protein content of soft wheat was 10.47 and that for hard wheat was 12.86% (Table 4.1).

These findings are not too far from Nwosu (2013) who reported the protein content of wheat flour to be 13.24%. The differences could be from variations among cultivars.

The protein content of the full fat morama bean flour was 26.83% whereas the defatted morama bean flour had a protein content of 47.31%. The difference in the protein content between the full fat morama bean and defatted morama bean flour suggests that defatting significantly affects the protein content of the morama bean flours positively. This can be explained by the fact that extraction of oil makes more protein available in the same quantity of the flour. Jideani *et.al* (2009) reported the protein content of morama bean to range between 29.6 and 41.8%, whereas Nepolo *et.al* (2010) reported theirs at 43%.

#### 4.1.2 Fat content of whole flours

The fat content of soft and hard wheat was 0.64 and 0.51% respectively whilst full fat morama bean flour showed a fat content of 39.25%. After defatting the fat content reduced to 9.29%.

The oil content of full fat morama agrees with what Jideani *et al.*, (2009) reported to range between 32.1-45.3%.

#### **4.1.3 Ash content of whole flours**

The ash content usually means the total mineral oxides in a food. Data in Table 4.1 show the ash content of soft and hard wheat to be 0.34 and 1.73% respectively. Nwosu (2013) reported ash content of wheat flour to be 0.70%.

Full fat morama bean flour showed ash content higher than that of wheat flours at 2.71% and defatted morama bean flour had 3.89% ash content. Jideani *et.al* (2009) found the ash content of morama bean flour to be 2.9% while Diana *et. al.*, (2006) found reported 3.08%

#### **4.1.4 Moisture content of whole flours**

The moisture content of the flour is important for two reasons, firstly the higher the moisture content the lower the dry solids in the flour and secondly, flours with moisture content greater than 14% are not stable at room temperature. Organisms naturally present in flour will start to grow at high moistures producing off odours and flavours.

The data on Table 4.1 show moisture contents for soft wheat to be 12.82 and hard wheat had a moisture content of 13.43%. Nwosu (2013) found the moisture content of wheat flour to be 12%.

Full fat morama bean flour on the other hand showed moisture content of 5.16% and defatted morama bean flour showed moisture content of 6.89%. Even after the oil was extracted from the full fat morama bean flour the moisture content still remained low but a little higher than that of full fat morama flour. Jideani 2009 *et al* found the moisture of morama bean flour to be between 6.4 and 6.9% while Diana *et.al* (2006) found the moisture content to be 3.5%.

**Table 4.1: Proximate composition of the wheat and morama bean flours (dry matter per 100g sample)**

	<b>Protein</b>	<b>Fat</b>	<b>Ash</b>	<b>Moisture</b>
<b>Soft wheat</b>	10.47±0.32	0.62±0.31	0.34±0.37	12.82±0.1
<b>Hard wheat</b>	12.86±0.21	0.51±0.02	1.73±1.93	13.43±0.3
<b>Full fat morama</b>	26.83±2.37	39.25±3.66	2.71±0.34	5.16±0.6
<b>Defatted morama</b>	47.31±1.88	9.29±2.20	3.89±0.42	6.89±0.26

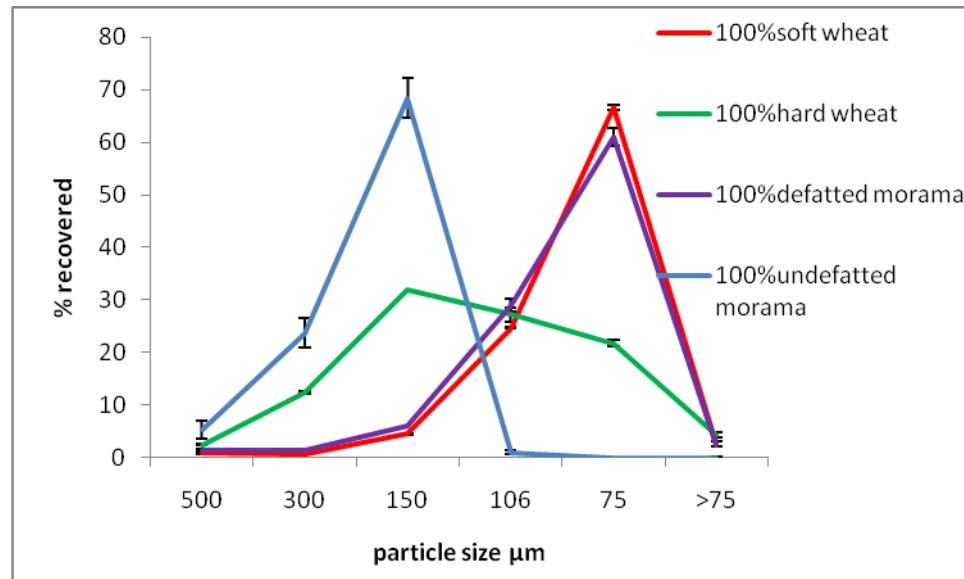
## 4.2 Analysis of the Wheat Flour and composite flours

Flour is known to be a homogenous mixture of particles of different shapes and densities (Sonaye *et. al.*, 2012). Particle size distribution of flour shows the different ranges of particle sizes present in the flour and that information helps to determine the texture or mouth feel of the end product. The grittiness, fineness or coarseness all depend on the size distribution of particles in the flour. (Sonaye *et. al.*, 2012) suggested that the particle size of certain flours were related to different characteristics like protein content, maltose, ash content, and gassing power.

### 4.2.1 Particle size distribution of whole flours

Figure 4.1 shows the particle size distribution of whole flours (soft and hard wheat, full fat and defatted morama bean flour). The data show that soft wheat flour and defatted morama flour have finer particles (averaging about 75µm) than full fat and hard wheat flour. The

particle size distribution of hard wheat was generally wider with a particle size range of 75, 106 and 150 $\mu\text{m}$  as well as 300 $\mu\text{m}$ . Full fat morama bean flour showed a high retention of coarse particles of 150 $\mu\text{m}$  and 300 $\mu\text{m}$ . This was probably because it contained high amounts of oil, which formed a layer around particles and also bound the particles together to form larger particles.



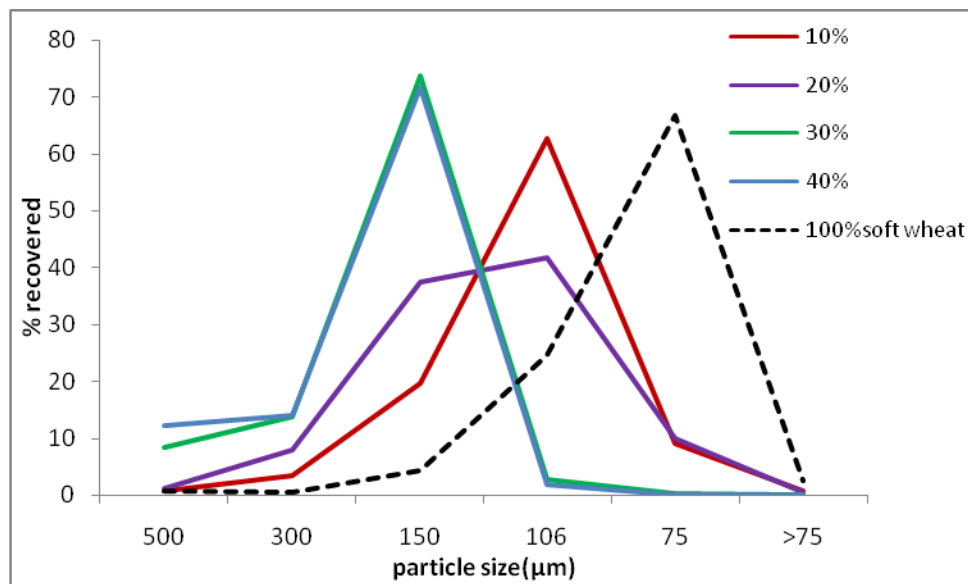
**Figure 4. 1: Particle size distribution of the wheat , full fat morama bean and defatted morama bean flours.**

#### a) SOFT WHEAT

##### 4.2.2 Soft wheat and full fat morama blends

Soft wheat flour showed a predominant particle size distribution of about 75  $\mu\text{m}$  (Figure 4.2), Substitution with 10% full fat morama bean flour shifted the average particle size from 75 $\mu\text{m}$  to 106 $\mu\text{m}$ . Substitution of wheat flour with 30 and 40% full fat morama bean flour further shifted the particle size to 150 $\mu\text{m}$ .

From Figure 4.2, it is clear that as the content of full fat morama bean flour was increased the particle size distribution shifted towards the coarse or larger particles. The presence of the oil in the full fat morama could be responsible for the large particle size as oil can form a layer around the particle and make it appear big or bind two or more particles together. From these results it shows that the composite of soft wheat and 10 percent level of morama bean flour have the closest particle size distribution to the 100 percent soft wheat.



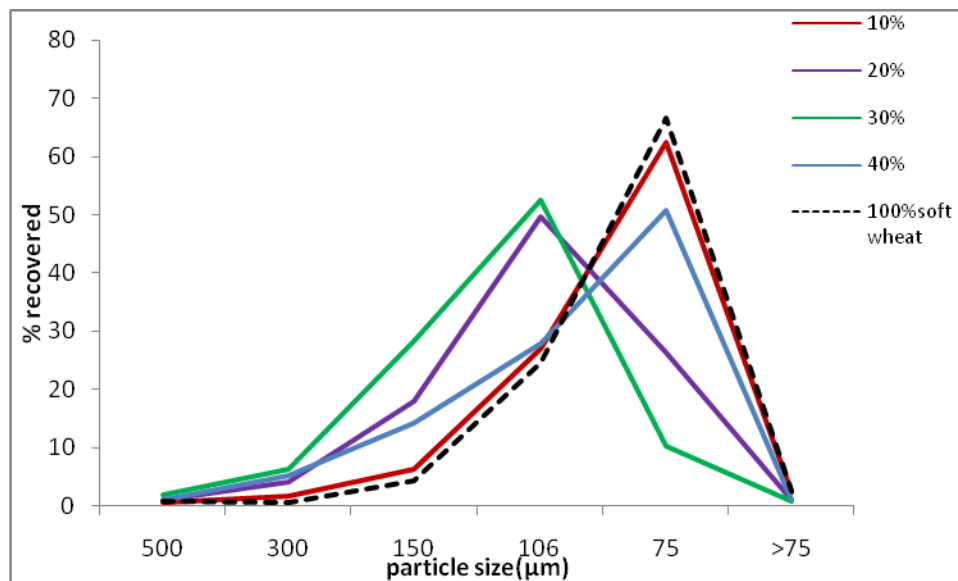
**Figure 4.2: Particle size distributions for soft wheat and full fat morama composite flours**

### 4.2.3 Soft wheat and defatted morama blends

The effects of defatted morama bean flour on the particle size distribution with soft wheat blends were different than with full fat flour. At the 10 percent level of substituting wheat flour with defatted morama bean flour, the particle size distribution was not different from 100% soft wheat flour (Figure 4.3). Higher levels of substitution of soft wheat with defatted morama bean flour broadened the particle size distribution towards larger particle sizes. The

20 and 30 percent level of morama bean flour retained 50% of the weight of particles within the size 106  $\mu\text{m}$ . Unlike for the full fat morama bean flour blends with wheat, all the composite flours with defatted morama bean flour had less than 20% of the weight of particles as large as 150  $\mu\text{m}$ . Extraction of oil from the morama flour helped to reduce the particle sizes of the defatted composite flours.

Figure 4.3 shows that soft wheat and defatted morama bean composite flours showed a shift of particle size distribution towards the finer particles. At 10 percent defatted morama bean the flour had more of the 75 $\mu\text{m}$  particles and 40 percent of defatted morama bean flour too showed an appreciable amount of 75 $\mu\text{m}$  particles. The 20 and 30 percent level of substitution had a higher amount of 106  $\mu\text{m}$  and for all the composites there were very little amount of coarse particles.



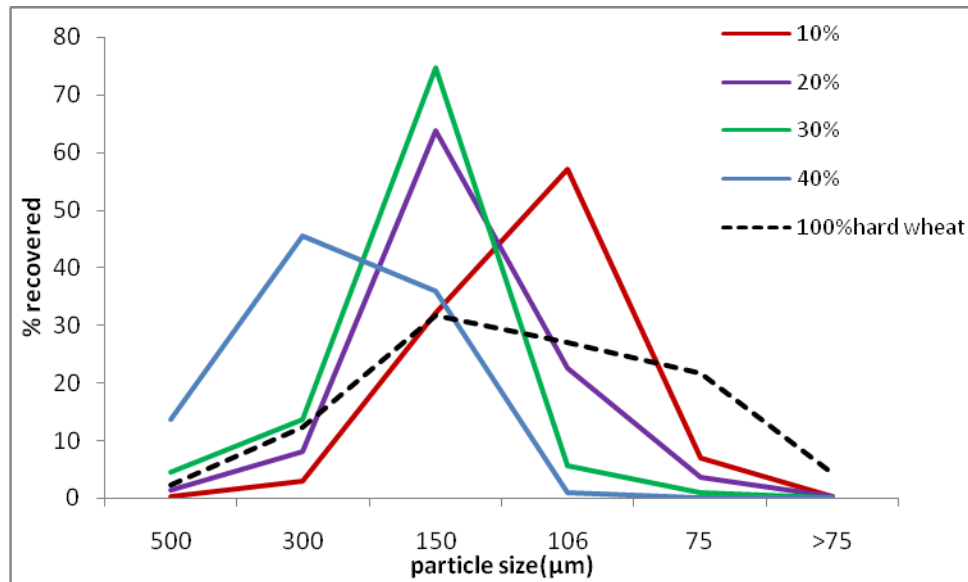
**Figure 4.3: Particle size distributions for soft wheat and defatted morama bean composite flours**

## **b) HARD WHEAT**

### **4.2.4 Particle size distribution of Hard wheat and full fat morama flour blends**

Hard wheat flour (100%) showed a broader particle size distribution than that of soft wheat flour (100%). The particle size of hard wheat ranged from fine particles of less than 75 $\mu\text{m}$  to coarse particles of 500 $\mu\text{m}$  (Figure 4.4). At 10 percent level of full fat morama bean flour more of the 106  $\mu\text{m}$  particles had been retained whereas 20 and 30 percent level of full fat morama bean flour retained more of the 150  $\mu\text{m}$  particles. The 40 percent had more of the 300 and 150  $\mu\text{m}$  particles.

Hard wheat generally has coarse particles, and as full fat morama bean flour was added to it a clear shift towards the coarse particles was shown. A higher retention of finer particles (106 $\mu\text{m}$ ) was observed in 10 percent level of full fat morama bean flour, while 20 and 30 percent level of full fat morama bean flour showed 150 $\mu\text{m}$  whereas 40 percent shifted the distribution to much coarser particle sizes and showed a higher retention of 300  $\mu\text{m}$  particles.



**Figure 4.4: Particle size distributions for hard wheat and full fat morama bean composite flours**

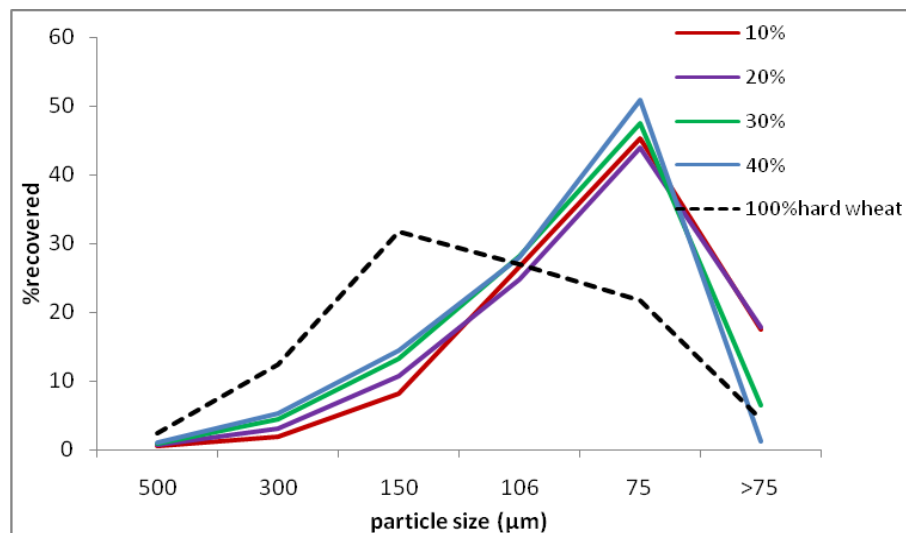
#### 4.2.5 Particle size distribution of Hard wheat and defatted morama flour blends

Blending defatted morama bean flour with hard wheat flour had the effect of shifting the particle size distribution towards finer flour (Figure 4.5). The 40 percent level of defatted morama bean flour showed the highest retention (about 50 %) of the 75 μm particles followed by the 30 percent level of defatted morama bean flour, followed by 10, then 20 percent level of defatted morama bean flour. All the composite flours had less than 20% of the 150μm particles. When the level of defatted morama bean flour was increased in hard wheat composites, the particle size distribution was similar to that of 100% soft wheat flour. The results also show clearly the effect of oil extraction. At 40% level of substitution of defatted marama bean flour to hard wheat, the amount of fine particles (ie 75μ or below) was high, while at the same level of substitution of full fat bean flour the amount of coarse particles (ie 300μ and above) was high.

### 4.3 Moisture content of composite flours

The data in Table 4.2 show the moisture content of composite flours. The moisture contents of soft and hard wheat were relatively high at 12.82 and 13.43% respectively. On the other hand the moisture content of full fat and marama bean flours were relatively low at 5.16 and 6.89% respectively.

The moisture content of all the composite flours ranged between 10.24-12.51%. The moisture contents of composites, both for soft and hard wheat and for full fat and defatted morama bean flour decreased as the substitution level of morama bean flour (full fat or defatted) increased in the composites. In all substitutions with morama bean flour, the moisture content seemed to increase because wheat flour, which had relatively higher moisture content, was always of higher proportions.



**Figure 4.5 Particle size distributions for hard wheat and defatted morama bean composites**

#### 4.4 Functional Properties

The term "functional property" is defined as any property, aside from nutritional attributes, that influences the ingredient's usefulness in food. Most functional properties play a major role in the physical behaviour of foods or food ingredients during their preparation, processing, or storage (Fennema 1985). The application of ingredients in specific food systems depend on their functionality in those systems.

**Table 4.2 Moisture contents of the different composite flours**

	<b>Soft wheat</b>	<b>Hard wheat</b>
10% Full fat morama	11.52±0.09	12.04±0.19
20% Full fat morama	11.25±0.13	11.15±0.3
30% Full fat morama	10.95±0.39	10.69±0.06
40% Full fat morama	10.24±2.39	10.33±0.19
10% Defatted	12.21±0.15	12.51±0.3
20% Defatted	11.96±0.23	12.3±0.05
30% Defatted	11.24±0.09	11.75±0.66
40% Defatted	10.90±0.33	11.1±0.2

#### 4.4.1 Bulk Density of the flours

Bulk density of the flour is important in the raw material handling, determination of the package material requirements and for transportation considerations. Flours with high bulk density have been known to be good for mixing purposes whereas those with lower bulk density may find a better usage in baby food industry. The bulk densities of both soft and hard wheat flour were significantly high in comparison with the morama bean flours (Table 4.3).

Full fat morama bean flour showed a higher bulk density than defatted morama bean flour. Their densities were at 60 and 55g /ml respectively. Defatting reduced the bulk density of the morama bean flour.

**Table 4.3: Bulk densities of wheat and morama flours**

Sample	Bulk density(g/ml)
Soft wheat	78.6 ± 1.4
Hard wheat	76.5 ± 0.67
Full fat morama	59.5 ± 0.7
Defatted morama	53.4 ± 0.3

Table 4.4 show the bulk density of the composites of both soft and hard wheat flours. At 10 and 20 percent level of full fat morama bean flour in soft wheat the bulk density was higher (73 g/ml),and went down as the level of full fat morama bean flour were increased. Hard wheat and full fat morama bean flour composites showed lower bulk densities. There was a slight decrease (from 70 to 68.5g/ml) as the level of full fat morama was increased in the composites.

For soft wheat and defatted morama bean flour 10 and 20 percent levels of substitution still had higher bulk densities followed by 30 and 40 percent level of defatted morama flour with the bulk density of 67g/ml. Hard wheat flour and defatted morama bean flour showed a clear decrease (ranging between 74 and 65 g/ml) as the level of defatted morama bean flour added to the hard wheat increased

The results in Table 4.4 suggest that addition of morama bean flour to either wheat (i.e soft or hard wheat) flour reduced the bulk density of composite flours. The substitution at 20% levels of morama bean flours ( full fat and defatted) in soft wheat flour showed a bulk density that was still low and close to that of 100 % soft wheat.

**Table 4.4: Bulk densities of composite flours**

	Full fat morama		Defatted morama	
	Soft wheat	Hard wheat	Soft wheat	Hard wheat
<b>10%</b>	73.6± 2.6	70.1± 1.1	10% 73.3± 0.7	73.5± 1.1
<b>20%</b>	73.9± 1.2	69.5± 1	20% 74.3± 0.6	70.1± 0.6
<b>30%</b>	71.8± 0.6	69.1± 0.5	30% 71.8± 0.6	68.2± 0.5
<b>40%</b>	70.8± 0.6	68.2± 0.5	40% 67.3± 0.5	65.4± 0.3

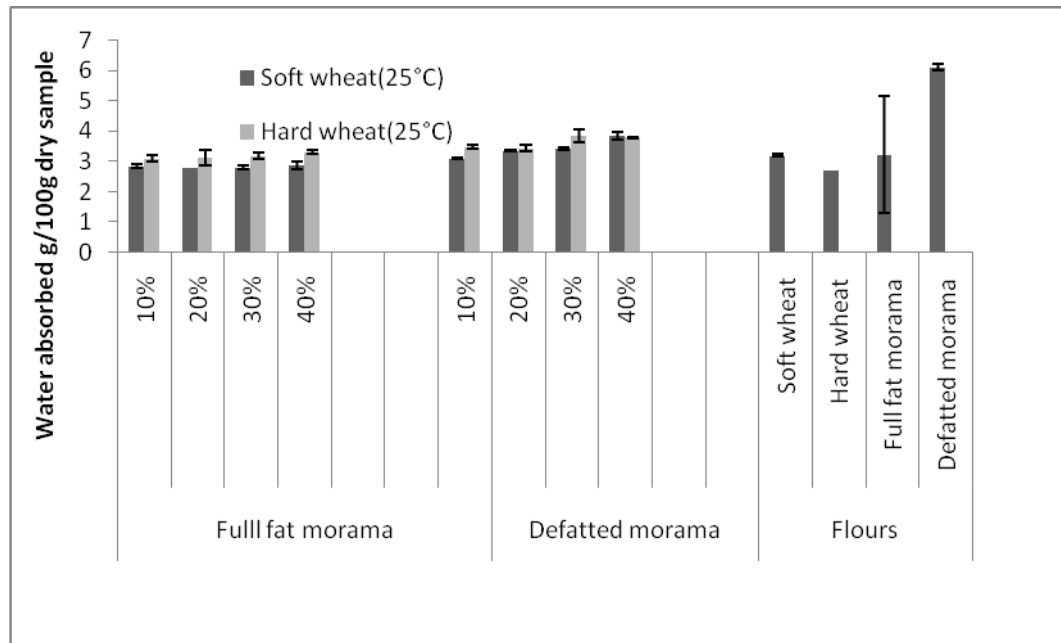
#### 4.4.2 Water absorption

Water absorption capacity of flours plays an important role in the dough preparation process because it influences other functional and sensory properties. The extent of application of flours as food ingredients is dependent to a large degree on their interaction with water

Generally there were no significant differences in the amount of water absorbed by the soft and hard wheat flour at 25°C. At that temperature however, the water absorption capacity by both full fat and defatted morama bean flour were significantly higher than both hard and soft wheat flours (Figure 4.6). Soft wheat and defatted morama bean flour composites showed no significant difference in water absorption capacity at 25°C. The results indicate that in the presence of full fat morama bean flour at 25°C the water absorption was not significantly changed.

Defatted morama bean flour's capacity was clearly higher and this is due to the fact that oil was extracted from the flour and thus the protein cake could accommodate more water. Maruatona et al. (2009) reported a water absorption capacity of 1.5 g/g of defatted unheated morama which was much lower than the results in Figure 4.6. Many factors could have contributed to the difference, conditions and the type of morama used i.e. one used in this research grows in South Africa and this grows in Botswana.

Starch is responsible for the behavior of the flours in the presence of water at high temperatures.



**Figure 4.6: Water absorption of wheat-morama bean flour composites and whole flours at 25°C**

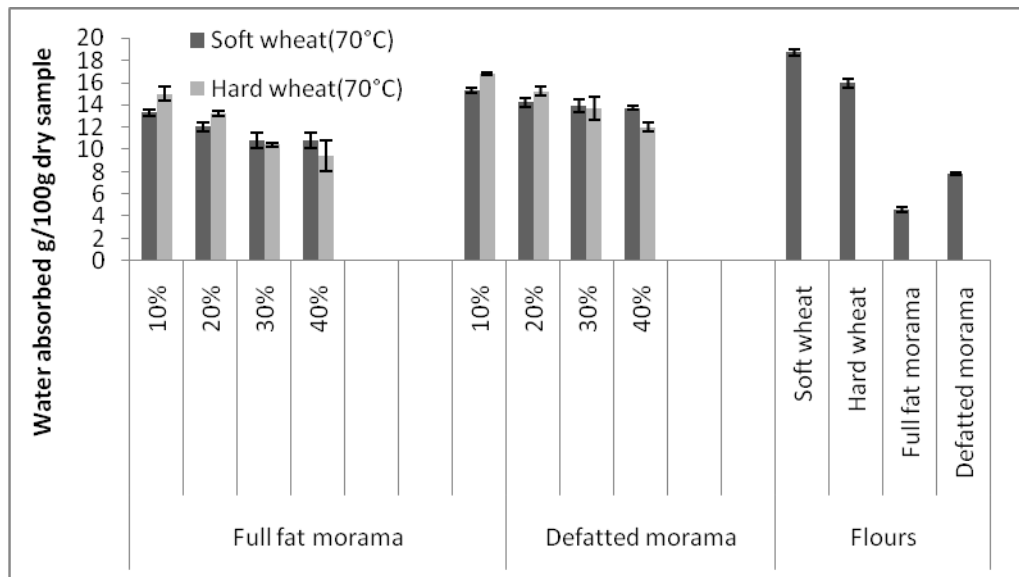
Wheat flours have high amounts of starch but morama bean flours do not have starch. Consequently as the temperature was increased to 70°C, the wheat starches absorbed water and swelled up at temperatures close to gelatinization. Soft wheat has less protein in comparison to hard wheat, thus has more starch and showed a higher water absorption capacity.

Figure 4.7 shows the water absorption behaviours of soft and hard wheat composites together with the flour at 70°C. The behavior of soft and hard wheat flour was different when the temperature was raised to 70°C. At that temperature soft wheat showed more capacity to absorb water than hard wheat flour. The water absorption capacity of both full fat and defatted morama bean flour at 70°C was significantly lower than the wheat flours.

A sharp increase was observed when the temperature was raised to 70°C. At the high temperature conditions composite flour with 10 and 20 percent level of full fat morama bean flour showed higher water absorption than blends with 30 and 40 percent full fat morama bean flour .

A significant increase in water absorption was observed in soft wheat and defatted morama bean flour when temperature was increased to 70°C. The 10 percent level of defatted morama bean flour showed a higher water absorption and 20, 30 and 40 percent were a little lower with no significant difference among them.

Addition of defatted morama bean flour to soft wheat improved the water absorption at 70°C. It is clear that the presence of oil in the morama bean inhibited the water absorption. This was observed in full fat morama bean flour composites, where the water absorption went down as the content of full fat morama bean flour was raised.



**Figure 4.7: Water absorption of wheat-morama bean flour composites and whole flours at 70°C**

The composite flours showed no significant difference in water absorption at 25°C when full fat morama bean flour was used in hard wheat substitution. As the temperature was increased to 70°C there was a significant increase in water absorption. When the level of full fat morama bean flour was increased there was a significant decrease in water absorption capacity of the composite flours ranging from 15 to 10 g of water absorbed per 100g of dry sample. The difference between 30 and 40 percent levels was not significant.

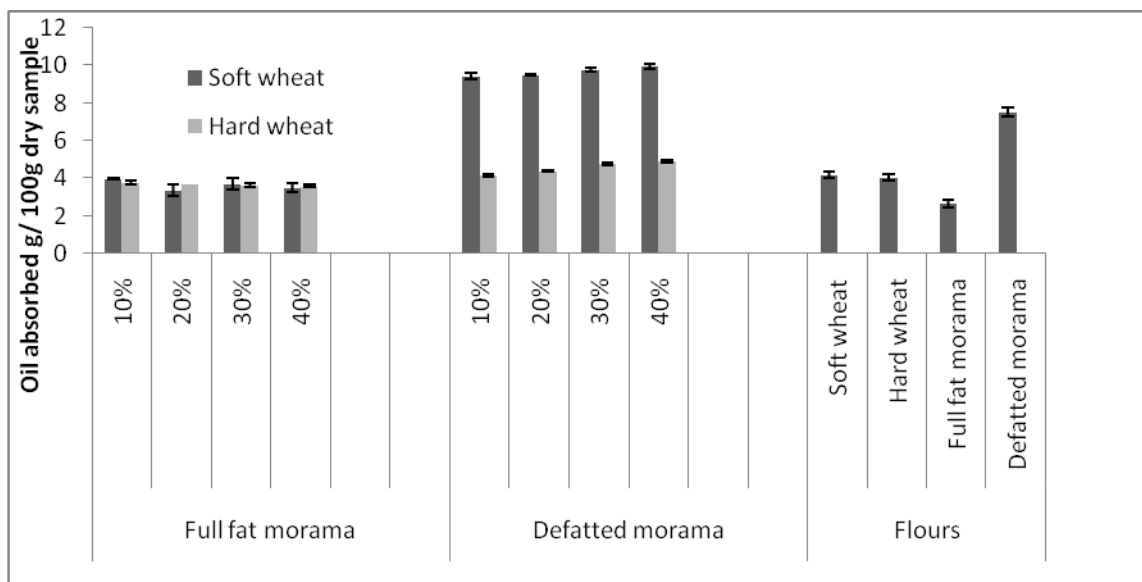
The water absorption capacity of composites made using hard wheat flour and defatted morama bean flour at all substitution levels showed no significant difference at 25°C (Figure 4.6). At higher temperatures (70°C) the water absorption capacities of all composite flours (hard wheat with defatted morama bean flour) increased. Increasing the level of defatted morama bean flour in the composite flour with hard wheat decreased the water absorption capacity at 70°C.

The decrease in water absorption with the increase of morama bean flour was more profound with hard wheat composites than with soft wheat composites (Figure 4.7). The major chemical compositions that enhance the water absorption of flours are proteins and carbohydrates, since these constituents contain hydrophilic parts, such as polar or side charged chains (Lawal and Adebawale 2004).

#### **4.4.3 Oil absorption**

Oil absorption capacity of any food is important because it relies mainly on its capacity to entrap oil by a complex capillary attraction process. The ability of a food component to entrap oil is a good characteristic because oil acts as a flavour enhancer, a consistency trait and an important enhancer of mouth feel (Khattab and Arntfield, 2009).

The oil absorption capacities of soft and hard wheat flours were not significantly different (Figure 4.8). The wheat flours showed a higher oil absorption capacity than full fat morama bean flour. Full fat morama bean flour showed a much lower oil absorption capacity than all the other flours. Full fat morama bean flour has a high content of fat (28%) as shown in Table 4.1, and consequently did not absorb more oil. Defatted morama bean flour, from which much of the oil has been extracted, absorbed more oil than all the flours. Maruatona *et al.* (2009) obtained 2.7 g/g for oil absorption capacity of defatted unheated morama bean flour. The results were lower than what the findings on Figure 4.8 show.



**Figure 4.8: Oil absorption capacity of whole flours and wheat-morama composites flours**

Addition of full fat morama bean flour at all levels (10-40%) did not have any significant effect on the oil absorption capacity of the soft and hard wheat composite flours. There was a change in trend in oil absorption when defatted morama bean flour was substituted with soft wheat. Soft wheat with defatted morama bean flour composites showed more affinity to oil

than hard wheat with defatted morama bean flour. Both soft wheat and defatted morama bean flour have finer particle sizes (Figure 4.1). They therefore both provide a larger surface area which allows for more oil sorption. Wheat proteins are generally hydrophilic, and soft wheat has fewer amounts of proteins than hard wheat flour. Consequently soft wheat flour will absorb more oil than hard wheat flour, when substituted with defatted morama bean flour as shown in Figure 4.8.

Chowdhury *et al.*, (2012) reported that the high oil absorption suggests the hydrophobic structure of jackfruit seed protein in protein subunits and also added that the oil absorption of jackfruit seed flour and its blends suggested that it could find useful application in bakery products like cake and cookies.

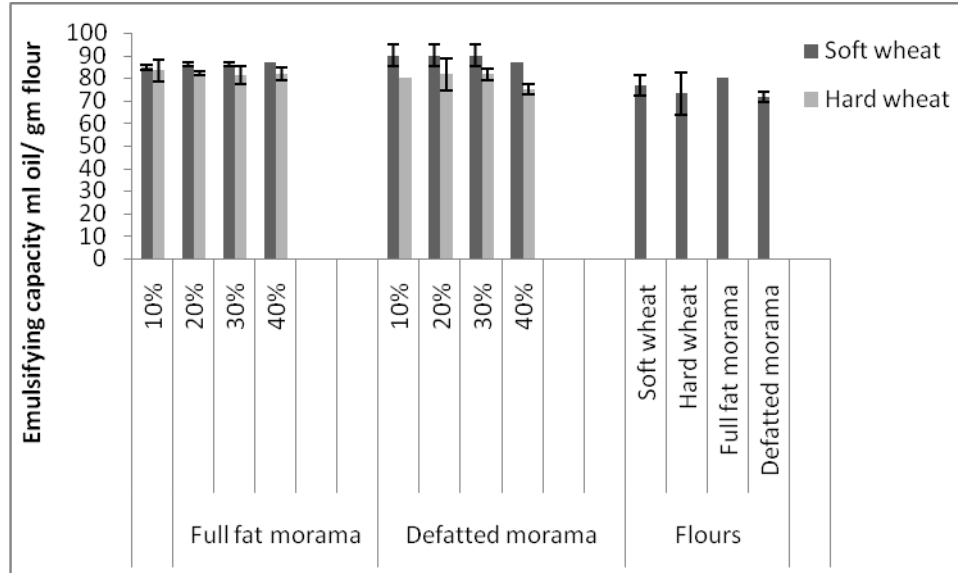
#### **4.4.4 Emulsifying properties (emulsifying capacity and emulsifying stability)**

##### **4.4.4.1 Emulsifying capacity**

Emulsion properties play a significant role in many food systems where the protein has the ability to bind fat such as in meat product, batter, dough and salad dressing (Sathe and Salunkhe, 1981; Odeleke and Odedeji, 2010).

Soft wheat and hard wheat flours in Figure 4.9 showed no significant difference in their emulsifying capacities.

Full fat morama bean flour had a higher emulsifying capacity compared to defatted morama bean flour and the wheat flours. Maruatona *et al.* (2009) found the emulsifying capacity of defatted unheated morama to be 59.9%. Figure 4.9 shows a higher emulsifying capacity (about 70%) for defatted morama bean flour compared to that reported by Maruatona *et al* (2009).



**Figure 4.9: Emulsifying capacity of whole flours and wheat-morama composites**

Addition of full fat morama bean flour improved the emulsifying capacities of both soft and hard wheat flours (Figure 9). The emulsifying capacities of soft and hard wheat flours were 76 and 74 ml/gm respectively. The composites of soft wheat showed a capacity above 80. Soft wheat and full fat morama bean flour composites showed better emulsifying capacities than hard wheat and full fat morama bean flour.

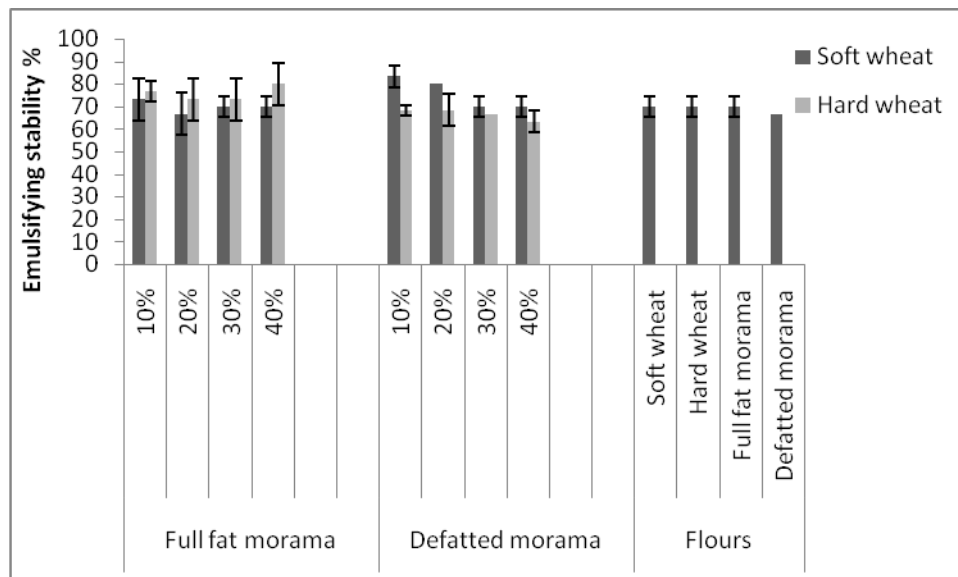
Addition of defatted morama bean flour showed a more improved emulsifying capacity with soft wheat than with hard wheat. Increasing the level of defatted morama bean flour did not significantly affect the emulsifying capacity of the composite flours for both soft and hard wheat. Hard wheat flour and defatted morama bean flour had a lower emulsifying capacity than soft wheat with defatted morama bean flour but generally, addition of morama bean flour to wheat flour improved the emulsifying capacity of the composite flours. Ali *et al.*, (2012)

reported that the emulsifying capacity of pearl millet was poor (7.47 oil ml/gm flour) but addition of 15% soybean protein improved the emulsifying capacity to 60.63ml oil/gm flour.

#### 4.4.4.2 Emulsifying stability

The emulsion stability normally reflects the ability of the proteins to impart strength to an emulsion for resistance to stress and changes (Sreerema *et al.*, 2012).

The data shown in Figure 4.10 indicate that there was no significant difference in the emulsifying stability of the wheat flours and full fat morama bean flour. Defatted morama bean flour showed a lower stability and this is probably because oil has been removed from it.



**Figure 4.10: Emulsifying stability of whole flours and wheat-morama composites**

Emulsions made using hard wheat and full fat morama bean flour composites were more stable than those made using soft wheat and full fat morama bean flour composites (Figure

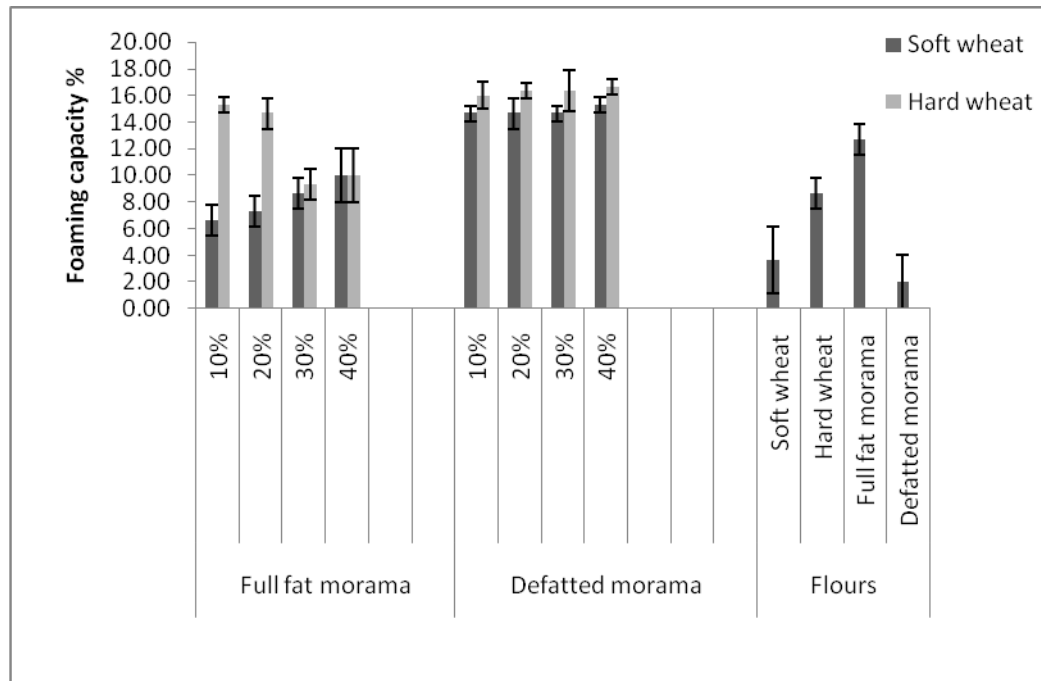
4.10). There was no significant change as the full fat morama bean flour levels were increased.

As defatted morama bean flour was added to soft wheat and hard wheat, emulsions of the soft wheat composites showed to be more stable than those of the hard wheat composites. The emulsions of 10 and 20 percent level of defatted morama bean flour with soft wheat were higher than emulsions of 30 and 40 percent level (Figure 4.10). Hard wheat and defatted morama bean flour composites showed lower stability and were not significantly different.

#### **4.4.5 Foaming properties (foaming capacity and foaming stability)**

Foam formation and stability generally depend on the interfacial film formed by proteins which keeps air bubbles in suspension and slows down the rate of coalescence (Sreerema *et al.*, 2012).

Figure 4.11 shows foaming capacity of whole flours, which significantly increased with the protein content of the flour, except for the defatted morama flour. Defatted morama bean flour was the one with the highest protein content but did not foam as was expected.

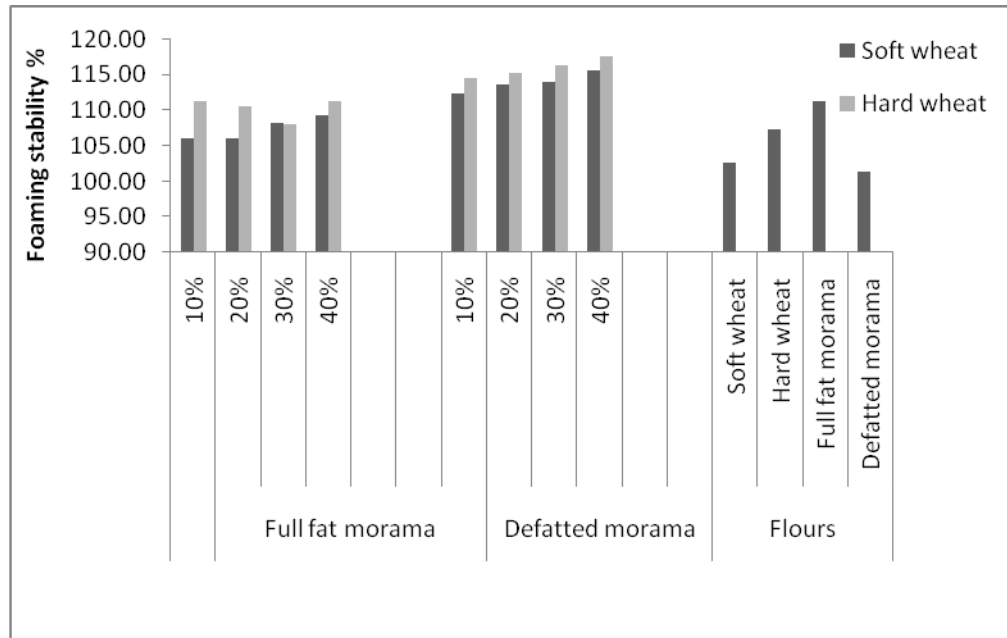


**Figure 4.11: Foaming capacity of whole flours and wheat-morama bean flour composites**

The defatted morama bean flour showed the least foaming capacity probably because the proteins being largely hydrophobic were less soluble.

The results in Figure 4.11 show that addition of full fat morama bean flour to soft wheat flour increased its capacity to foam. The increase of full fat morama bean flour in the blend seemed to increase the foaming capacity, though there were no significant differences among the composite flours. Hard wheat flour with full fat morama bean flour foamed more especially at the 10 and 20 percent level of substitution but were not significantly different. The foaming capacity reduced when full fat morama bean flour level in hard wheat was increased but still foamed more than the soft wheat composites. Addition of defatted morama bean flour to both soft and hard wheat showed a significant increase in foaming capacities and

this was the case for all the composites. Hard wheat flour composites foamed more and seemed not affected by the increment of defatted morama bean flour content.



**Figure 4.12: Foaming stability of wheat-morama bean flour composites and whole flours**

The stability of foams (Figure 4.12) showed that the composite flours that formed more foam were also more stable as well. Composites from full fat morama bean flour formed more stable foam.

Foams obtained from soft wheat and full fat morama bean flour composites were less stable in comparison with that obtained from the hard wheat composites.

With defatted morama bean composites, the soft wheat still formed less stable foams while hard wheat composites were more stable. The stability of foams obtained from both composites (i.e soft and hard wheat) increased with the increasing level of defatted morama

bean flour. In general all composites, especially hard wheat composites depicted high foam stability and may find applications in baked and confectionery products, especially those requiring high and stable foams.

#### **4.4.6 Least gelation concentration**

Least gelation concentration can be defined as the lowest protein concentration at which gel remained in the inverted tube was used as index of gelation capacity (Eltayeb *et al.*, 2011)

Whole flours of wheat showed a least gelation concentration of 2 percent while full fat morama bean flour and defatted morama bean flour had a least gelation concentration of 10 and 8 percent respectively.

At 10, 20, and 30 percent level of full fat morama bean flour blends with soft wheat the least gelation concentration was not affected, and remained at 2 percent. However at 40 percent level of full fat morama bean flour the least gelation concentration was raised to 8. For blends of soft wheat and defatted morama bean flour the least gelation concentration went up at 30 and 40 percent level of defatted morama bean flour to 6 and 8 percent respectively.

At 10, 20 and 30 percent level of full fat morama bean flour substitution with hard wheat flour, the least gelation concentration was not affected. An increase was however observed at 40 percent level of full fat morama bean flour. Substitution of hard wheat flour with 10 and 20 percent defatted morama bean flour did not affect the least gelation concentration but at 30 and 40 percent level of substitution the least gelation increased to 6 percent.

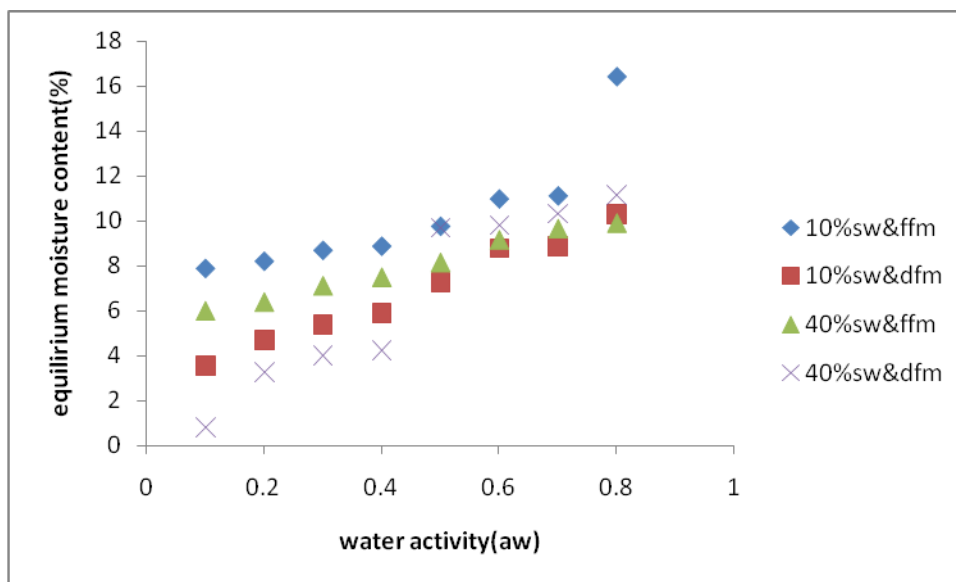
It was observed in Table 4.3 that the composites with full fat morama bean flour were only affected at 40 percent level and for composites with defatted morama bean flour a change was observed at 30 and 40 percent. The results obtained by Ali *et al.* (2012) indicated that pearl

millet flour level of concentration for gelation was significantly ( $P \leq 0.05$ ) lower than that of soybean flour, because pearl millet flour contained starch, which induced gelation due to starch-starch and/or starch-protein interactions.

#### **4.5 Sorption isotherms for soft wheat and morama bean flour at 30°C**

The moisture sorption isotherm of a product is usually valuable information on its storage stability as well as prediction of shelf life since they give information about the humidity–water activity relation, at a given temperature (Al-Muhtaseb *et al.*, 2004; Ayranci and Duman, 2004). In the water activity interval from 0.1 to 0.8, the equilibrium moisture content values increased with an increase in water activity at constant temperature. The behavior of the flours has been shown in Figure 4.13. The Figure 4.13 shows that the equilibrium moisture content of composite flours made using full fat morama bean flours in soft wheat were more stable to changes in water activity than those made using defatted morama bean flour at 30°C. The least stable composite flour was the one obtained with 40% defatted flour and soft wheat.

At the minimal change of water activity from 0.4 to 0.5 the equilibrium moisture content rapidly increased from 4% to 9%. This sorption behavior reflects some amount of hygroscopicity of the composite flour made using defatted morama bean flour, and will require stricter storage regimes and packaging than the full fat composites. The observed sorption behavior could be explained on the basis of differential particle size distribution as discussed in Figure 4.1. The defatted morama bean flours had finer particle size distribution than the full fat flours. Consequently they also had a larger surface to volume ratio, and would therefore adsorb more moisture at a given water activity and temperature than the full fat flour.



**Figure 4.13: Sorption isotherms for soft wheat and morama bean flour at 30°C**

#### **4.5.1 Sorption isotherm of soft wheat – morama bean flour based on GAB model**

The experimental data of the equilibrium water content of all samples at each water activity at 30°C are given in Table 4.6. These data were fitted to the sorption model suggested by GAB (Maroulis *et al.*, 1988; Chirife *et al.*, 1992) given as follows:

**Table 4.5 Least gelation capacity of whole flours and composite flours**

Sample	Least Gelation Concentration (%)
<b>Flour</b>	
Soft wheat	2
Hard wheat	2
Full fat morama	10
Defatted morama	8
<b>Soft wheat composites</b>	
10% Full fat morama	2
20% Full fat morama	2
30% Full fat morama	2
40% Full fat morama	8
10% Defatted morama	2
20% Defatted morama	2
30% Defatted morama	6
40% Defatted morama	8
<b>Hard wheat composites</b>	
10% Full fat morama	2
20% Full fat morama	2
30% Full fat morama	2
40% Full fat morama	4
10% Defatted morama	2
20% Defatted morama	2
30% Defatted morama	6
40% Defatted morama	6

$$M = \frac{X_m C K a^w}{(1 - K a^w)(1 - K a^w + C K a^w)}$$

$a^w$  = the water activity

$M$  = the water content on a dry basis at equilibrium

$X_m$  = water content when each sorption site contains one molecule (monolayer)

$C$  and  $K$  = sorption constants that are related to the energy interaction between the first and further sorbed molecules at the individual sorption site

After introducing the parameters the GAB equation then takes the form

$$(a^w/M) = \alpha a^{w2} + \beta \cdot a^w + \gamma$$

Where:

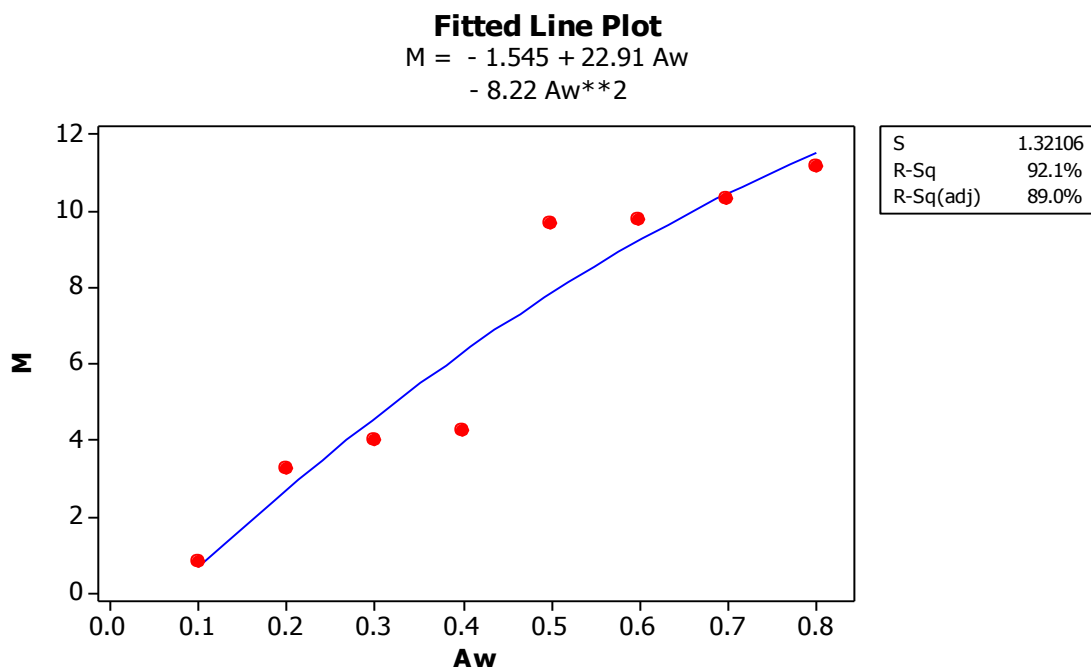
$$\alpha = (K/X_m) \cdot [(1/C) - 1]$$

$$\beta = (1/X_m) [1 - (2/C)]$$

$$\gamma = 1 / (X_m \cdot C \cdot K)$$

The experimental data was fitted to the GAB model and the isotherm obtained is shown in

Figure 4.14 for 40% full fat morama bean and soft wheat flour at 30°C.



**Figure 4.14 Sorption isotherm for 40 percent full fat morama bean flour at 30°C based on GAB model**

The values of parameters  $\alpha$ ,  $\beta$ ,  $\gamma$  obtained using nonlinear regression analysis of the experimental data in the  $a^w$  range 0.1-0.8 are given in Table 4.6. From the parameters  $\alpha$ ,  $\beta$ ,  $\gamma$  the monolayer capacity and its energy constant sets of values of  $X_m$ ,  $C$  and  $K$  were calculated through the following relations (Abramoviè and Klofutar, 2002):

$$K = \frac{(\sqrt{\beta^{**2} - 4(\alpha \cdot \gamma)} - \beta)}{2 \cdot \gamma}$$

$$C = \beta + 2$$

$$\gamma \cdot K$$

$$X_m = \beta / \gamma \cdot K \cdot C$$

The results in Table 4.6 show that as the full fat morama bean flour level was increased (10 and 40 percent full fat morama bean flour) the monolayer moisture content also increased (0.3823 to 0.9416).

An increase in monolayer moisture content was also observed when the level of the defatted morama bean flour was increased (from 0.9021-1.0522). The monolayer moisture content of defatted composites was higher than that of the full fat morama bean flour composites and this could be explained by the fact that the oil has been extracted and thus there is more surface area for sorption. To further explain this, defatted morama bean flour has finer particles (this was observed in Figure 4.1) and it has been reported by Hebrard (2003) that the finer the particles sizes the faster their sorption kinetics.

The (non-linear) regression of water activity ( $a^w$ ) on moisture content for soft wheat- full fat morama bean flour at 40 percent level of substitution at 30°C was adequate with an  $R^2=0.99$ . Similarly, the non-linear regression of water activity on moisture content for soft wheat-defatted morama bean flour at 10 percent level of substitution at 30°C was adequate with  $R^2=0.98$ . All the flours showed an  $R^2$  higher than 90% (Table 4.6).

#### 4.5.2 Sorption isotherm of soft wheat – morama bean flour based on BET model

The experimental data of the equilibrium water content of all samples at each water activity at 30°C (Table 4.6) were fitted to the BET equation (Anderson, 1946; Iglesias and Chirife, 1976)

given as: 
$$M = \frac{XmC \cdot aw}{(1-aw)(1-aw+C \cdot aw)}$$

Where:

$M$  = water content on a dry basis at equilibrium

$X_m$  = water content when each sorption site contains one water molecule (monolayer)

$a^w$  = water activity

$C$  = sorption constant which is related to the energy interaction between the first and further sorbed molecules at the individual sorption site.

**Table: 4.6 Values of parameters  $\alpha$ ,  $\beta$ ,  $\gamma$  of the GAB equation and their regression coefficients.**

Flour	$\alpha$	$\beta$	$\gamma$	K	C	$X_m$	$R^2$	SE
10SW&FFM	22.16	10.18	9.179	0.896	3.237783	0.382293	0.9	0.365362
10SW&DFM	1.289	8.355	2.782	0.163	20.42476	0.90208	0.98	0.127951
40SWandFFM	0.191	5.842	5.325	0.034	34.26733	0.941635	0.99	0.072726
40SWandDFM	-8.22	22.91	-1.545	0.368	-38.2948	1.052226	0.92	0.467044

*SW = soft wheat*

*FFM = full fat morama bean flour*

*DFM = defatted morama bean flour*

The equation takes the following form after introducing the parameters

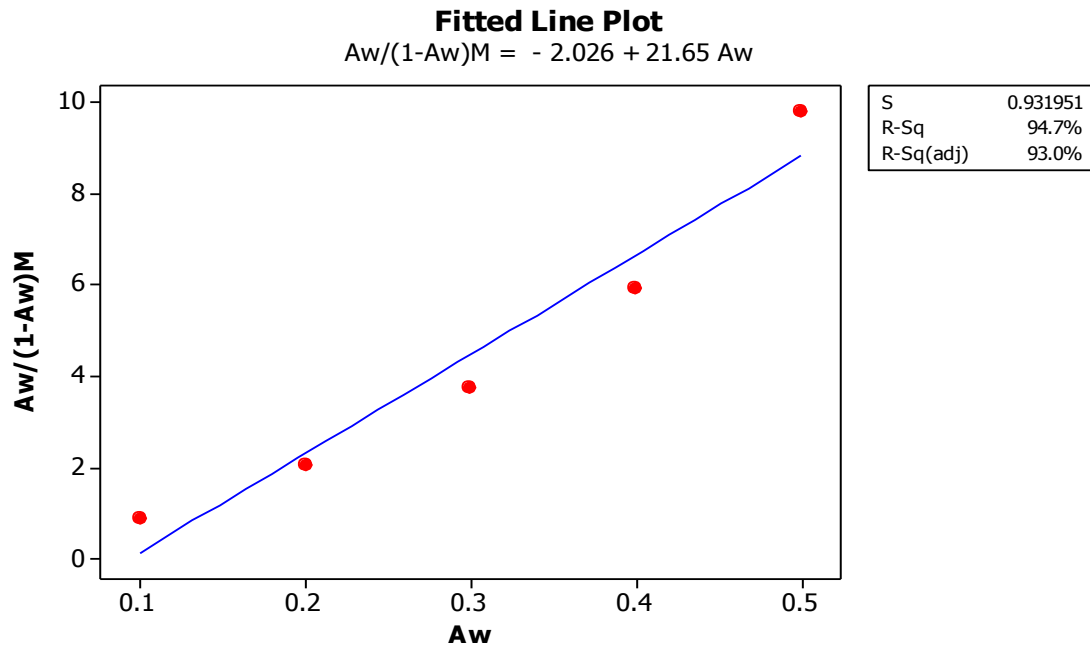
$$\frac{aw}{(1 - aw)M} = \alpha + \beta \cdot aw$$

Where:

$$\alpha = (1/X_m \cdot C)$$

$$\beta = (C-1)/X_m \cdot C$$

The experimental data were fitted to the BET model and the isotherm obtained is shown in Figure 4.15 for 40% full fat morama bean and soft wheat flour at 30°C.



**Figure 4.15: Sorption isotherm for 10 percent full fat morama bean flour at 30°C based on BET model**

The values of the parameters were obtained from the linear analysis after log transformation of the BET model. The monolayer moisture content and the energy value were calculated using the following relations:

$$Xm = 1/(\alpha+\beta)$$

$$C = (\alpha+\beta)/\alpha$$

In the water activity interval from 0.1 to 0.5, the equilibrium moisture content values increased with an increase in water activity at constant temperature.

Data in Table 4.7 show that the monolayer moisture content of soft wheat- full fat morama bean flour increased (0.04222 – 0.0494) with increase in the full fat morama bean flour level(10 and 40%). However, the pattern was broken for soft wheat- defatted morama bean flour as the monolayer moisture content decreased as the content of defatted morama bean flour was increased.

Both the full fat morama bean flour composites (10 and 40%) showed the best fit with the ( $R^2 = 0.95$ ) followed by the soft wheat- defatted morama bean flour at 10 percent level of substitution at 30°C at ( $R^2 = 0.92$ ). The 40 percent level of substitution of defatted morama bean flour was not a good fit compared to other flours ( $R^2 = 0.76$ ).

#### **4.5.3 Monolayer Moisture Content**

Modelling of sorption data of wheat-morama bean flour using BET and GAB equations allows the determination of monolayer moisture content values, ( $X_m$ ), which are the measure of sorption capability of the food material. The monolayer moisture content calculated from the BET and GAB models ranged between 0.040-0.054 g/g (dry basis) and 0.382-1.052 g/g (dry basis), respectively, at 30°C. Lomauro *et al.* (1985) reported that the monolayer moisture content values ( $X_m$ ) of starchy foods generally ranged from 0.032 to 0.160 g/g.

**Table 4.7: Values of parameters  $\alpha$ ,  $\beta$ ,  $\gamma$  of the BET equation and their regression coefficients**

Flour	A	$\beta$	$X_m$	C	$R^2$	SE
10%SWand FFM	2.026	21.66	0.042219	11.69102	0.95	0.329476
10%SWand DFM	1.941	16.56	0.054051	9.531685	0.92	0.319435
40%SWand FFM	1.823	18.41	0.049424	11.09874	0.95	0.274534
40%SWand DFM	3.332	21.22	0.04073	7.368547	0.76	0.780823

From the monolayer moisture contents given on the Tables 4.6 and 4.7, it can be deduced that the introduction of morama bean flour to wheat, regardless of whether defatted or full fat increases the sorption ability of wheat flour. It has been reported that the ( $X_m$ ) value given by the BET isotherm is always smaller than the monolayer value ( $X_m$ ) corresponding to the GAB isotherm, (Timmerman, 2003) and the results on Tables 4.6 and 4.7 agree with this.

#### 4.5.4 Best of fit

The moisture content models were compared according to their non-linear regression coefficient ( $R^2$ ) and the Standard errors of the fit (S.E). Based on these, the GAB equation gave a more satisfactory prediction of the water sorption behavior of all samples.

#### 4.6 Pasting properties of doughs

The pasting temperature is a measure of the minimum temperature required to cook a given starchy food sample (Sandhu, Singh and Malhi, 2005). It gives an indication of the minimum temperature and energy costs involved.

The results in Table 4.8 show that the pasting temperature of the wheat-moroma bean composite flours increased as the level of moroma bean flour increased. The pasting temperature of the composites ranged from 75.6°C to 85°C.

Peak viscosity, is the maximum viscosity during the heating cycle. The data show that the wheat flours had the highest peak viscosity of 360 and 351 for soft and hard wheat flour respectively. A maximum viscosity of 263 was observed when 5 percent level of full fat moroma flour was added to soft wheat and a maximum of 20 when the level of full fat moroma bean was increased to 40 percent.

During the 95°C hold period the viscosities of both the soft and hard wheat flour as well as the composites decreased. It is an indication of the stability of the starch gel during cooking (Zaidhul *et al.*, 2006). The ability of a mixture to withstand heating and shear stress that is usually encountered during processing is an important factor for many processes especially those requiring stable pastes. The final part of the cycle was the cooling from 95°C to 50°C (Table 4.8). The viscosity at the cooling stage indicates the ability of the starch based food to form a gel or paste after cooking and during cooling. This ranged between 310 and 298 BU for soft and hard wheat and 237 and 20 BU for wheat –moroma bean composite flours.

The viscosity after cooling to 50°C represents the setback or the viscosity of the cooked paste. The soft wheat and hard wheat showed higher setback viscosities (130 and 154) and this may be attributed to the high content of starch in wheat as compared to moroma bean and thus explains its behavior in gel formation (ranges from 0 to 112).

Higher values of breakdown are associated with higher peak viscosities which in turn are related to the degree of swelling of starch granules during heating (Ragaee and Abdel-Aal, 2006).

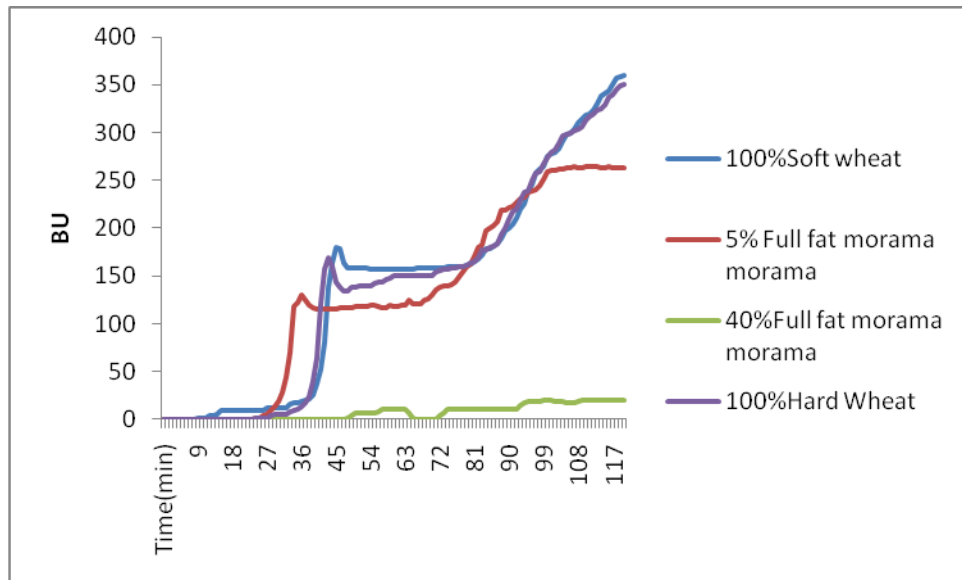
The low peak viscosity, breakdown value and set back value of the wheat morama composites indicate that the flour would be more stable when compared with wheat flour. The high setback value of wheat is desirable especially in bread making.

**Table: 4.8 Pasting properties of the whole flours and composite flours**

	<b>GT(°C)</b>	<b>PV(BU)</b>	<b>V 95°C(BU)</b>	<b>V 50°C(BU)</b>	<b>SV(BU)</b>
Soft wheat	44.8	360	180	310	130
Hard wheat	68.9	351	144	298	154
5% undefatted morama	77.5	263	125	237	112
10% undefatted morama	75.6	117	44	56	12
10% defatted morama	80.3	51	47	20	0
40% undefatted morama	85.9	20	6	20	14
40% defatted morama	81.7	26	21	26	5

*GT= gelation temperature, PV= peak viscosity, V= viscosity, SV= setback viscosity*

Figure 4.16 show the pasting behaviour of the wheat flours and the composite flours. Substantial decreases were observed in all of the pasting properties of the soft wheat flour as the level of full fat morama bean flour increased.



**Figure 4.16: Pasting behavior of whole flours and composite flours**

#### 4.7 Biscuit Dough formation

Dough forms an important transitional product between flour and biscuits. Mixing is one of the key stages in biscuit making. The gluten network that is formed during the mixing stage is responsible for the viscoelastic properties of the dough and determines its machinability as well as the final quality of the biscuits (Contamine *et al.*, 1995).

The dough should be sufficiently extensible to be easily sheeted without being so elastic that it prevents the biscuits from retracting after cutting. The absence of retraction is considered a good factor in the quality of biscuits. It determines the potential of biscuits for packaging. Contamine *et.al* (1995) concluded his findings that biscuit dough must be poorly elastic but sufficiently supple and extensible to allow an easy and stable shaping of the material.

Of the sixteen composite flours samples, only nine were used in the biscuits making. This is due to the fact that some of the flours were forming doughs that were not suitable for biscuits.

They were either too elastic or crumbly and thus got eliminated. Composites of defatted morama bean flour and hard wheat (10 and 20%) were too elastic and sticky, whereas 30 and 40% were too dry and crumbly forming a very hard ball of dough. Composites of hard wheat and full fat morama bean flour became soggy as the content of morama bean flour was increased and eventually giving a soft dough which is not suitable for rolling and shaping to make biscuits

#### **4.8 Physical analysis of the biscuits**

The thickness of the biscuits increased as the level of morama bean flour was increased. Generally the spread ratio decreased as the protein content was increased (Table 4.9). This was more pronounced with the samples prepared from defatted morama bean flour. When comparing the biscuits made from soft wheat (control) with those made from soft wheat and defatted morama bean flour, the spread ratios of those made from soft wheat and defatted morama bean flour were low. At 40 percent level of defatted morama in the mixture the ratio observed was 45.3. The spread ratio for soft wheat biscuits were at 58.23.

Similar results were reported by Atuonwu *et al.*, (2010) for cookies supplemented with defatted pumpkin (*Cucurbita pepo*) seed flour. For the composite flours, the increasing numbers of hydrophilic sites available due to increased protein content compete for the limited free water in dough (Zucco *et al.*, 2011). Rapid partitioning of free water of these hydrophilic sites occurs during dough mixing and increases dough viscosity, thereby limiting cracker biscuits spread and top grain formation during baking (Eissa *et al.*, 2007).

**Table 4.9 Physical analysis of biscuits**

	Width (mm)	Thickness (mm)	Spread ratio
10% Full fat morama	186.33	32	58.23
20% Full fat morama	178.3	31.67	56.32
30% Full fat morama	185.67	33.33	55.7
40% Full fat morama	178.67	34.67	51.52
Soft wheat*	178.67	30.67	58.26
10% Defatted morama	177	36.67	48.27
20% Defatted morama	174.33	37	47.25
30% Defatted morama	178	37.667	47.25
40% Defatted morama	173.67	38.33	45.3

#### 4.9 Colour analysis of biscuits

The colour of the biscuits was described by the parameters L, a and b where L represents lightness, a redness and b yellowness of the biscuits. It was observed that for both the full fat composites and defatted composites, lightness of the biscuits decreased as the content of morama bean flour was increased in the composite. The yellowness increased as the whiteness decreased. The L\* values for soft wheat and full fat morama bean flour composites ranged between 88.7 and 83.2 whereas those for soft wheat and defatted morama bean flour composites were ranging between 99.26 and 91.99.

The data in Table 4.10 show an increase in b\* values as the L\* values were decreasing. For the full fat morama bean composites the range for b\* values was between 31.11 and 44.54.

For defatted morama bean flour composites the  $b^*$  values ranged from 39.8 to 42.2. The results suggest that the presence of the oil in the flour was responsible for the colour magnitudes that were observed and there were differences between samples with defatted morama bean flour and those with full fat morama bean flour.

**Table 4.10: Colour of wheat-morama composite flour biscuits**

Sample	L	a	b
10% Full fat morama	88.72±0.03 <sup>a</sup>	8.23±0.08 <sup>i</sup>	31.11±0.09 <sup>c</sup>
20% Full fat morama	88.24±0.03 <sup>b</sup>	8.46±0.06 <sup>g</sup>	41.31±0.09 <sup>e</sup>
30% Full fat morama	85.98±0.03 <sup>c</sup>	9.22±0.03 <sup>e</sup>	42.47±0.06 <sup>f</sup>
40% Full fat morama	83.27±1.02 <sup>c</sup>	10.39±0.07 <sup>f</sup>	44.54±0.17 <sup>h</sup>
Soft wheat*	92.99±0.09 <sup>e</sup>	7.46±0.09 <sup>d</sup>	43.95±0.05 <sup>g</sup>
10% Defatted morama	99.26±0.01 <sup>f</sup>	3.3±0.04 <sup>a</sup>	39.83±0.04 <sup>a</sup>
20% Defatted morama	95.75±0.04 <sup>g</sup>	5.27±0.01 <sup>c</sup>	41.53±0.10 <sup>b</sup>
30% Defatted morama	93.89±0.02 <sup>h</sup>	4.59±0.08 <sup>b</sup>	42.08±0.08 <sup>d</sup>
40% Defatted morama	91.99±0.03 <sup>d</sup>	9.83±0.04 <sup>h</sup>	42.21±0.09 <sup>e</sup>

#### 4.10 Sensory evaluation of biscuits

Biscuits prepared from soft wheat and wheat-morama bean composite flour in various combinations were subjected to sensory evaluation for appearance, colour, crispiness, texture, taste and overall acceptance.

For the purpose of biscuits making the behavior of doughs were evaluated. , some would not mix well; some would become too sticky to work with. It is from these factors that some doughs were rejected and remained with just eight composites that were well suited with the recipe of biscuits. Composites of hard wheat and defatted morama bean flour were elastic and dry (10 and 20%) requiring more flour so as not to stick to rolling pin,30 and 40% were too dry and crumbly requiring more shortening so they can be rolled our easily. Composites of hard wheat with full fat morama bean flour were too soft, even softer as the content of full fat morama bean flour was increased, requiring more flour to thicken them and roll them out evenly to make biscuits. It is these eight samples (composites of soft wheat and full fat morama bean flour and composites of soft wheat and defatted morama bean flour 10,20 30 and 40%) plus the control that were later used for sensory evaluation.

#### **4.11 Appearance**

Data on the appearance of biscuits show that they were significantly different. Table 4.11 show that at 40 percent level of defatted morama bean flour the biscuits were more favored, followed by the 20 percent level of full fat morama bean flour. The appearance of biscuits was judged based on the smoothness of the biscuits, if the biscuits have cracks and if they were appealing to the eye. The biscuits made from soft wheat and defatted morama bean flour at 20 and 30 percent level though received the lowest scores of 4.90 and 4.95 respectively

#### **4.12 Colour**

The analysis of variance for the sensory scores of colour of the biscuits made from different levels of morama revealed that there was a significant difference in the colour of biscuits. The

biscuits from 40% defatted morama bean flour substitution were scored highest (6.85) in terms of colour as seen in Table 4.11 which basically meant it is the kind of colour a consumer would be more likely to buy when found in store.

#### **4.13 Crispiness**

Results in Table 4.11 show that the biscuits prepared from soft wheat and full fat morama bean flour were generally well accepted for crispiness with the ones at 20 percent level of substitution receiving the highest score of 6.7. The soft wheat and defatted morama bean flour composites were less favored

The biscuits from soft wheat and full fat morama bean flour may be crispier because of the oil content of morama which is already high and the rolling which thinned them out, the defatted with less oil content thus just remained hard and difficult to break or crumble.

#### **4.14 Texture**

The same pattern that was observed with crispiness, were observed for texture, since crispness is a textural attribute. Soft wheat and defatted morama bean flour biscuits were less favored and the ones from soft wheat and full fat morama bean flour well received and the 20 percent level of full fat morama bean flour being scored the highest (6.6). All the composites were treated the same (that is same time for mixing, same amount of ingredients and same baking time) regardless of the pre treatment of the flour and the defatted morama bean composites clearly showed they needed more fat during biscuits making and thus resulted in biscuits that are hard. Biscuits from composites that had 40 percent defatted morama bean flour were scored the least (4.7) in terms of texture which meant were probably too hard.

#### **4.15 Taste**

Data in Table 4.11 showed that biscuits from soft wheat and 20 percent level of full fat morama bean flour were the most favored with a score of 6.6. The soft wheat and 40 percent level of defatted morama bean flour substitution was least scored at 4.7 but all other biscuits were accepted for taste.

#### **4.16 Overall acceptance of the biscuits**

Although all the treatments were accepted, biscuits made from soft wheat and 20 percent level of full fat morama bean composite flour were best accepted by the panel (Table 4.11). The observation was that the overall acceptance was not a different quality parameter on its own; it might have been affected by individual trends like texture, crispiness.

**Table 4.11: Sensory acceptability ratings of biscuits made from soft wheat- morama bean composite flour**

	<b>Appearance</b>	<b>Colour</b>	<b>Crispiness</b>	<b>Texture</b>	<b>Taste</b>	<b>Overall Acceptance</b>
10% Full fat morama	6.015±1.94 <sup>a</sup>	5.815±2.291 <sup>a</sup>	5.692±2.433 <sup>a</sup>	6.600±1.902 <sup>ab</sup>	6.415±2.015 <sup>ab</sup>	6.431±1.785 <sup>ab</sup>
20% Full fat morama	6.785±1.85 <sup>b</sup>	6.554±2.187 <sup>ab</sup>	6.662±1.906 <sup>b</sup>	6.631±1.917 <sup>ab</sup>	6.631±1.917 <sup>ab</sup>	6.615±1.974 <sup>a</sup>
30% Full fat morama	5.923±2.056 <sup>a</sup>	6.200±2.181 <sup>ab</sup>	6.431±1.620 <sup>b</sup>	6.185±1.776 <sup>ab</sup>	6.200±1.864 <sup>ab</sup>	6.062±1.886 <sup>ab</sup>
40% Full fat morama	5.123±2.260 <sup>c</sup>	5.385±2.460 <sup>c</sup>	5.892±2.047 <sup>ab</sup>	6.031±2.099 <sup>b</sup>	6.200±1.938 <sup>ab</sup>	5.769±2.082 <sup>bc</sup>
Soft wheat 10% Defatted morama	6.308±1.819 <sup>ab</sup>	5.985±2.388 <sup>ac</sup>	6.369±1.892 <sup>b</sup>	5.954±1.948 <sup>b</sup>	6.615±1.924 <sup>a</sup>	6.400±1.703 <sup>ab</sup>
20% Defatted morama	5.877±2.019 <sup>a</sup>	6.692±1.686 <sup>ab</sup>	5.277±2.183 <sup>a</sup>	6.538±1.532 <sup>ab</sup>	6.600±1.487 <sup>ab</sup>	6.246±1.458 <sup>ab</sup>
30% Defatted morama	4.908±2.170 <sup>c</sup>	4.908±2.383 <sup>c</sup>	4.292±2.435 <sup>c</sup>	5.492±2.173 <sup>bc</sup>	5.446±2.208 <sup>bc</sup>	5.431±2.236 <sup>bc</sup>
40% Defatted morama	4.954±2.308 <sup>c</sup>	5.262±2.056 <sup>c</sup>	3.338±2.181 <sup>d</sup>	5.769±2.324 <sup>b</sup>	5.708±2.310 <sup>b</sup>	5.051±2.246 <sup>c</sup>
40% Defatted morama	6.846±2.279 <sup>b</sup>	6.846±2.071 <sup>b</sup>	5.231±2.120 <sup>a</sup>	4.708±2.234 <sup>c</sup>	4.692±2.249 <sup>cd</sup>	5.154±2.470 <sup>c</sup>

*Means followed by different letters are significantly different 9-point hedonic scale*

*1= dislike extremely 2= dislike very much 3= dislike moderately*

*4= dislike slightly 5= neither like nor dislike 6= like slightly*

*7=like moderately 8= like very much 9= like extremely*

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Conclusion

Composite flours of wheat and morama bean flour showed varied physical and functional properties depending on whether the morama beans were defatted or not. The type of wheat flour also influenced some of the functional behavior of the composite flour.

Addition of full fat morama bean flour to both soft and hard wheat shifted the particle distribution to the coarse particles whilst defatted morama bean flour shifted it to finer particle distribution.

Functional properties (bulk density, foaming properties, water and oil absorption, emulsifying properties) of composite flours were related to the protein content, oil content and the particle size distribution of the flours.

For all the flours there was a significant effect of water activity on the equilibrium moisture sorption in the range of the water activity studied. The equilibrium moisture content of full fat morama bean composite flour was more stable than the defatted composite flours with changes in water activity. Composite flours made using defatted morama flour were relatively more hygroscopic. The presence of morama bean flour in wheat composite flours increased the monolayer value of the flour. The GAB model was more suitable for describing the relationship between the equilibrium moisture content and the water activity, for the soft wheat-morama bean flour at 30°C.

The amount of morama bean flour influenced the gelation and the viscosity characteristics of composite flours. Pasting characteristics were reduced as the morama bean flour was increased.

Soft wheat flour can only be substituted up to 20 percent with full fat morama bean flour without changing its organoleptic properties. This composite gave the best combination for biscuits making.

These findings show that morama bean flour has a good potential in food applications. Such successful food applications of morama bean flour will enhance its utilization and improve food and nutrition security especially for the people in areas where it grows.

## **5.2 Recommendations**

1. Studies on dehulling characteristics of morama bean seeds should be taken into consideration as shelling takes most of the time and if the product goes commercially would be a big setback. Shelling increases the oil extraction efficiency and reduces wear in the expeller as the husks are abrasive, and the morama shells are particularly harder. A wide range of manual and mechanical decorticators are available and one can be designed for morama too.
2. More work on nutritional quality of morama bean protein and the efficacy should be looked into as little is known on this.
3. More work on sorption isotherm modelling at different temperatures for wheat-morama bean composites should be considered since the storage and transportation temperatures are never stable.
4. Wheat morama composites can find use in the baby industry, complementary foods because of the paste that they produce and the protein content they will bring into the blends which is desirable, I recommend that this be considered and also from the functional

properties morama bean flour composites showed good foaming properties and maybe might be useful in the making of foamy products like fudges.

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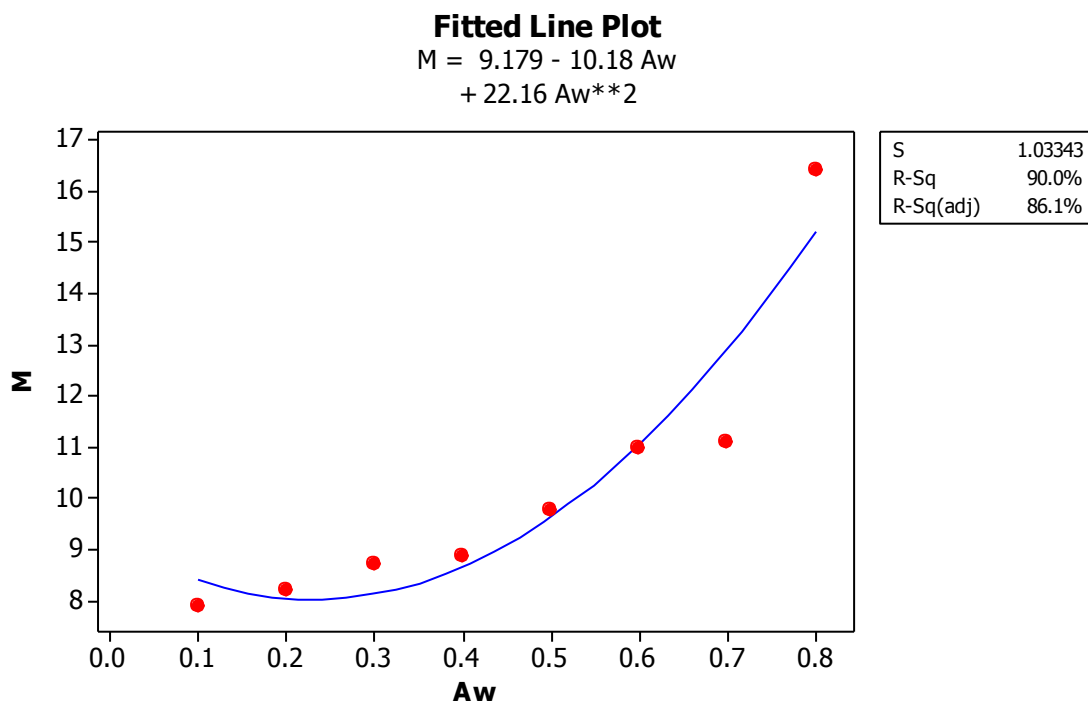
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## APPENDICES

Appendix 1ISOTHERMS BASED ON GAB EQUATION10% SOFT WHEAT AND FULL FAT MORAMA

The regression equation is  
 $M = 9.179 - 10.18 Aw + 22.16 Aw^{**2}$

S = 1.03343    R-Sq = 90.0%    R-Sq(adj) = 86.1%

## Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	48.2539	24.1269	22.59	0.003
Error	5	5.3399	1.0680		
Total	7	53.5937			

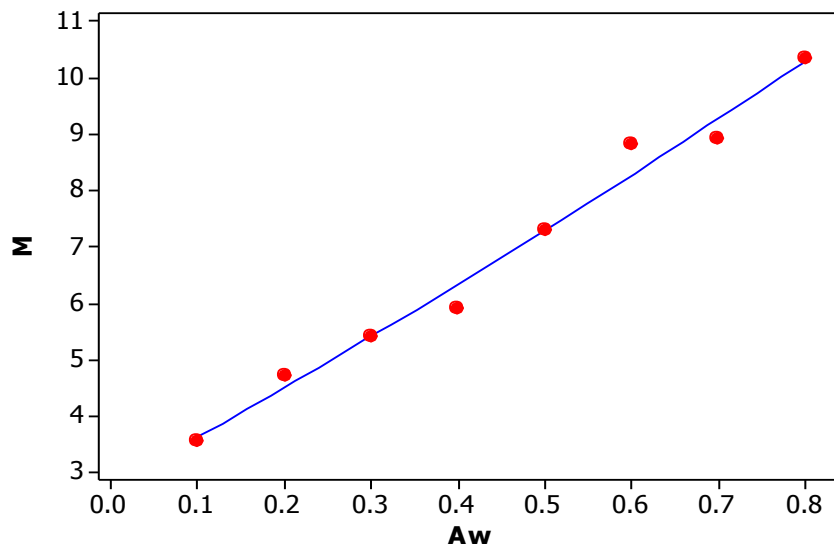
## Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	40.0059	17.67	0.006
Quadratic	1	8.2480	7.72	0.039

## 2. 10% SOFT WHEAT AND DEFATTED MORAMA

### Fitted Line Plot

$$M = 2.782 + 8.355 Aw + 1.289 Aw^{**2}$$



S	0.361976
R-Sq	98.3%
R-Sq(adj)	97.6%

### Polynomial Regression Analysis: M versus Aw

The regression equation is

$$M = 2.782 + 8.355 Aw + 1.289 Aw^{**2}$$

$$S = 0.361976 \quad R\text{-Sq} = 98.3\% \quad R\text{-Sq}(\text{adj}) = 97.6\%$$

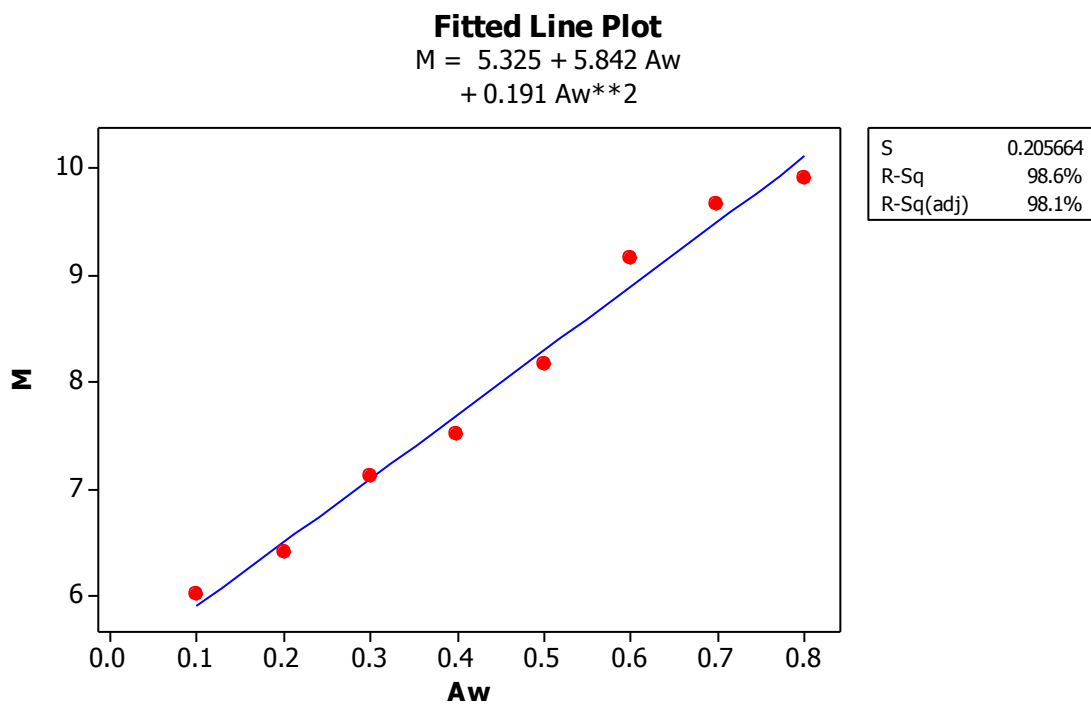
#### Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	38.0532	19.0266	145.21	0.000
Error	5	0.6551	0.1310		
Total	7	38.7083			

#### Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	38.0253	334.02	0.000
Quadratic	1	0.0279	0.21	0.664

### 3. 40% SOFT WHEAT AND FULL FAT MORAMA



#### Polynomial Regression Analysis: M versus Aw

The regression equation is

$$M = 5.325 + 5.842 Aw + 0.191 Aw^{**2}$$

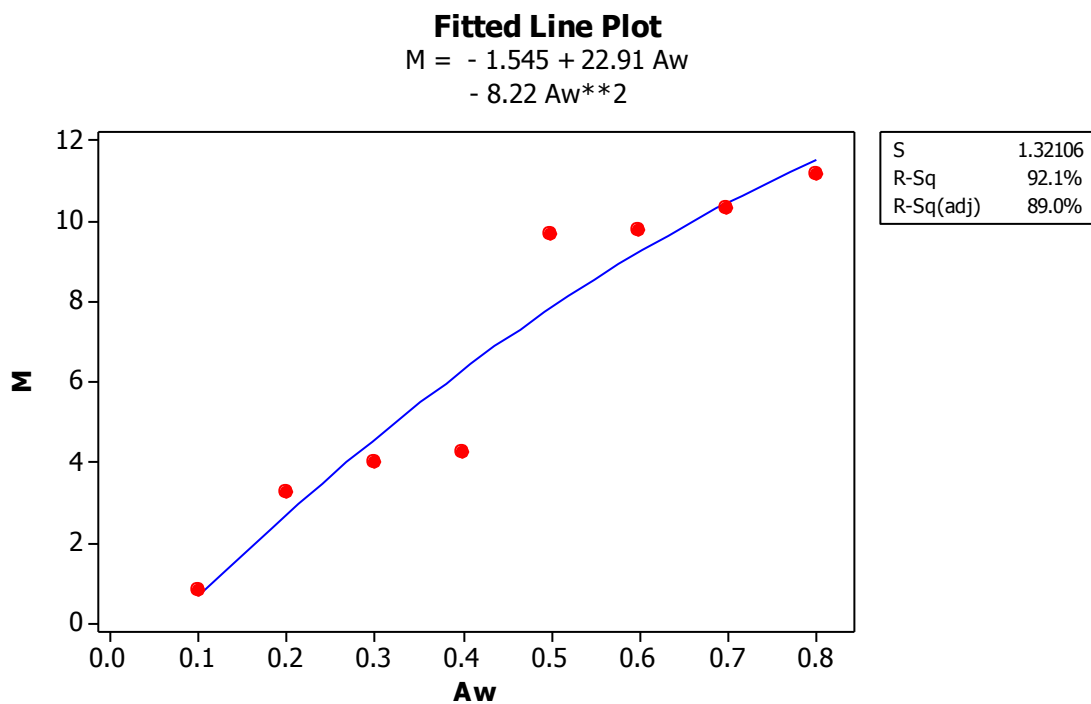
$$S = 0.205664 \quad R-Sq = 98.6\% \quad R-Sq(adj) = 98.1\%$$

#### Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	15.1875	7.59377	179.53	0.000
Error	5	0.2115	0.04230		
Total	7	15.3990			

#### Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	15.1869	429.62	0.000
Quadratic	1	0.0006	0.01	0.909

**4. 40% SOFT WHEAT AND DEFATTED MORAMA****Polynomial Regression Analysis: M versus Aw**

The regression equation is  
 $M = -1.545 + 22.91 Aw - 8.22 Aw^{**2}$

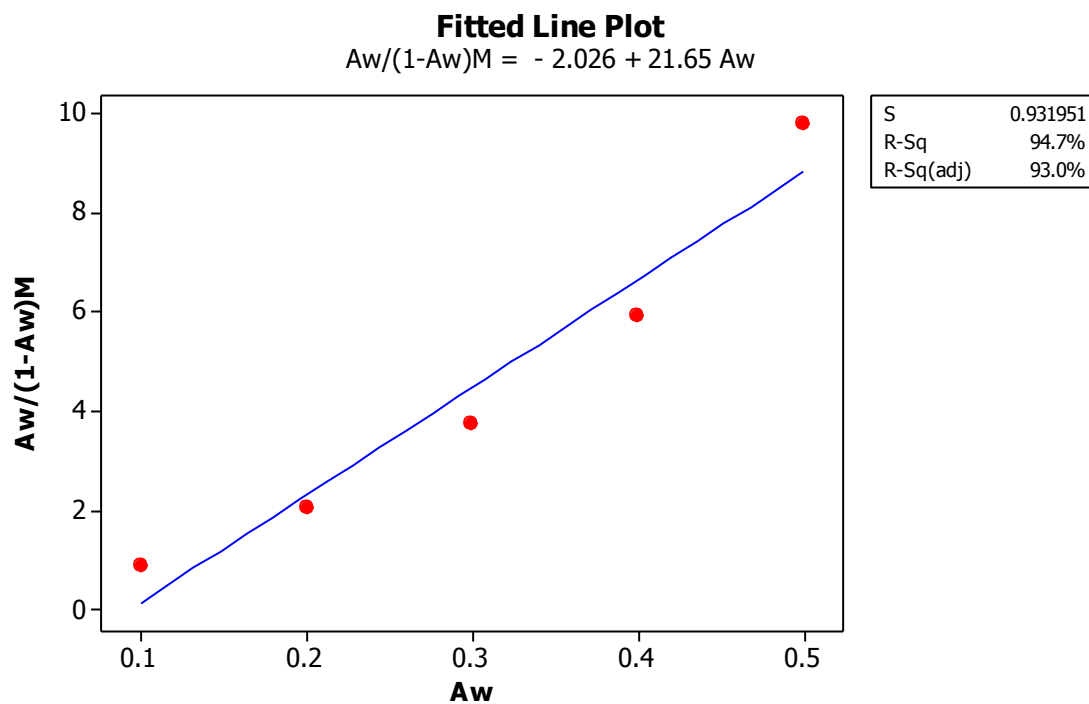
S = 1.32106    R-Sq = 92.1%    R-Sq(adj) = 89.0%

## Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	102.147	51.0733	29.26	0.002
Error	5	8.726	1.7452		
Total	7	110.873			

## Sequential Analysis of Variance

Source	DF	SS	F	P
Linear	1	101.011	61.46	0.000
Quadratic	1	1.136	0.65	0.456

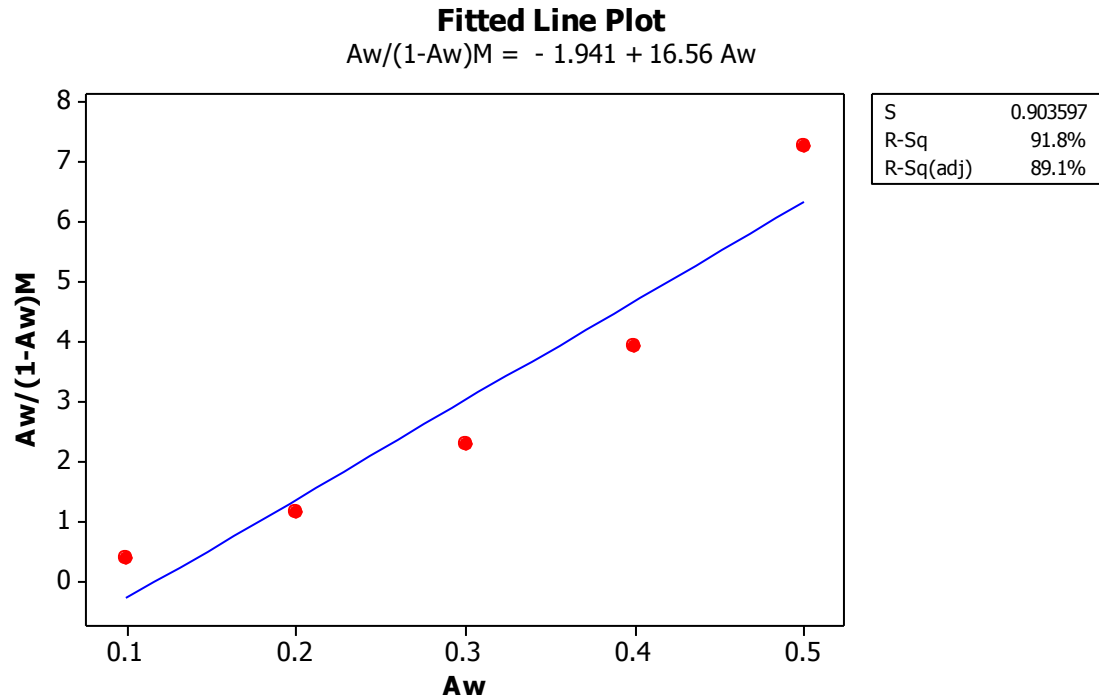
**SORPTION ISOTHERM BASED ON BET EQUATION****10% SOFT WHEAT AND FULL FAT MORAMA****Regression Analysis:  $Aw/(1-Aw)M$  versus  $Aw$** 

The regression equation is  
 $Aw/(1-Aw)M = - 2.026 + 21.65 Aw$

S = 0.931951    R-Sq = 94.7%    R-Sq(adj) = 93.0%

## Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	46.8769	46.8769	53.97	0.005
Error	3	2.6056	0.8685		
Total	4	49.4825			

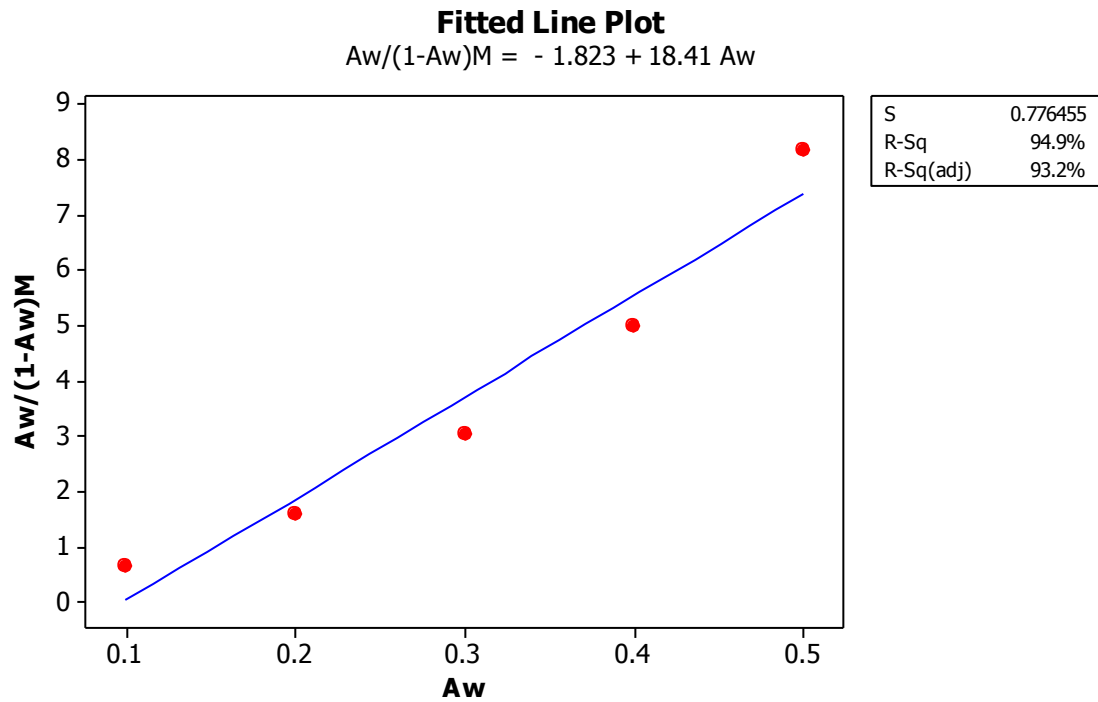
**10% SOFT WHEAT AND DEFATTED MORAMA****Regression Analysis: Aw/(1-Aw)M versus Aw**

The regression equation is  
 $Aw/(1-Aw)M = - 1.941 + 16.56 Aw$

S = 0.903597    R-Sq = 91.8%    R-Sq(adj) = 89.1%

## Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	27.4195	27.4195	33.58	0.010
Error	3	2.4495	0.8165		
Total	4	29.8690			

**40% SOFT WHEAT AND FULL FAT MORAMA****Regression Analysis: Aw/(1-Aw)M versus Aw**

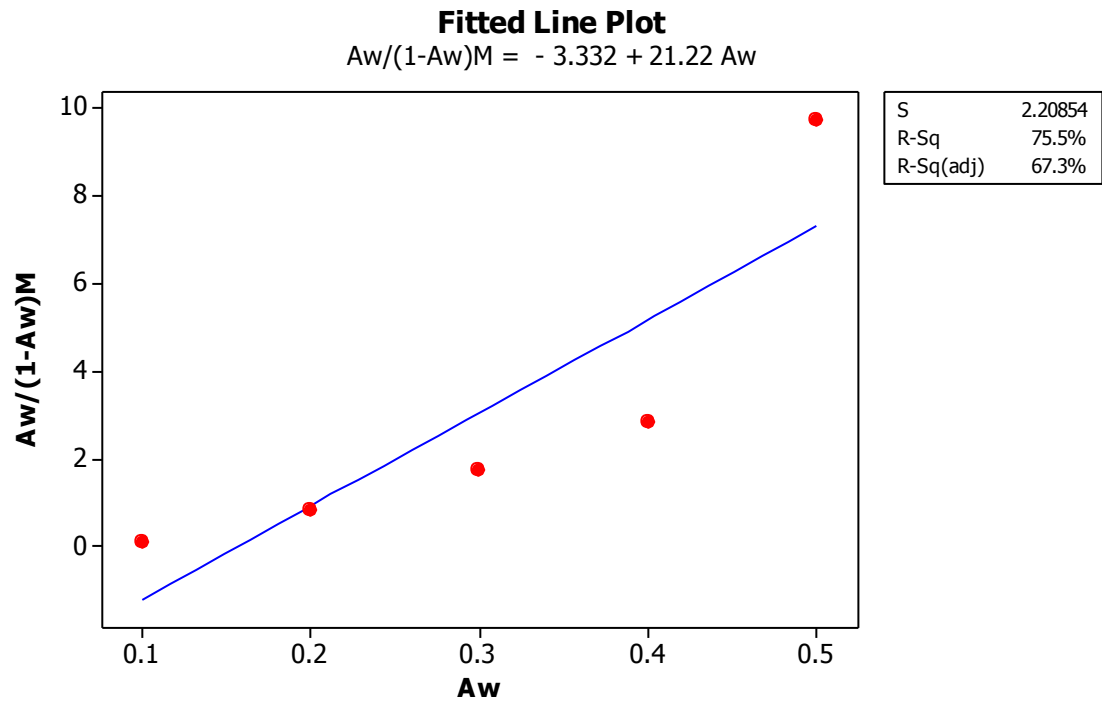
The regression equation is

$$Aw/(1-Aw)M = -1.823 + 18.41 Aw$$

$$S = 0.776455 \quad R-Sq = 94.9\% \quad R-Sq(adj) = 93.2\%$$

## Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	33.9055	33.9055	56.24	0.005
Error	3	1.8086	0.6029		
Total	4	35.7141			

**40% SOFT WHEAT AND DEFATTED MORAMA****Regression Analysis: Aw/(1-Aw)M versus Aw**

The regression equation is

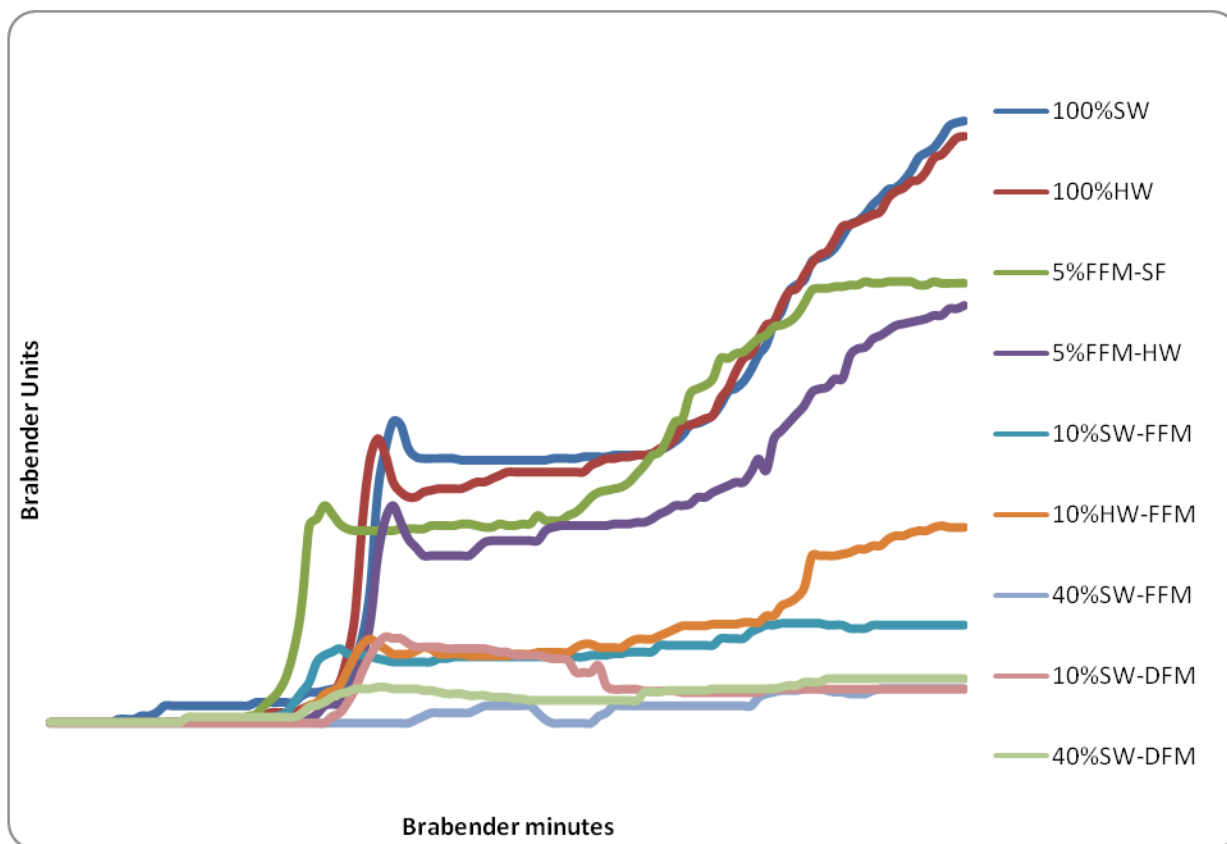
$$Aw/(1-Aw)M = -3.332 + 21.22 Aw$$

$$S = 2.20854 \quad R-Sq = 75.5\% \quad R-Sq(adj) = 67.3\%$$

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	45.0190	45.0190	9.23	0.056
Error	3	14.6330	4.8777		
Total	4	59.6520			

## Appendix 2

**PASTING BEHAVIOR OF THE WHEAT FLOURS AND THE WHEAT –MORAMA  
BEAN COMPOSITE FLOURS**

### Appendix 3. Sensory Ballot sheet

BALLOT SHEET FOR SENSORY ACCEPTABILITY OF WHEAT-MORAMA BEAN  
BISCUITS

DEPARTMENT OF NUTRITION AND FOOD SCIENCE

Panelist .....

UNIVERSITY OF GHANA

Sample: Wheat-Morama biscuits formulation

Date .....

Instructions:

**NOTE: DO NOT ATTEMPT THIS EVALUATION IF YOU ARE ALLERGIC TO  
NUTS**

You have been presented with 9 coded samples of Wheat-Morama cookies formulations made from flours of wheat and Morama bean. Please assess the attributes of the various biscuits formulations. Rinse your mouth with water after evaluating each sample. Please rank the intensity of your liking for each attribute of the cookie formulation by using the 9-point hedonic scale given:

1= dislike extremely

2= dislike very much

3= dislike moderately

4= dislike slightly

5= neither like nor dislike

6= like slightly

7= like moderately

8= like very much

9= like extremely

### A. APPEARANCE

Please look at the samples and indicate your **liking** for *appearance* (in terms of smoothness, cracks on the surface) by writing the codes of the samples in the spaces below and ranking the score from the 9-point hedonic scale in the space below the code.

Sample        .....        .....        .....        .....        .....        .....        .....

Rank            .....        .....        .....        .....        .....        .....        .....

### B. COLOUR

Please look at the samples and indicate your **liking** for *colour* by writing the codes of the samples in the boxes below and ranking the score from the 9-point hedonic scale in the space below the code.

Sample        .....        .....        .....        .....        .....        .....        .....

Rank            .....        .....        .....        .....        .....        .....        .....

### C. AROMA

Please take a sample and place it very close to your nose, take a sniff and indicate your **liking** for *aroma* by writing the codes of the samples in the boxes below and the score from the 9-point scale in the space below the code.

### D. CRISPINESS (*firm but easily broken or crumbled; brittle*)

Please break the sample with your hands, and indicate your **liking** for *crispiness* by writing the codes of the samples in the boxes below and ranking the score from the 9-point hedonic scale in the space below the code.

Sample .....  
.....

Rank .....  
.....

### E. TEXTURE

Please break a small piece of the sample, put it in the mouth and indicate your **liking** for *texture* as you chew by writing the codes of the samples in the boxes below and ranking the score from the 9-point hedonic scale in the space below the code.

Sample ..... Sample .....

Rank ..... Rank .....

### F. TASTE

Please chew the sample and indicate your **liking** for *taste* (sweetness, off taste, aftertaste) by writing the codes of the samples in the boxes below and ranking the score from the 9-point hedonic scale in the space below the code.

Sample ..... Sample .....

Rank ..... Rank .....

### G. OVERALL ACCEPTANCE

Please indicate your *overall liking* by writing the codes of the samples in the boxes below and ranking the score from the 9-point hedonic scale in the space below the code.

Sample ..... Sample .....

Rank ..... Rank .....

Comments

.....  
.....  
.....  
.....

Thank you for your time