STORAGE AND PACKAGING STUDIES ON DEGERMED MAIZE FLOUR

BY

PAUL. A. F. HOUSSOU

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JUNE, 2000

DECLARATION

I declare that this thesis is the result of my own research work carried out in the Department of Nutrition and Food Science, University of Ghana, Legon under the supervision of Professor G.S. Ayernor of the Department of Nutrition and Food Science. References cited have been duly acknowledged.

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PAUL A .F. HOUSSOU

(STUDENT)

……………………………

Prof. G.S. AYERNOR

(SUPERVISOR)

DEDICATION

This work is dedicated to my Heavenly Father, God Almighty who is the source of my strength and to my entire family.

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First and foremost, I thank and praise the Almighty God for bringing me this far in my education.

I do wish to recognize specifically the support of Prof. G.S. Ayernor, my supervisor and Professor at the Department of Nutrition and Food Science, University of Ghana, Legon, without his support and direction, ventures of this kind would not have been possible.

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ABSTRACT

Preservation and storage of whole maize flour poses a lot of problems owing to its fat content among other factors. This study therefore sought to develop processing and preservation procedures for maize flour and also to determine the effect of storage time on some quality indices of the product.

Degermed maize flour was prepared using a maize sheller and grits obtained milled into flour using a disc attrition mill and non-degermed maize flour prepared by direct milling of the maize into the flour. Flour drying was by oven and solar drying at 40°C for 4 hours and 30-45°C for 6 hours respectively. Chemical (proximate) analyses were determined using AOAC (1990) methods. Physical and functional properties of the maize flours were determined. Water sorption characteristics were also determined and related to storage.

The proximate composition of degermed maize flour showed lower fat, ash, and fiber content as compared to non-degermed maize flour (control). The percentage fat, ash, and fiber content were 1.42 ± 0.34, 0.2 ± 0.03, and 0.51 ± 0.01 respectively for degermed maize flour and 6.02 ± 0.63, 1.51 ± 0.16, and 1.84 ± 0.05 for non-degermed flour. Carbohydrate content was relatively higher (79.96%) in degermed maize flour than in the non-degermed maize flour which was 74.14% as a result of germ and hull.

The moisture sorption isotherm of degermed maize flour (DF) and non-degermed maize flour (nDF) followed a type (II) isotherm pattern (Labuza,1984). The water absorption pattern of DF and nDF in relation to the various Water Activities (Aw) was higher for DF as compared to nDF at Aw between 0.11 to 0.71 indicating that the DF is more hygroscopic. DF showed a higher monolayer value of 3.9g/100 solid matter as compared to nDF which was 2.98 g/100 solid matter. The heat of sorption of DF and nDF decreased with increasing moisture concentration. But at low Aw ranging from 0.11 to 0.44 the total heat of sorption of nDF is higher than that of DF.

Water vapor permeability test conducted on packaging materials used, showed that low Density Polyethylene has a higher water vapor transmission rate than Polypropylene (PP) and High Density (HD) which had similar rates. The initial moisture content of the flour samples ranged between 10.39 ± 0.49% (solar dried sample) and 10.74 ± 0.87% (Oven dried sample) for nDF, and 11.0 ± 0.6 % (solar dried sample) and 10.57 ± 0.78 % (Oven

dried sample) for DF when packaged in HD and PP packaging materials and stored at 29 ± 1°C. After six months storage period, the final moisture content attained by both flour samples were between 10.63 ± 0.63 % (Solar dried sample) and 12.61± 0.77% (Oven dried sample) for nDF and 12.37 ± 0.31% (Oven dried sample) and 11.27 ± 0.48% (solar dried sample) for DF. These values are less than 13% moisture standard set for the storage of cereal flour (Kent, *et al.*, 1970). After 6 months storage the non-degermed maize flour samples showed high percentage free fatty acid content (0.54 ± 00 %) as compared to degermed maize flour samples (0.44 ± 00 %) owing to the initial differences of fat content of the flour samples.

Based on the results obtained it can be concluded that degermed maize flour can be stored for at least 6 months or longer with minimal changes in quality; and that the degermed maize flour has a higher potential for storage than the non-degermed maize flour.

CHAPTER ONE

1.0 INTRODUCTION

Maize *(Zea mays L.)* belongs to the grass family *(gramineae*). It has a fibrous root system and an erect stalk with a single leaf at each node and leaves in two opposite ranks. Maize provides nutrients for humans and animals and serves as a basic raw material for the production of starch, oil and protein, alcohol, beverages, food sweeteners and, more recently, fuel.

1.1 Maize : Origin and Production

After wheat and rice, maize is the third most important agricultural product in the world. Millions of people in Mexico, South Africa and Asia depend on it. (FAO, 1991).

Originating from South America maize *(Zea mays. L)* was introduced in Africa during the sixteenth century by the Spaniard and the Portuguese (Adande, 1984). The total production in Africa was estimated to exceed 39 million tonnes in 1989 and about 33 million tonnes in 1991 (FAO, 1992). The most important maize producing countries of the continent are South Africa and Egypt. In Benin maize is one of the most important crops in terms of quantity per year as well as area cultivated, with a total annual production of about 710 000 tonnes. It comes in third position after cassava 1,918,436 tonnes and yam 1,407,677 tonnes (Anon, 1991). In Ghana maize is the predominant cereal used for processing (Sefa-Dedeh and Mensah., 1989).

Unlike the other cereals, maize has no wild forms. The present maize has only resulted from successive selection and hybridisation. It has maintained almost all its botanical characteristics over the years of cultivation.

1.2 Types of maize

There are an estimated fifty different varieties which can be distinguished from each other by colour, structure, kernel shape and morphology. The prevailing colours are white, red and yellow, but colours such as red-brown, bright red and orange also exist . Furthermore, there is a distinction in the shape, which can be round or flint corn, and horse tooth or dent corn.

The most important varieties are:

- **White corn** which has both shapes, depending on its origin, with different varieties of texture;
- **Plata corn** with red, round kernels and hard glossy texture, and
- **Yellow corn,** usually bright yellow or light red, with dent-type kernels and soft texture.

1.3 Processing of maize

Besides traditional home processing a large variety of maize foods are produced and sold by food processing micro-enterprises. These include porridges and dough which are made either with the wet maize flour or dry maize flour obtained by milling maize by the use of disc attrition mills. In Cotonou (Benin) about 85% of maize-used is for based fermented foods are produced commercially, against only 15% of maize flour (Hounhouigan, 1994). These fermented foods are derived from *ogi* and *mawe*. Ogi is obtained by the fermentation of a suspension of wet milled maize in water without dehulling and degerming maize. While for the mawe, maize is partially dehulled and degermed by using a disc attrition mill, which is not very appropriate for dehulling and degerming. The mass of grits obtained is blended with a fine endosperm fraction and milled to obtain *mawe*. However some few individuals have dehulling machines imported from Cote-d'Ivoire and Nigeria for maize grits production. But this machine is more used to produce non-fermented degermed maize flour than to produce *mawe*. The products obtained after this operation are grits, germ and hull. The germ and the hull are used to feed animals while the grits is milled into the flour and solar dried. This flour, named *Gabari Lifin* is used in preparation of a very nice white *owo* consumed during the festivals. In spite of the fact that the flour is nice, very appreciated, and can be preserved for relatively long period, people cannot get it easily at any time of year because of the various constraints related to its processing. These constraints are:

- Irrespective of the high demand of degermed flour in areas of high consumption of this flour, the high cost and non-availability of equipment has had a profound effect on the level of production of degermed maize flour. The high purchasing and importation cost of this equipment has resulted in the limited ownership of these equipment as well as the production levels of the flour.

- Generally an estimated level of 40% degermed maize flour is obtained as finished product after processing by using the dehulling machine. Thus nearly 60% of the maize processed for degermed maize flour is treated as by-product used for feeding animals. In view of this the degermed maize flour on the local market is expensive culminating into the non-affordability of the commodity by low and middle-income earners, who in general, form the larger part of the population.

- The seasonal variations in weather and climatic conditions. After the grits are milled the flour obtained is spread out on a polyethylene sheet or mat for sun drying. This is to reduce the moisture content to allow for long period of storage. But the problems of high humidity and the moisture during rainy season is a limiting factor that hinders drying efficiency owing to the short period of sun light in this period.

In Ghana a similar flour is produced but here it is fermented. The product is called *Abro-gari* . To produce the flour, corn is dehulled and soaked for 2 days, milled into a fine flour and sun-dried for 24-48 hours (Figure 1). The sun drying is done on large polyethylene sheets spread on the ground. The dried flour is then sieved and packaged in polyethylene bags. The process for making *Abrogari* and *Gabari lifin* is basically dehulling, milling and drying. These products are intermediate products used for the preparation of the various dishes. Since the flour is sun dried on the ground it is important that this process be improved. Sometimes the bran of the maize is removed by pounding in a mortar followed by winnowing, the extracted flour obtained is whiter than whole meal flour and is used in making kenkey called *akporhe (in Dangme / Ewe)* or *nsiho (in Fanti)* (Orraca-Tetteh 1989).

In spite of the fact that the processing of maize is very laborious and time consuming, in Benin as well as in Ghana, the traditional food processors are mainly women.

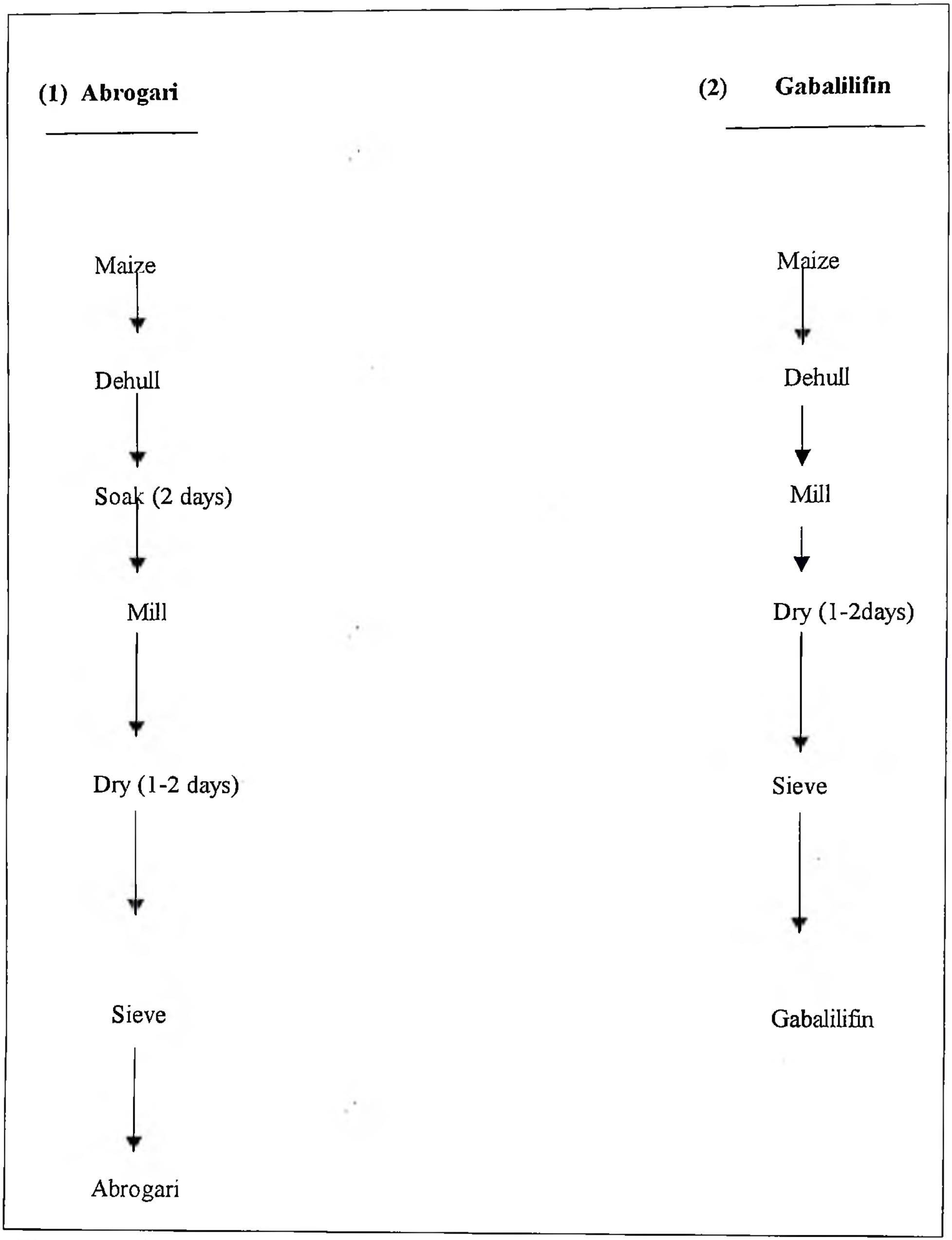

Figure 1: Flow diagram of *abrogari* (1) and *gabalinfi* (2) production

Source :(1) Sefa-Dedeh and Mensah (1989), (2) Producers

1.4 Utilisation of maize

The finished products made from maize are numerous and have varied uses, for example :

- for human consumption: maize flakes, grits, beer, meal and flour, germ oil, and
- for industrial processing: production of alcohol, starch, dextrin and glucose.

Maize is the basic food for subsistence farmers in many areas of the world . In tropical Africa, virtually all the maize is utilised as food. Relatively insignificant quantities are used as feed by farmers, and most of that seems to go to poultry (Marvin, 1966). The adaptability of the maize to different agro-ecological zone and the diversity of the processing methods used are the main reasons for its adoption as a basic diet by majority of the population in West Africa.

In Benin, almost all the maize produced is used for human consumption consumed everywhere although the ratio used in alimentary ration varies from one part of the country to another. About 40 different ways of maize processing have been recorded (Nago, 1990). Among these products, the most currently consumed are porridges (fermented or non-fermented) used generally as breakfast or weaning diet and the fermented cooked dough (*akassa, ablo, lio*) or non-fermented dough (*owo*) made from non degermed maize flour and consumed for dinner with vegetable sauce, meat or fish sauce. In Ghana various dishes are prepared from maize grain, mainly various types of kenkey made in the Southern and forest zone (Sefa-Dedeh and Mensah., 1989).

1.5 Maize flour preservation

Food preservation processes have in common the goal of extending the shelf life of foods to allow for storage and convenient distribution (Owen *et al.,* 1975). According to Kent (1970) the moisture content for the storage of white flours is 13 % . At moisture contents higher than 13%, mustiness due to mould growth, may develop, even if the flour does not become visibly mouldy. In the tropical countries, the fluctuation of temperature and the humidity coupled with inefficient preserving method used, favour spoilage of many traditionally processed food products during storage. Under these conditions the rate of many undesirable chemical reactions in flour and growth of spoilage micro-organisms accelerate (Labuza, 1980). Plahar *et al.*, (1982) noted that the storage characteristics of the traditionally processed food products are very poor and they only keep for short periods ranging from hours to few days. This is due to the poor method of preservation used that influences the chemical and physical properties of the food. Labuza, (1968), showed that most deteriorative reactions in food systems have their lowest rates at the monolayer level, which usually corresponds to 0.0 – 0.25 water activity range.

Understanding the role of the water activity in food is important for food quality and safety. Water activity is an important property that can be used to predict food stability with respect to microbial growth, rates of deteriorative reactions, and physical properties.

1.6 Justification

In Benin the storage of maize flour poses serious problems for the processors as well as the consumers. This is due to the lack of appropriate technology and poor practices limiting the use of the maize flours for long period of time after production. In deed, storage and packaging are basic methods of preserving foods against spoilage caused by the influence of environmental factors. In developing countries foods product are preserved under uncontrolled conditions using traditional methods and age-old techniques. For instance, preserving cereal flour in open receptacles or in porous bags so that the product is in contact with environmental factors (temperature, humidity, etc) which may affect the water activity required for good storage. Elsewhere owing to consumption patterns, certain products like maize, millet and sorghum are processed into dry flour (direct milling) without prior degerming. This method does not enhance storage for a long period because of the level of the fat in the flour which can cause oxidative rancidity with time of storage. According to FAO (1991), the shelf life of the maize meal is very low because maize has a relatively high fat content, and the meal tends to go rancid quickly.

1.7 Main objective

The study aims at the investigation and understanding of the conditions of preserving degermed maize flour under tropical ambient conditions for improved distribution, marketing, utilisation and for convenience in domestic, and commercial food preparations and food service delivery, and promote degermed maize flour as an Intermediate Food Product (IFP) applicable in other food industries.

1.8 Specific objectives

The specific objectives of the study focus on:

i. Influence of degermination on the physico- chemical and other functional properties of the flour.

ii. Moisture sorption properties of degermed and non-degermed maize flour.

iii. Effect of storage conditions and suitable packaging materials on the physico-chemical and microbiological qualities of the degermed maize flour during storage

iv. Making recommendations on the processing, packaging and storage conditions of degermed maize flour under tropical ambient conditions.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Characterisation of the maize grain

Maize *(zea mays)* belongs to the grass family (*Grassineae*) and is a tall annual plant with an extensive fibrous root system. It is a cross-pollinating species with the female (ear) and male (tassel) flowers in separated places on the plant. The kernels are often white or yellow in colour, although black, red and a mixture of colours are also found. The kernel weight may be quite variable ranging from about 19 to 40g per kernel (FAO, 1992). Wolf *et al.*, (1952) described the maize kernel as a caropsis, made up of four physical structures, namely the pericarp, the germ, the tip cap, and the endosperm.(Figure 2.1).

The endosperm, the largest structure, provides about 83% of the kernel weight, while the germ averages 12% and the pericarp 5%. The remainder is the tip, a conical structure that together with the pedicel attached the kernel to the ear of maize. (FAO, 1992). The sticking feature of the maize kernel composition is that it consists of two types of endosperm which together constitute about 83% of its weight (Guy, 1994).

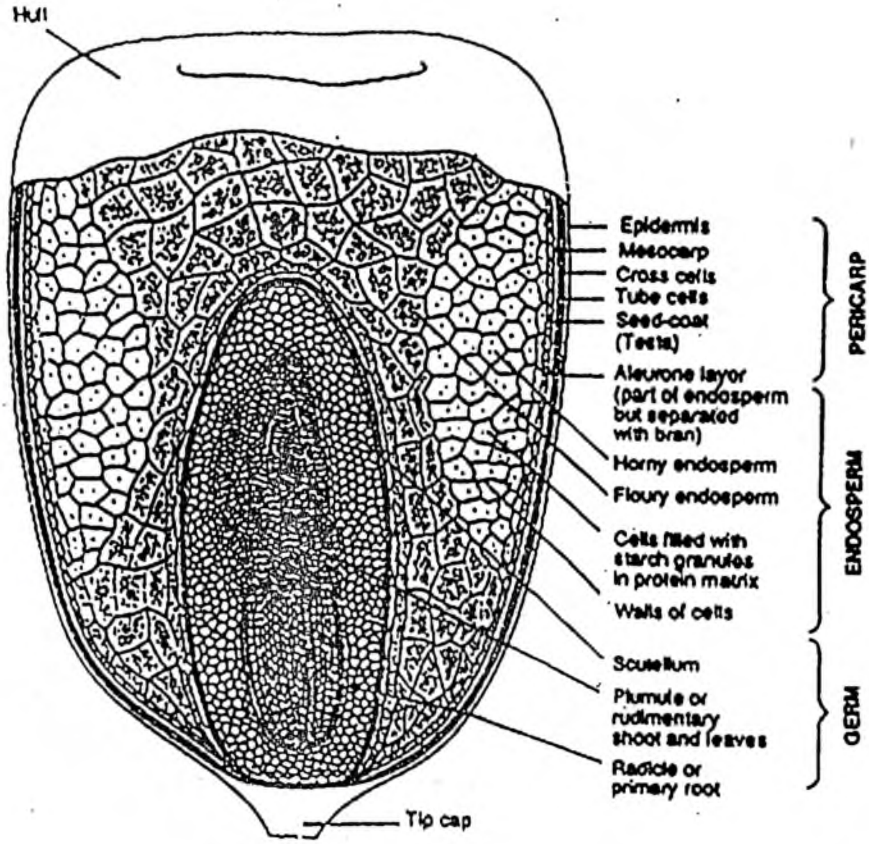

Figure 2.1 : Maize kernel structure : longitudinal section

Source : Wolf *et al.*, (1952).

The outer layer of endosperm is hard and vitreous, with densely packed polygonal shaped starch (Guy, 1994) and protein fractions. In the central part of the grain the endosperm is soft and meaty. It contains loosely bound starch and protein bodies with air cavities in between them. The starch granules are globular with smooth surfaces (Guy, 1994). It is this portion that is broken into smooth flour during milling processes.

2.1 Varieties of maize grain

The relative proportions of the two-endosperm types make the difference between the varieties of maize. Popular maize varieties include dent, flint, popcorn, sweet and waxy corn (Kent, 1983). Starch content, structure and composition (i.e. starch granule size, amylase: amylase amyl pectin ratio, crystal structure, etc.) differ among the varieties, to give different functional and physical properties. Sefa-Dedeh (1993) classified locally cultivated maize varieties in Ghana into three groups based on their cooked paste viscosity.

Group I: Local, *Dorke, Hilysine, Pool 16 and Safita 2.*

Group II: Composite *W, Golden Crystal, la Posta, Mexican and T2E.SRW.*

Group III: *Diamentes and dobidi.*

Dry flours from varieties in group (I) have high gelling properties, while those in group (II) have medium gelling properties and group (III) the most difficult to gelatinise. The varieties are also grouped based on the 1000 seed weight (i.e. seed bulk density) seed water absorption and swelling characteristics. They also differ in sugar and amylase composition. These quality indices, largely influenced by starch content and composition, can be used to select the appropriate maize variety for specific food applications.(Louis-Alexandre, 1991)

In Benin, one can find local ecotypes and related (improved) varieties. The local ecotypes are often named and classified by referring to their colour, shape and size of their grains and the length of their vegetative cycle (Nago, 1997). Among these local ecotypes, the varieties that have white seeds and short cycle (70-90 days) or intermediary (90-100 days) are predominant (Nago, 1989; Dokoui, 1993). A few varieties with yellow seeds, and rarely varieties with multiple colours (white, red, blue or purple parts) are also found (Nago, 1997). Improved varieties comprise cultivars that have long or intermediary cycle, yellow or white in colour. All the varieties of maize used in Benin (local or improved) belong to three types: indurata, indentata and amylacea (Nago, 1990).

2. 3 Physical characteristics of maize grain

a) Thousand grain mass

The thousand grain mass is the weight of 1000 dry grains. It is an indirect but significant means of expressing the size of the grain, size with which it is in close relation (Chasseray, 1991). Accordingly, the size of grains influences directly their weight because of the ratio surface (envelop)/volume (fruit). This thousand grain mass permits to characterise a variety and to put in evidence the anomalies such as the heating properties to study the influence of the treatments plant or of the climatic conditions that modifies the thousand grain mass (Godon, and Loisel., 1984). It is also influenced by the variations in the water content (Godon,and Willm., 1991) and constitutes one of the six basic components of the yield in grains of the maize (Gay and Bloc, 1984).

b) *Percent dented grains*

It is determined by the visual examination of the apical part of grains. According to Mestres *et al.*, (1991), one can predict from the present dented grains the "virtuosity" and the drying milling aptitude of the grains.

c) *Grain Density*

The density of the grain or real volumic weight shows properly the density of the fruit but takes account of that of the sheaths that surround it and of an average density of each constituent of the grain. According to Chasseray (1991), it depends essentially on:

i the proportion of the fruit,

ii the compactness and the texture of the fruit,

iii the texture of the sheaths, and

iv the moisture content of the grain.

Willm,(1991) has shown that it is impossible to establish a relation between the density and the thousand grain mass. But there is a good correlation between the density and the viscosity of the grain. Watson (1987) has shown that the density is highly correlated to the hardness. Moreover, a density of grain that is high reveals high ratio virtuous albumen/flour albumen.

d) *Type of Albumen*

The albumen is a highly developed part of the grain where starch reserves accumulate. It consist of a virtuous part and a floury part. Willm, (1991) reported that from one variety to the other the proportion of virtuous and floury albumen are variable and that is obvious that all conditions being equal the percentage of fruits of virtuous texture and its level of resistance to crushing determines the granulometric spectrum of produces.

e) *Hardness of Grains*

The "physical" hardness of grains are defined by their resistance to crushing, fragmentation or reduction and it is certainly the characteristic that influences directly the grinding aptitude (Chasseray, 1991). Fliedel *et al.*,. (1989) have also reported that this criterion is an important characteristic that can have an influence on the behaviour of the grain in the course of its transformation (primary and secondary). From this characteristic, one can predict the technologic quality of a cereal. Some works have revealed the influence of the hardness on the quality of the traditional kitchen preparations. Louis-Alexandre (1991) reported that among the chemical components of corn grain, only the protein content is correlated positively and significantly with the hardness of the grains. The hardness of the grains is genetically and culturally controlled (Hosney and Faubion, 1992). Among the techniques developed for the determination of the hardness the PSI (Particle Size Index) method has widely been used and appreciated because it is simple, fast and presents a good capacity of differentiation between varieties. (Fliedel *et al.*, 1989 ; Louis Alexandre, 1991).

2.4 Chemical components of maize grain

Maize ranks as the second most important food plant in the world from the standpoint of total production . With the recent discovery of two high-lysine mutants (Matz, 1969) maize may play an even more important role in human nutrition. The chemical composition of the maize grain varies from one part of its structure to the other. Therefore our interest will be put on the composition of the whole grain.

a) *Starch*

Starch is the major constituent and principal carbohydrate of the corn kernel and occupies 86.7% of the albumin (Watson, 1987). Free sugars range between 1.0 and 3.0% with sucrose as the major component. It constitutes the main source of energy and plays a considerable role in alimentary technology because of its physico-chemical and functional properties. The component of the maize starch are amylase (25-30% of the starch in the grain) and amylopectin (Watson, 1987).

b) *Proteins*

Corn protein comes mainly from the endosperm, but the contribution of the germ (embryo) cannot be ignored. Matz (1969) found the following distribution of nitrogen in normal yellow maize hybrid US 4251: endosperm (including aleurone layer) 81.2%, embryo 15.5%, and per carp (Hull) 3.3%. Elsewhere maize for instance lacks both lysine and tryptophan and therefore has low content of nicotinic acid, which is derived from tryptophan (Ihekoranye and Ngoddy 1985). Watson (1971) reported that the protein content of maize is 9.5g/100g.

c) *Lipids*

About 85% of corn lipids occur in the germ, mainly as triglycerides of fatty acids. About 10% of the energy derived from corn combs from the metabolism of lipids. Nissen (1982), noted that corn is one of the cereals that have lot of oil.

d) *Raw fibres*

The raw fibres are essentially made up of cellulose and are concentrated in a proportion of 87% in the seminal integument that constitute a source of alimentary fibres (Matz 1969).

e) *Ashes*

The germ is rich in mineral elements; it contains 78% of the minerals in the grain (Watson, 1987). The content in ashes of the grain of maize varies between 1 and 1.6 % (Watson, 1987). This content depends among others, on factors such as: the hardness, the size and the content in integument of the grains (Godon and Loisel.,1984). The grain of corn is principally rich in iron (Nissen, 1982). Like all the cereals, the corn has a high content of phosphorus, but its calcium content is poor (Favier, 1989).

f) *Minerals*

About 80% of the minerals are in the germ (Earle *et al.*, 1946). Corn is especially low in calcium (about 0.03%) with potassium and phosphorus the most abundant mineral elements (about 0.35%).

g) *Vitamins*

Yellow corn contains about 490 IU of vitamin A activity per 100gm. White corn has practically no vitamin A activity (Matz, 1969). Both types of corn contain about 10mg of vitamin E as alpha tocopherol per pound (mainly in the germ) with little or no vitamin K or D.

2.5 Maize flour

2.5.1 Dry milled maize flour

Dry maize flour is a staple food consumed almost in all West African countries where maize is produced. In Benin ordinary maize flour called *'lifin'* obtained by direct milling of the whole maize grain is widely used to prepare 'owo' (non fermented dough), cake, porridges and also used as thickening agent in products such as soups. About 65.5 tonnes of corn are ground everyday into flour for making owo.(Nago *et al.*, 1990). Unfortunately this flour cannot be kept for more than a week because of the fat content and the non-adequate storage conditions. However maize degerminated and dehulled before milling into the flour may be kept for relatively long period of time if it is stored under good conditions.

2. 5.2 Degermed maize flour Production

Basically, mechanical dehulling and degerming operation involves a physical separation of the corn kernel into its component parts, hull, endosperm and germ. The endosperm separation is then graded into various particle sizes, and these are used with a minimum further modifications.

The first step in degerming processes, after the grain is cleaned is tempering, the corn is brought to moisture content of about 20% by means of a water spray or steam. Since this is done rapidly, there is a marked difference in moisture percentage in various portions of the kernel. This unequal distribution of moisture is of decided advantage in the next phase of the milling operation. Then the tempered corn is fed into a degerminator.

The dehulling as well as degerming are the units operations accomplished at the same moment (simultaneously) during the maize processing system and aimed to remove from the grain kernel the germ that has a high fat content of about 85% susceptible to accelerate the rancidity of the flour. These unit operations may be achieved by using manual methods (e.g. earthenware mashing bowl stone grinding or mortar and pestle) or mechanical size reduction using disc attrition mill (Sefa-Dedeh, 1993) or Sheller type Engelberg. The processing losses due to the utilisation of the disc attrition mill and Sheller commonly used in our countries for dehulling-degerming has not been seriously been studied. Nevertheless Diop., (1997) have found out that the processing losses by using Engelberg are relatively high about:15 to 20%.

2.5.3 Characteristic of degermed maize flour

Very little work has been done on the characteristic of degermed maize flour. Kafui, (1996) has determined the proximate composition of the dehulled and degermed maize flour as shown below.

Table 2.1 Proximate composition of dehulled and degermed maize flour

Constituents	**Percentage**
Moisture content	12.0%
Crude protein	8.5%
Crude fat	0.9%
Carbohydrate	78.06%
Ash	0.54%

Source : Kafui (1996).

The standard granularity of degermed maize meal should be as follows: not less that 95% of degermed maize shall pass through a sieve of 0.85mm aperture size, not less than 45% through a sieve of 0.71mm aperture size, but not more than 25% through a sieve of 0.210mm aperture size. (Codex Alimentarius, 1994).

2.6 Food preservation

Food preservation processes have in common their goal of extending the shelf life of food to allow storage and convenient distribution. Therefore enzymatic and microbial changes must be prevented or at least delayed. Several food preservation processes achieve this aim by lowering the availability of the water to the microorganisms.

2.6.1 Dehydrated food preservation

According to Labuza *et al.*, (1968) the presence of water in food influences the chemical and physical properties of that food. In 1970, the same author showed that most deteriorative reactions in food systems have their lowest rates at the Brunauwer-Emmett-Teller (BET) monolayer which usually corresponds to the 0.0 – 0.25 water activity (Aw). Beyond this region it will induce an increase in reaction rate generally by a factor of 50 – 100 % for each 0.1 Aw range. The quality of the dehydrated products such as cereals and legume flour as well as root and tubers are influenced by chemical changes occurring during and after the removal of the moisture. These changes invariably affect the texture and appearance of the product and nutrient losses may occur.

2.6.2 Moisture sorption Isotherm

The relationship between total moisture content and corresponding Water activity (Aw) over a range of values at a constant temperature yields a moisture sorption isotherm when graphically expressed (Rizvi, 1986). Moisture sorption isotherms are non-linear, generally sigmoidal in shape. Labuza *et al.*, (1968) identified four general types (Fig 2.2).

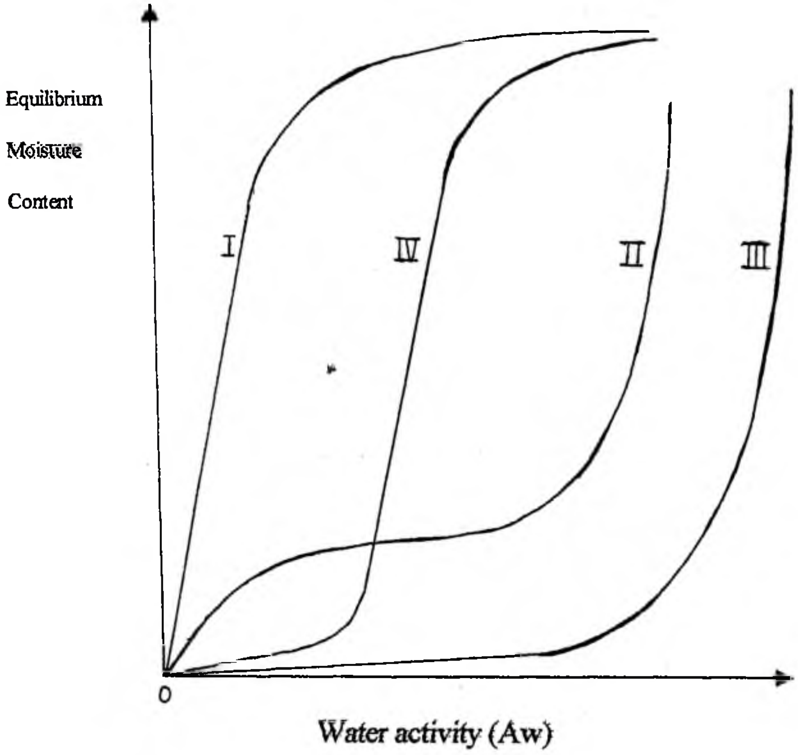

Figure 2.2 : Different types of water sorption isotherm

Source : Brunauer *et al.*, 1940.

The type (I) isotherm is called Lagmuir and type (II) is S-shaped or sigmoid. According to Rizvi (1986), moisture sorption isotherms of most foods are non-linear, generally Sigmoid in shape and have been classified as type (II). Foods that are rich in soluble components, such as sugars have been found to show the type (III) parttern (Rizvi, 1986). Type (IV) pattern describes sorption isotherm of the pure water.

It has been observed that moisture isotherms of the foods may not necessarily be smooth sigmoid curves, but may have more than one inflexion point each reflecting a transition point in the binding energy of the water and therefore related to different modes of the water binding (Iglesias and Chirife, 1976). It was shown (Labuza, 1968,) that sorption isotherms can be divided into segments / zones (see Figure 2.3) representing the Aw range in which three principal types of the water binding predominate .

Section A::

That is the low humidity range. For that section the curve is concave and it's called the local isotherm and has Aw = 0.0-0.25 where it is believed that water bound by ionic groups predominate. Labuza (1968) referred to this region as corresponding to the absorption of a monolayer film or water.

Indeed a portion of the total water content present in food is strongly bound to specific sites. These sites include the hydroxyl groups of polysaccharides, the carbonyl and amino groups of proteins, and others on which water can be held by hydrogen bounding, ion-dipole bounds, or by other strong interactions. The most effective way of estimating the contribution of absorption of specific sites to total water binding is the use of the BET (Brumauer-Emmet-Teller) isotherm equation that is:

$$\frac{a}{m(1-a)} = \frac{L}{m_1 c} + \frac{c-1}{m_1 c}$$

where :

a : is water activity,

m : is water content (gH_20/g solids),

m_1 : is the monolayer value, and

c : is a constant.

This equation is based on over simplified assumptions but is extremely useful as an estimate of so called "monolayer value" which can be considered as equivalent to the amount of water held absorbed on specific sites.

Section B :

Midrange :it has a region of inflection which is approximately linear. Generally, this region lies between Aw values of 0.25-0.75 and it corresponds to local isotherm II. It appears to be related to the covalently bound water (Rizvi, 1986).

Section C:

With high humidity ranges the curve is concave to the moisture content axis. Free solute and capillary region lies between Aw values of 0.75-1.00 and it is referred to as local isotherm (III). It is believed to represent water multilayers on protein and carbohydrate polymers.

Labuza (1968) suggested that Brumauer-Emmet-Teller (BET) equation is probably the most useful in the study of isotherm of concern to the processing and storage of food materials particularly for predicting the monolayer value of coverage and heat of absorption.

2.6.3 Temperature Dependence of Sorption Isotherm

When the temperature of a product is changed, the vapour pressure exerted by the moisture in the product changes so that the humidity of the product atmosphere remains at almost constant fraction of that of saturated atmosphere at the same temperature. Labuza (1968) observed that this relationship indicates that the heat of sorption at low moisture contents is higher than theory indicates and also fall of gradually, indicating the gradual change from Langmuir to capillary.

In fact knowledge of the temperature dependence of sorption phenomena provides valuable information about the changes related to the energetic of the system. The variation of Aw with temperature can be determined using either thermodynamic principle or the temperature terms incorporated into sorption equations.

$$\frac{d(\ln a)}{d(1/T)} = \frac{-Qs}{R}$$

Where Qs = heat of absorption, R = gas constant and T = absolute temperature.

2.6.4 Methods of Moisture Sorption Curve determination

The moisture sorption isotherm relates moisture content of the material to its water activity (Aw) at a given temperature. In order to obtain a given point, a sample is equilibrated against a solution of constant and known Aw and its moisture content determined. The primary standard for Aw equilibration is a saturated salt solution; the National Bureau of the standards (Greespan, 1977) published a list of 28 salts covering the Aw range 0.03-0.98. Two basic methods described by Owen *et al.,* (1975) is used in determination of isotherms of food usually obtained at constant temperature. These methods are: Nanometric method and gravimetric method

a) Manometric Method

Taylor (1961) reported a simple manometric method of measuring equilibrium partial pressure. A food of known moisture content is allowed to come to equilibrium with a small headspace in a light enclosure and partial pressure of water activity is measured manometrically. Water activity is equal to equilibrium relative humidity divided by 100.

$$Aw = ERH/100$$

Relative humidity sensors of great variety are available for this purpose, including electric hygrometers, dew point cells, hair psychrometers, and others.

b) Gravimetric Method

The second basic method of preparing isotherms is the exposure of the sample of the food to various constant humidity atmospheres. After equilibrium is reached the moisture content is determined gravimetrically or by other methods. Saturated salt solutions have the advantage of maintaining a constant humidity as long as the amount of salt present is above saturation level. Solutions of glycerine or sulphuric acid also can be used to control humidity, provided their concentration is known (or determined) at the end of the equilibration period.

2.7 Water activity and Food spoilage

Water activity affects the stability of food and therefore it must be brought to suitable level at the condition of drying and maintained within an acceptable range of activity values during storage in order to avoid the occurrence of many chemical reactions in foods and microbial growth (Labuza, 1980) (Figure 2.3).

Dried or freeze-dried foods, which are of great stability during storage usually, have water contents in the range of about 5-15%. Intermediate moisture foods may have moisture content of about 20-40%, eg. dates and cakes.

The water in the dried food corresponding to the lower part of the sorption isotherm is called type (I) water which is very tightly bound and some authors refer to it as true bound water. In this region where water activity is between 0 and 0.25, enzyme activity is virtually non-existent. Not surprisingly, growth of micro-organisms at this level of Aw is also virtually zero. According to Owen et al, (1976) it is in this region that one sees an acceleration of lipid phase reactions such as oxidative rancidity. As the water content is increased above the optimum level into zone (II) lipid oxidation increases presumably because of increased catalyst mobility and because new catalytic surfaces are exposed as the matrix swells. Moulds and yeast start to grow at Aw between 0.7 and 0.8, the upper limit of capillary water. Bacterial growth takes place where Aw reaches 0.8 the limit of loosely bound water. Enzyme activity increases gradually between Aw of 0.3 and 0.8 then increases rapidly in the loosely bound water area (Aw 0.8 to 1.0), the water activity range between 0.25 and 0.8 is called type (II) water that is substantially more difficult to remove than type III water (Aw between 0.8 to 1.0). the removal of a given increment of type II water results in a much greater reduction of the remaining water activity than occurs when a like increment of type (III) water is removed. Partial removal of type (II) water eliminates the last possibility of microbial growth and greatly reduces most of the chemical reaction. Complete or non complete removal of type (II) (to 3-7% moisture level depending on the product and temperature) corresponds approximately to optimum stability of dry products.

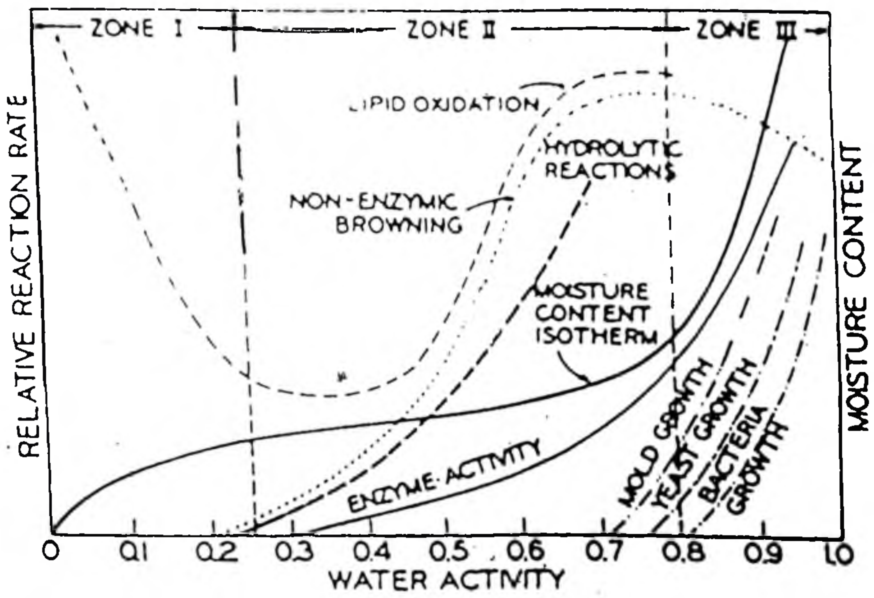

Figure 2.3 : Water activity-stability map (Labuza,1980)

2.8 Food preservation

Food preservation can be accomplished in several ways : reduction in degree of spoilage by removal of contaminant, delaying spoilage by making conditions unfavourable for microbial growth. Unfavourable conditions for growth of microorganisms vary depending on the organism. All micro-organism require moisture in order to multiply and hence drying is an effective delayer of spoilage. The moisture content for the storage of the white flour is 13%. At moisture contents higher than 13%, mustiness, due to mould growth, may develop, even if the flour does not become visibly mouldy (Kent,1970).

2.8.1 Preservation of Traditionally Processed Food

Storage characteristics of traditionally processed food products are very poor and they only keep for short periods ranging from hours to a few days (Plahar *et al.*, 1982) due to the nature of their high moisture contents which facilitate deterioration in food products. In another study, Plahar *et al.*, (1982) reported that fermented maize dough could be made to store for longer periods by dehydrating the dough. The process of dehydration involves the removal of moisture from the product so as to provide a product which can be safely stored for longer periods and the low moisture content of the dried product significantly reduces the processes of deterioration which otherwise occur rapidly in fresh products (Brett *et al.*, 1995). Plahar *et al.*, (1983) also reported that Ghanaian fermented maize meal could be air-dried using a cabinet drier at 62^0 C with minimal loss of protein quality and colour. Therefore dehydration could be used to produce convenient flours for most traditional foods with long storage stability.

2.8.2 Packaging

In most developing countries only the daily rations of food is bought, so the package has an inferior role (Fellows and Axtell.,1993). Packaging is nevertheless important for the storage of food between consecutive harvests, for making available industrially produced foods that are richer in nutrient from a physiological standpoint for any supplies from distant countries (such as animal protein) and, quite generally, for the distribution and export of agricultural produce (Birch *et al.*, 1977). The importance of packaging on the economy of a country therefore depends principally on the status of the food industry, on the existence of a stockpiling economy, and on the expected volume of harvested (Heiss and Munich.,1970). Nowadays, with the advances in modern technology and increased demand for consumer convenience a multitude of new packages have emerged. These new packages have brought about the need for more research to understand how food interacts with the package (I.T.C : International Trade

Centre Geneva, 1993).

2.8.3 Role of Food Packaging

A package must protect the product from physical damage, from losses or deterioration during storage and display, and must be convenient in use. It must also be attractive for product trademark identity, and it must perform these functions at minimum cost, since the package itself has intrinsic value to the consumer (Heiss and Munich.,1970).

The objective of the packaging is to provide a carrier and a protective atmosphere so as to conveniently deliver the product to the user in the best possible condition and to establish identity, invite purchase at the point of sale, and contribute to resale by being convenient in use (Marilyn *et al.*, 1986).Fellows and Axtell (1993) reported that good packaging serves two purposes which are essentially technical and presentational. Technical aspects of packaging aim at extending the shelf life of the product by better protecting the food from all the hazards it will meet in storage, distribution and use.

While presentational aspects of packaging do not actually do anything to make the food keep longer or in better condition, such packaging increases sales by creating a brand image that the buyer instantly recognises (ITC, 1993). It also aims to appeal to the customer in terms of shape, size, colour, convenience, etc. Tressler *et al.*, (1957) also showed the primary function of a packaging material, which is to contain, carry and dispense product. The other functions of packages, which have been added, are to preserve, measure, communicate (aesthetics) and display (aesthetics) the product (Heiss and Munich., 1970).

To achieve these functions of protection and preservation, Tressler *et al.*, (1957) identified seven types of packaging containers. These are wooden barrels, wooden boxes, tin cans, glass containers, plastic containers and fibre boxes. Among all these containers, plastic films provide very good protection to flours for long shelf life if the package is properly sealed (Fellows and Axtell, 1993). They have good barrier properties, permit visibility of the contents, are tough and are obtainable in wide range of barrier properties. On the other hand, this wide variety also means that care must be exercised in the choice of film used for any particular product.

2.8.4 Some Properties of selected Plastic materials

a) Low Density Polyethylene (LDPE)

Low density polyethylene is one of the most widely used commercial plastics. (Briston ,1968). It is tough, transparent and has relatively low permeability to water vapour. Chemically, it is very inert and is practically odourless and tasteless. One of its biggest advantages is the case with which it can be heat-sealed. It has high tear resistance and impact strength. (Briston , 1968). It also has a wide temperature range and use being usable down to under 50 ^{0}C and up to about 70 ^{0}C. Low-density polyethylene film does, however, possess a relatively high permeability to gases such as oxygen and carbon dioxide (Heiss and Munich , 1970). It is therefore unsuitable for packaging foods, which are subject to oxidation, or as a film for vacuum packaging. (Heiss and Munich , 1970).

b) High Density Polyethylene (HDPE)

High-density polyethylene film has a lower permeability to both water vapour and gases than low-density polyethylene by a factor of about 2-3 times. According to Bakke and Eckroth.,.(1986) HDPE is a milky-white, odourless and tasteless nonpolar thermoplastic. Each molecule is made by addition polymerisation, which covalently bonds together end to end by way of a catalyst to form a long linear chain of carbon atoms. HDPE has a higher tensile strength and is more rigid than low-density polythene, but has lower impact strength. The softening point of high-density polyethylene is above the boiling point of water so that it could be steam sterilised without softening (Heiss and Munich, 1970).

c) Polypropylene (PP)

Polypropylene film is normally produced by extrusion into a chilled roller and in this form is referred to as cast film (Bakke and Eckroth.,1986). The film so produced has a good standard of clarity. In general, the permeability of polypropylene is a little greater than that of high-density polyethylene although it can be lowered by biaxial orientation of the film (Heiss and Munich, 1970). Polypropylene has an even higher softening point than high-density polyethylene but is inclined to brittleness at low temperatures (Heiss *et al.*, 1970). Polypropylene has been found applicable for the wrapping of cheese, bacon, and cooked meats and especially for foods sensitive to moisture and oxygen, such as biscuits and potato chips. Oriented polypropylene can also be used as a shrink-wrap film. Tressler *et al.*, (1957).

2.8.5 Packaging requirement of dried Foods

For low moisture content foods like cereal and legume flours, spices, pasta products, dry fruits and vegetables, nut products which are supposed to be preserved for several months depending on the humidity of the area in which they are stored the following packaging requirements are minimal if however, there is a rainy season or the foods are transported to other more humid regions there is a risk of moisture pickup and consequent spoilage (Fellows and Axlell., 1993).

Heiss and Munich.,.(1970) reported that dry products must always be maintained at an equilibrium moisture that inhibits any growth of moulds as is usually the case when the moisture of the food is in equilibrium with a relative humidity lower than 70 percent.

Elsewhere food which consist mainly of fat frequently require additional packaging protection since their keeping qualities are more easily endangered by oxygen and light than all other dry foods, which have to be protected mainly against the influence of water-vapour (Fellows and Axtell., 1993). When these foods are not packaged in hermetically tight metal or glass containers, there will always be a moisture exchange with the ambient atmosphere since the equilibrium relative humidity over the packaged produce will rarely be the same as the relative humidity of the surroundings (Heiss and Munich, 1970). For this reason the demand for adequate moisture tightness will be most frequent.

The packaging material must be compatible with the packaged product, ensuring that the packaging material does not impact any odours or flavours to the product, and that no substance soluble in the product may have any toxicological effects (Heiss, and Munich., 1970). For nearly all-dry foods, it is most important that no insects are included in the package during the filling operation and that the package is resistant to all insect attacks.

The given water content is valid for the usual turnover time. Heiss, and Munich., 1970 proposed that flour, semolina for usual storage, should not exceed moisture content of 14%. For longer turnover periods water-vapour, moisture content lower than 12% and oxygen impermeability is required.

The foods which consist mainly of fat are oxygen-sensitive product, for such product it is best to use a high oxygen impermeable package and to either evacuate the package or fill it with an inert gas, air space in the package should be minimal, whereas the dry products with low fat content have to be protected mainly against the influence of water-vapour (Fellows and Axtel.,1993).

A water vapour light packaging material is usually also gas-tight to a high degree. According to Food and Drug Association (FDA) polyethylene is generally recognised as safe packaging material. Polyethylene is one of the most inert polymers and constitutes no hazard in normal handling. In 1993, Fellows works mentioned that plastic film such as high-density polyethylene, low-density polyethylene and oriented polypropylene constitute a normal package material for cereal diets and flour.

CHAPTER THEE

3.0 MATERIALS AND METHODS

3.1 Materials

-Food material

Maize : Maize *(Zea mays . L. cv. Obatanpa)* used was bought from market place at Madina (Ghana), and was used for the entire work.

- Packaging material

Polyethylene packaging material High density polyethylene, (HDPE) , Low Density Polyethylene (LDPE), and Polypropylene (PP) were bought from Polyproducts (GH) Limited Accra, for the experiment .

3.2 Methodology

3.2.1 Sample preparation

(i) **Degermed maize flour** : The maize grains were dehulled and degerminated using a maize sheller (Rex Gold, type Vertical BB, India. by : Goldline Export MUMBAI- 400026) (Figure 3.1). After dehulling, the grits obtained were milled into flour using a disc attrition mill.

(ii) **Non-degermed maize flour**. The whole maize flour was obtained by direct milling of the maize grain into flour. The flow chart for the preparation of the flours is as shown in Figure 3.2.

(iii) Drying of flour. The flours obtained from the above milling process were dried using oven drying for 4 hours at 40^0 C and solar drying for 6 hours with temperature varying between 30°C and 45° C.

3.2.2 Effect of storage conditions and packaging material on the physico-chemical and microbial qualities of the degermed maize flour.

Five hundred grams of degermed and non-degermed maize flour samples obtained after preparation were packaged in High density polyethylene, (HDPE) and Polypropylene (PP) (Figure 3.3) and stored for a period of six (6) month under tropical ambient conditions . Samples were taken after every two (2) months in storage for the following analysis : moisture, pH, titrable acidity, crude fat, free fatty acid, paste viscosity, mould, and bacterial. See section 3.3 for specific details)

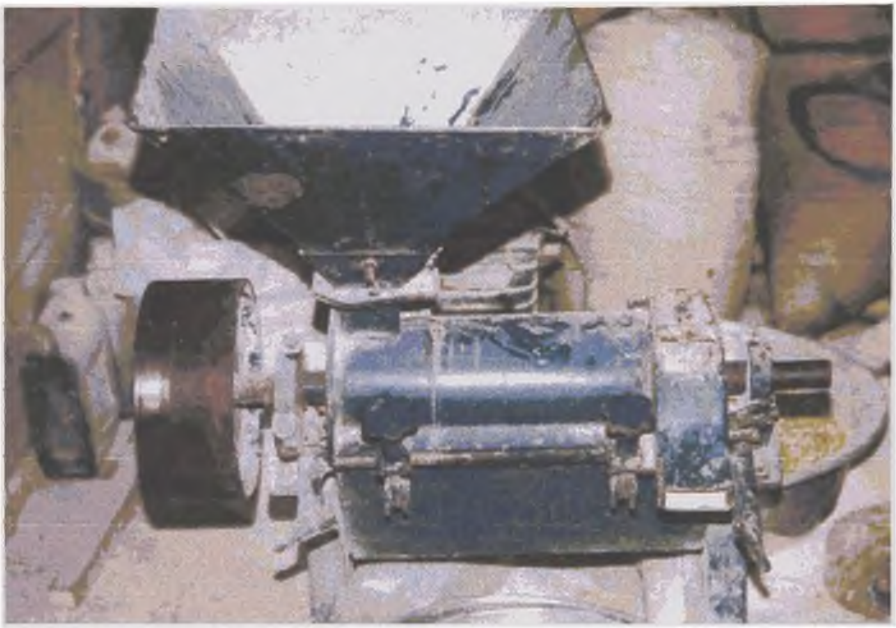

Fig. 3.1: Dehulling and degerming machine

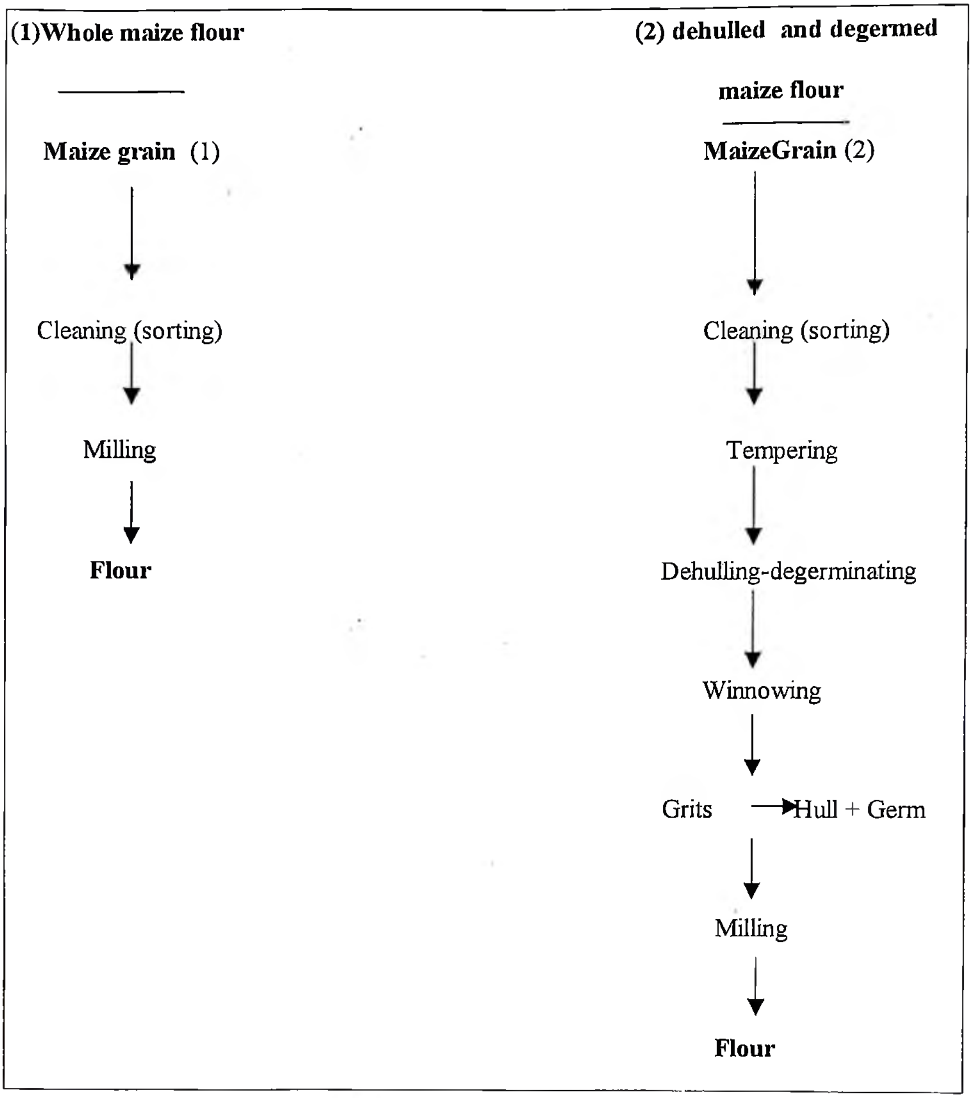

Figure 3.2 Flow chart for the preparation of maize flours

Fig 3.3: Packaged maize flour samples

A_1 - non-degermed maize flour in polypropylene bag

A_2 - non-degermed maize flour packaged in high-density polyethelene bag
B_1 - Degermed maize flour in polypropylene bag

B_2 - Degermed maize flour packaged in high-density polyethelene bag

Experimental design

A (4 x 2 x 2 x 2) factorial design was used to analyse the flour. The principal factors include;

i- storage period : 0 ; 2 ; 4 ; 6 months (4)

ii- type of the flour : degermed flour and non-degermed flour (2)

iii- drying method : oven drying and solar drying (2)

iv- Packaging material : High density polyethylene, (HDPP) and Polypropylene (PP) (2)

Analysis of variance was done to determine the effect of storage conditions and packaging materials on the indices measured.

3.3 Analytical Methods

3.3.1 Physical Analyses

a) Material Balance

The method of material balance (Earle, 1983) based on the law of conservation of mass was used to calculate the material balance of the flour production. That is:

i- degermed maize flour :

Weight of maize = Weight of the flour + weight of the hull and germ + processing losses.

ii- non degermed maize flour

Weight of maize = Weight of the flour + processing losses

b) Particle size analysis

The particle size analysis was based on modifications of the method of Ken Jones *et al.*,(1967).

Five hundred grams (500g) of the maize flour was placed on the uppermost sieve of five sieves placed one on top of the other having sieve aperture of 2.00mm ; 1.00mm; 0.5mm; 0.250mm; 0.063 mm respectively. The amplitude of the vibration used was 50 Hz and the mode of the vibration was continuous. This was monitored for 5 minutes. And at the end of the vibration, the weights of the amount of the sample on each sieve was weighed in addition to adhering particles on the underside of the sieve. These were expressed as percentages of the particle having passed through preceding sieve.

3.3.2 Functional Characteristics

a) Hot Paste Viscosity of the flours

Ten per cent (10 %) slurry (on dry matter bases) of each of the flours was analysed in the Brabender visco-amylograph (Brabender, Duisburg). The samples were heated at a rate of 1.5^0C/min continuously from 30^0 C to 95^0 C, and held at this temperature for 30 minutes. The viscosity (BU) was monitored continuously using a 500 cmg sensitivity cartridge and the Brarbender visco-amilograph indices were monitored .

b) Swelling Capacity

The method described by Fleming *et al.*, (1974) was used. Ten grams (10g) sample were weighed into 100ml graduated measuring cylinder, and the volume noted. The measuring cylinder was filled to the mark with distilled water and quickly stirred. The mixture was made to stand for one hour in the measuring cylinder and the swelled volume were noted after time intervals of 1, 5, 10, 15, 20, 25, 30, 45, and 60 minutes. The maximum swelled volume was noted.

c) Water Absorption

This was determined according to the method reported by Anderson *et al.*, (1969). Five gram (5.0g) of each flour sample were weighed into a centrifuge tube and 30.0 ml of water added and mixed thoroughly. This was allowed to stand for 30 minutes and centrifuged at 3,000 r.p.m for 15minutes. The supernatant was then decanted and the sample weighed again. The amount of the water retained in the sample was recorded as weight gain and was taken as water absorbed. The results were expressed as weight of water absorbed in grams per 100g dry matter of the sample.

3.3.3 Chemical Analysis

a) Proximate Analysis

The moisture, crude protein (Nx6.25), fat, ash and crude fibre contents were determined by Association of official Analytical chemist Approved methods 925.10, 920.87, 920.85 , 923.03 and 963.09 respectively (AOAC, 1990). Carbohydrate contents were determined by difference.

b) pH determination

Ten (10) grams of each sample was added CO_2 free distilled water and made up to 100 ml in a measuring cylinder. The moisture was allowed to stand for 30 minutes with occasional stirring and filtered. The pH of the filtrate was measured using a pH-meter (TOA electronic Ltd, Japan. Model HM-30S).

c) Titratable Acidity

Ten (10) ml aliquots were pipetted and titrated against 0.1M NaOH using phenolphthalein as an indicator. Acidity was calculated as grams lactic acid / 100g dry mater sample.

d) Fat acidity test

The method in Kent (1970) for corn flour was used. Hundred grams (100g) of the maize flour was weighed and the free fatty acid leach by shaking the flour in 500 ml of water to extract the acidic material. The mixture was then filtered and the fatty acid content of the filtrate was determined by titrating with standard potassium hydroxide (KOH) solution using phenolphthalein indicator. The result was then calculated as per cent lactic acid.

3.3.4 Microbiological Analysis

Ten grams (10g) of each flour sample was weighed into a stomacher bag with 90 ml diluents. This was blended for 60 sec and then serially diluted. One (1)ml 10^{-2} sample solution was pipetted into each petri dish. 10 ml media (Potato Dextrose Agar & Plate count agar) was poured on the sample in the petri dishes and incubated. Plates with PCA were incubated at 37^0C for 24 hours while plates with PDA were incubated at 25-26^0C for 72 hours.

3.3.5 Determination of Moisture Sorption Isotherm

3. 3.5.1 Determination of moisture content of the sample at equilibrium

Atmospheres of different relative humidity (or water activities) were established using saturated solutions of the different salts as described by Speiss & Wolf (1987). For convenience, the saturated solutions applied are listed in the Table 1.

The set-up used for exposing the food samples to the various relative humidities was based on the principles of Proximity Equilibrium cells (Lang *et al*., 1981). Each saturated salt solution was held in small sorption container as described by Lang *et al*,. (1981). This consisted of a small cylindrical glass jar (90 mm long and 75 mm diameter) with a tightly fitted lid.(Figure 3.4) Each sorption container was filled to about a third of its volume with saturated solutions of the salts as given in Table 3.1 .

About two grams (2g) of the sample were weighed into polypropylene weighing boats, 44 x 44mm in size, and incubated under concentrated sulphuric acid solution for 24 hours to zero its moisture content. After that the sample in the boat was suspended over the saturated salt solution, with a wire string attached to the lid of the sorption container. The sorption containers with the food samples were placed inside an incubator set at 30^{0}C. Duplicate determinations were made at each A_w, and weight of the sample recorded. Samples became equilibrated between 10 and 15 days then the water gain was calculated as a percentage moisture content of the sample

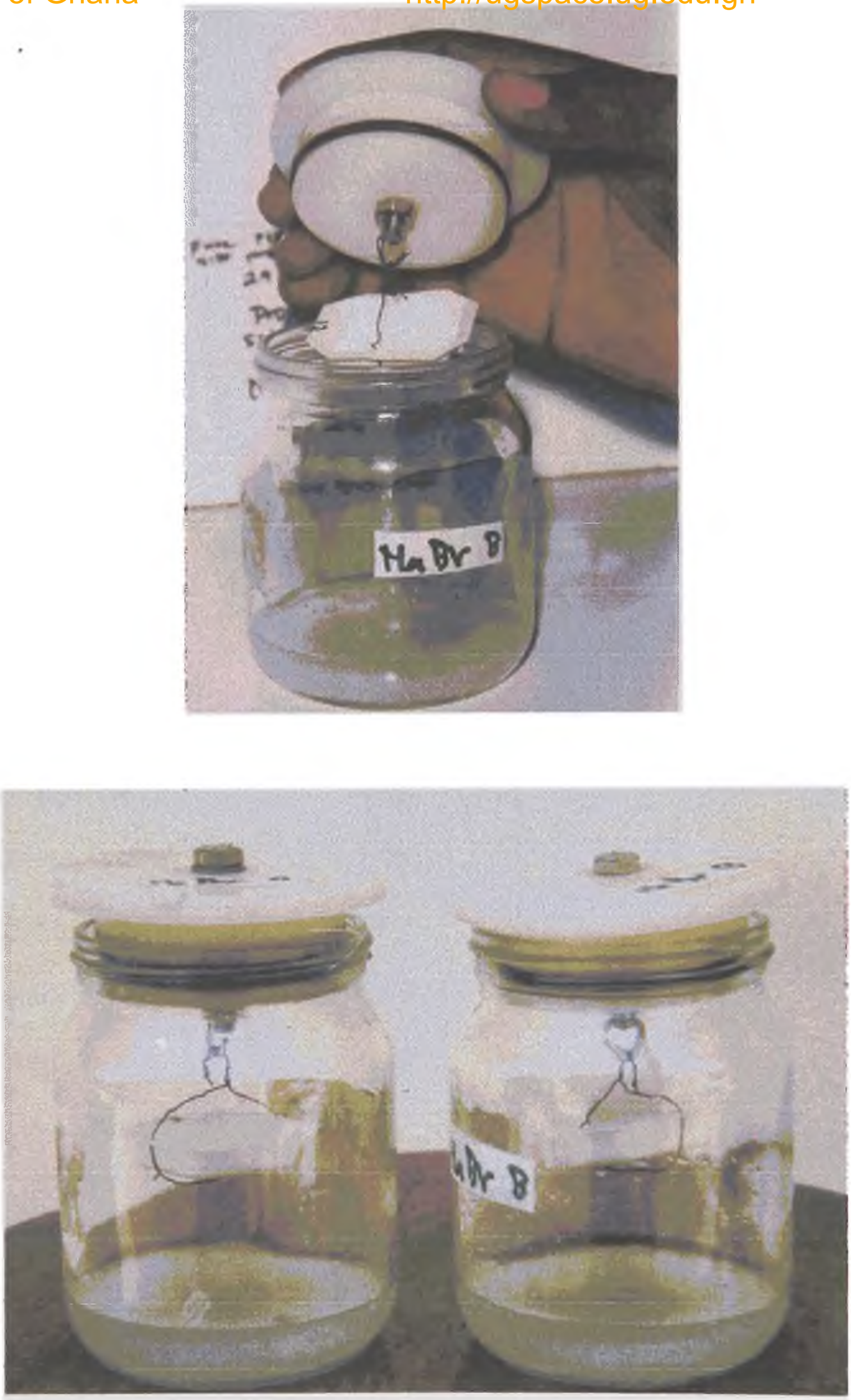

Fig 3.4: Containers used for sorption isotherm experiment

Table 3.1 Saturated solutions of the salts used for the experiment (Ayernor, 1976 ; Speiss *et. al.*, 1987)

Salts	Corresponding Aw at 30°C
Lithium Chloride	0.11
Potassium Acetate	0.23
Magnesium Chloride	0.33
Potassium Carbonate	0.44
Magnesium Nitrate	0.53
Sodium bromide	0.58
Strontium Chloride	0.71
Sodium Chloride	0.75
Potassium Chloride	0.84
Zinc Sulphate	0.89
Potassium Nitrate	0.93

3.3.5.2 Fitting of BET

The BET model was fitted to data obtained for A_w range 0.23 to 0.53 in order to estimate the monolayer moisture content of the samples. It was obtained from the relationship (Labuza, 1968).

$$\frac{a}{m(1-a)} = \frac{1}{m_1 c} + \frac{c-1}{m_1 c}$$

where:

a: is water activity,

m : is water content (gH_20/g solids),

m_1 : is the monolayer value, and

c : is a constant.

3.3.5.3 Heat of Sorption (Qs)

Heat of sorption of the maize flours was determined from sorption experiment . It was obtained from the relationship :

V= Vm x ba/ K+ba (Labuza) .... (E1)

Where $b = \frac{K}{RT} \exp(Qs/RT)$ = constant ....(E2)

Substituting equation E2 in E1 and rearranging for Qs, we have

$$Qs = RT \ln \frac{KRT_o}{\dfrac{Ka\,(Vm - 1)}{V}}$$

Where Qs = heat of sorption,

V = volume (water) adsorbed (g/g solid),

Vm = monolayer value,

k = Boltzman constant =1.38×10^{-16} erg /K,

a = water activity,

R = gas constant = 8.31×10^{7} erg /K,

T = absolute temperature (273K),

To = absolute temperature ^{0}K (303K), and

K = 1/po ; po = vapour pressure of water at To (0.0314).

3.3.5.4 Specific Surface

The specific surface of the flours was calculated from the relationship below : (Labuza,1968; Ayernor, 1976).

$$S = Vm \frac{1}{MH_20} . No . AH_20,$$

Where S = Specific surface,

Vm = monolayer value (water adsorbed /g solid),

AH_20 = area of water molecule = 10.6 x $10^{-20}m^{2,}$

MH_20 = molecular wt. Of water = 18g/mole, and

No = Avogadros number = 6 x 10^{23} .

3.3.6 Determination of the water vapour transmission of the selected packaging material

The method described in International Standard ISO 1663, (1999) and Bakke and Eckroth.,.(1986) with modification was used. The test material bag was sealed to the open mouth of a dish containing water as desiccant (figure 3.5). The assembly was then placed in an oven at 40° C for 24 hours. The weight of the assembly was taken after 24 hours to determine the amount of the water lost from the assembly. The experiment was done in triplicate. The results were expressed as rate of transmission of water vapour in units of mass per package per day : dW/dt. (Clyde, 1974),

.dW = water lost by assembly during experiment, and

. dt = Time (hour) for experiment.

a. Distance between test material and water surface (7.5cm)

b. Depth of water (8.5cm)

c. Diameter of dish (23cm)

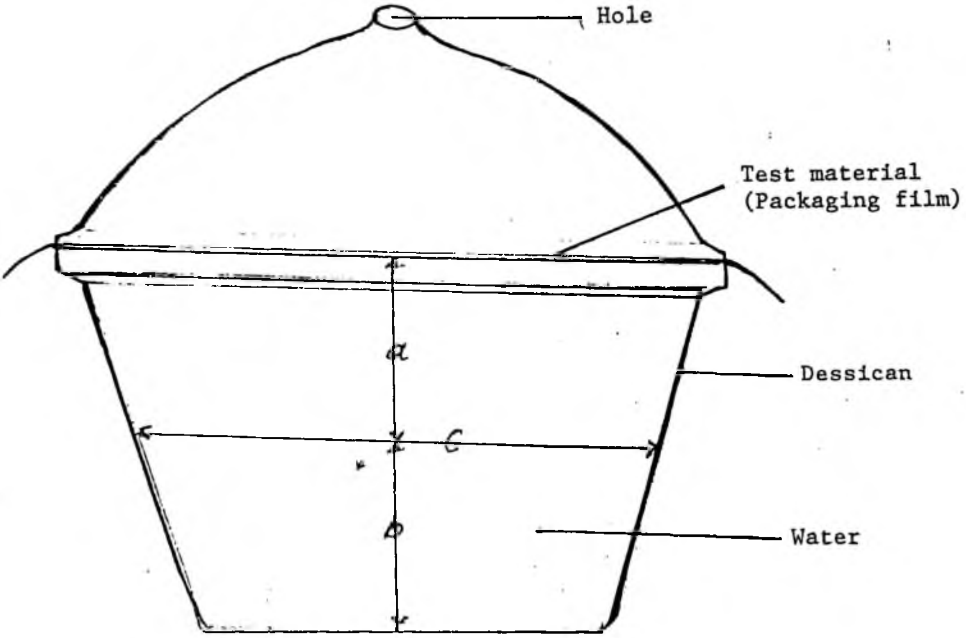

Figure 3.5: Test assembly for the determination of water vapour permeability of the packaging materials

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Influence of dehulling and degerming on the physico- chemical and other functional properties of the flour.

4.1.1 Material Balance

The material balance of dehulled and degermed maize for production of the flours is presented in the Table 4.1a and 4.1b below. The percent weight of material lost during the processing was 41.55% (Weight of the hull +germ +processing losses) for degermed maize flour and 7.61% (processing losses) for non degermed maize flour respectively. The total weight of hull and germ was 35 %. The losses recorded during the milling process of the flours could be attributed to the processing method that is semi-mechanised where the processor as well as the machine (Disc attrition mill) are involved. On the other hand, the mode of operation.

Table 4.1a : Material balance in degerming and dehulling of maize

Material balance	Weight of maize (%)	Weight of the hull + germ	Weight of flour (%)	% processing losses
Degermed flour	100	34.75± 0.25	58,45 ± 4.03	6.8 ± 0.91
Non degermed flour	100	---	92.4 ± 0.4	7.61 ± 0.38

Table 4.1b : Efficacy of degerming and dehulling of maize and yield of flour

	First passing	Second passing	Total
Weight of hull + germ	19 %	16 %	35 %
Deg. Flour yield	81%	65%	65 %
Non degermed flour yield	-----	-----	92 %

of the disc attrition mill which is open circuit grinding, combined with inaccuracy of the processor might have also contributed to the weight of material loss recorded.

Concerning the efficacy of dehulling and degerming of the maize it was observed that the total amount of the hull and germ after the processing was higher than the total percentage weight of bran plus germ and tipcap for the whole maize grain that is 18% (Kent, 1970). This higher value could be attributed to the degerming and dehulling processes where some quantity of endosperm is removed with the hull and the germ during the operation, mainly during the second passing (sending back again the product to the machine). As a result of that the processors affirmed that the second passing by-product can be used to make porridge for human consumption. While the by-product for first passing is used for animal feeding because it is made up basically of hull and germ.

4.1.2 Product Composition

The Proximate result analysis on degermed maize flour, non-degermed maize flour, and the by-products is as shown below in Table 4.2 .The proximate composition of whole maize flour prepared from *Obatanpa* almost agrees with results reported in Kent (1970) in the study of the maize variety *Dent* which has protein content of about 9.4 % fat 4.1% ash 1.4% crude fibre 2.0% and carbohydrate 72.1%. The values obtained for degermed maize flour fell within the range admitted by Codex Alimentarius (1994) which report that ash content should not be more than 1.0% on a dry weight basis; protein content (Nx6.25) not less than 7.0 % on a dry weight basis; crude fat content not more than 2.25% on a dry weight.

Proximate analysis results obtained for the degermed maize flour (DF) was different from that of the non-degermed maize flour (nDF). DF had lower fat, ash, and fibre content than nDF respectively (Table 4.2) . While carbohydrate was relatively higher in DF (79.9 %) than in the nDF (74.14%). These differences could be attributed to the degerming processes during which the machine leaves only the endosperm and a trace of the bran (hull) and germ to be milled. The bran is about 5% of the weight of whole grain and is made up of 2% protein, 1% fat, and 2% ash, whilst the germ plus tipcap which make up about 13 % contain about 84% of the total fat of the whole maize grain. (Kent, 1970) . Thus, by dehulling and degerming almost all these constituents of hull and germ are lost always with some amount of endosperm. From Table 4.3, the proximate composition of the by-product of the first passing and the second passing showed some differences in percentage of crude protein obtained, 12.99 % for first by-product and 4.01 % for second by-product. There was also significant difference ($p \leq 0.05$) in fat and carbohydrate content of both first and second passing by-products, 13.05% and 47.99% for first by-product and 8.98% and 68.53% for second by-product respectively. These differences could be explained by the fact that, during the first passing, almost all the germ which is rich of fat was removed as compared to the second passing where more flour from endosperm get into the second by-product; hence making the second by-product suitable for human consumption. Analysis of variance conducted on the data (Table 4.3) showed that with the exception of protein, there were significant differences ($p \leq 0.05$) in ash, fat, fibre, and carbohydrate content between the degermed and non-degermed maize flour samples.

Table 4.3 : ANOVA summary table showing F-values of proximate composition

Process Variable	Protein	Fat	Ash	Fibre	carbohydrate
Flourtype	25.694	999.999 *	101.544*	1000.000*	1000. 000 *
Replicates	2.855	999.999	2.136	2.250	0.000

* Significant F. ratio at $p \leq 0.05$

Table :4.2 Proximate composition of dehulled - degermed maize flour and the whole maize flour (dry weight basis).

Proximate composition (%)	Degermed maize flour	Non degermed maize flour	Hull+germ after first passing	Hull+germ after second passing
** Crude protein	7.46 ± 0.27	8.20 ± 0.07	12.99±0.35	4.01 ± 0.66
Crude fat	1.42 ± 0.34	6.02 ± 0.63	13.05 ± 2.22	8.98± 0.40
Ash	0.2 ± 0.03	1.51 ± 0.16	3.97±0.18	2.42 ± 0.078
Crude fibre	0.51 ± 0.01	1.84 ± 0.05	4.76±0.51	5.75 ± 0.33
*Carbohydrate	79.96	74.14	47.99	68.53

Mean value (g/100g dry matter basis) from duplicate analyses ± SD .

* Calculated by difference

** N x 6.2

4.1.3 Physico-functional properties

a) Particle size analysis

The degermed maize flour sample was very white while the non-degermed maize flour was cream. The results of the particle size analysis of the flours are shown in Figure .4.1. Fliedel (1993) has defined the average granularity **(G50)** as being the aperture sieve that allows 50% of the flour to pass through. According to this definition, the average granularity of the DF and nDF analysed was between 0.5 and 1 mm sieve aperture. In spite of the fact that both flours had the same average granularity , a difference was noticed between 0.5mm pass through of particle for DFG and nDF which were 96.47% and 71.88 % respectively. The same observation was also made for 0.25mm pass through which were 38 % for DF and 13.32% for nDF. These observations could be attributed to the difference in the crude fibre content of the two flours which was about 0.51% for DF and about 1.84 % for nDF respectively (Table 4.2) . There was also a slight difference between the results obtained for DF compared to the value of the Ghana Standard's board (Codex Alimentarius, 1994), which are: not less than 95% of the DF shall pass through a sieve of 0.85 mm aperture size, not less than 45% through a sieve of 0.71mm aperture size, and not more than 25% through a sieve of 0.210 mm aperture sieve. These slight differences could be due to the milling and sieving conditions and different aperture size of sieve used.

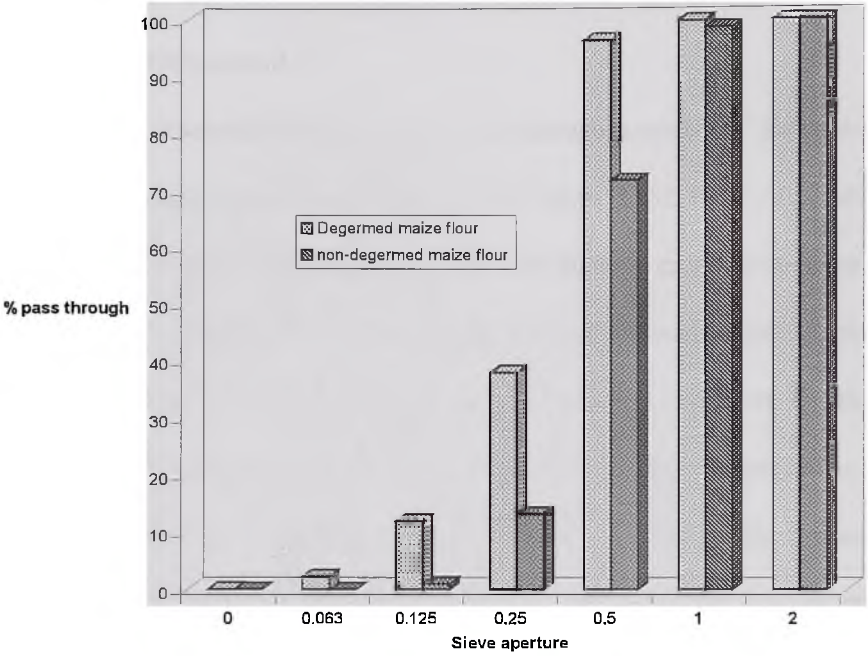

Figure 4.1: Particle size Analysis

b) Water absorption

Water absorption capacity is an important functional characteristic in the development of a ready to eat food for cereal grains, since a high water absorption capacity may assure product cohesiveness. Proteins are mainly responsible for the bulk of the water uptake and to lesser extent the starch and cellulose at room temperature.

From the results obtained (Figure 4.2) the percentage amount of the water absorbed by non-degermed maize flour was lower (152.46%) than the Degermed maize flour which recorded 197.016% though crude protein and crude fibre which contribute to a higher water absorption was higher in the non-degermed maize flour. The higher water absorption recorded for the degermed maize flour could be due to its particle size, giving a larger surface area and high capillarity in the flour. The relative higher carbohydrate content (79.96%) might also have contributed to the higher water absorption capacity of DF.

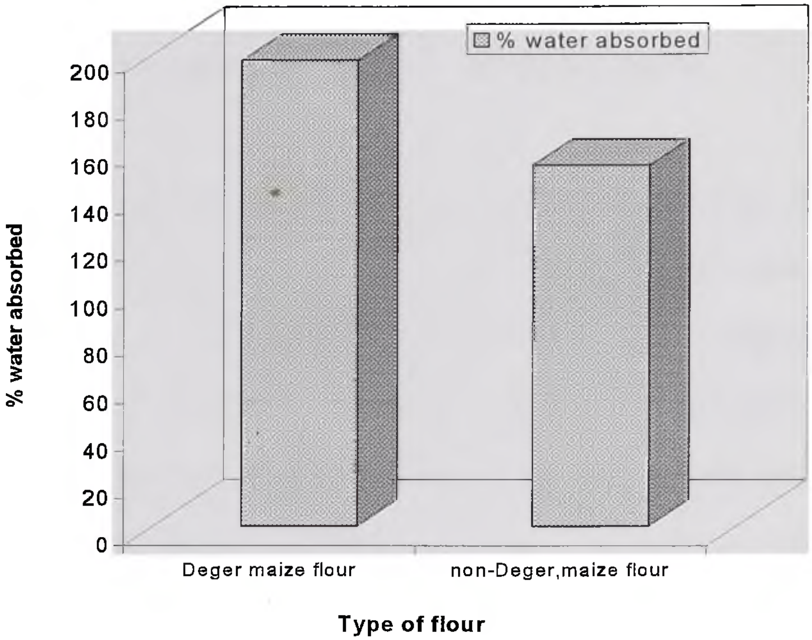

Figure 4.2 : Water absorption of the flour samples at 29 1°C

c) Swelling in water

The swelling capacity is a function of the process conditions, nature of the material and the type of treatment. Biopolymers such as starch and proteins contribute to the development of this characteristics. Swelling can be defined as the volume of expansion of a molecule in response to water uptake which it possess until a colloidal suspension is achieved or until further expansion and uptake is prevented by intermolecular forces in the swelled particle.

Swelling capacity for degermed maize flour and non-degermed maize flour was determined at 29±1° C (corresponding to room temperature) and the results obtained were as shown in Figure 4.3 . It was observed that differences existed in swelling capacities of degermed maize flour and non-degermed maize flour sample. The two samples showed a rapid swelling within the first minute increasing by about 18 ml in volume for degermed maize flour(DF) and 12ml in volume for non-degermed maize flour (nDF), after which there was hardly any further change in volume . However swelling in water for DF was higher than the nDF by 6ml. This could probably be due to the effect of dehulling and degerming processes on the maize flour. The DF has a high carbohydrate or starch content from the results obtained on proximate analysis and also finer particle size than nDF. These factors are known to enhance the swelling capacity of the flour, hence the DF recorded a higher swelling capacity than nDF. Afoakwa.,(1996) reported that the role of protein in the swelling and viscosity characteristics of food is less well known than those of starch.

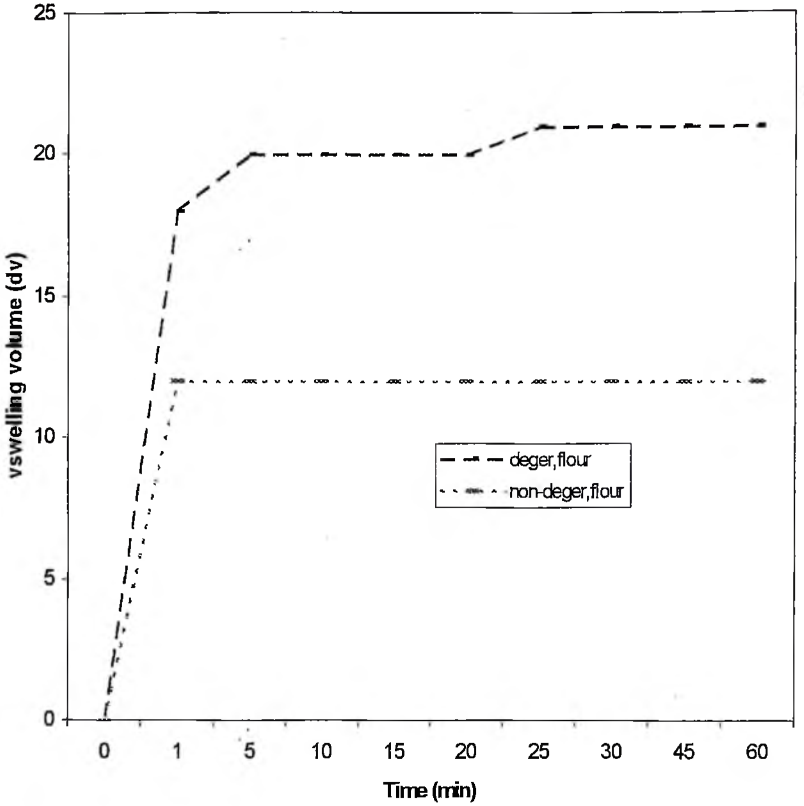

Figure 4.3: Swelling capacity of the flour at 29 1°C

d) Brabender Visco-amylograph Viscosity indices

The effect of dehulling and degerming of maize in production of maize flour were investigated using Brabender Visco-amylograph to measure the cooked paste characteristics of the degermed maize flour (DF) and non-degermed maize flour (nDF) sample. The Brabender visco-amylograms used was to give information on the hot past viscosity characteristics of the starch in the flours. Preliminary experiments revealed that 10% slurry gives a standard consistency (500 BU) for the DF. Pasting temperature is indicated by the temperature at which the first detectable viscosity is measured by the amylograph. It was observed that DF (fresh sample) flour started gelling at a temperature of 70.5 °C after 27 minutes cooking and nDF at a temperature of 79 °C after 31 minutes. Peak viscosity and viscosity at 95 °C for DF were 505 BU and 495 BU respectively while for nDF it was at 370 BU and 360 BU respectively (Figure 4.4).

The lower BU or peak viscosity and viscosity at 95 °C recorded for nDF could be due to the fact that the nDF has a higher percentage fat content which could lead to lower frictional force during the testing process and probably result in emulsification, therefore lowering the viscosity. Also the high fibre content of the nDF may have contributed to the lower viscosity by reducing the starch cohesiveness.

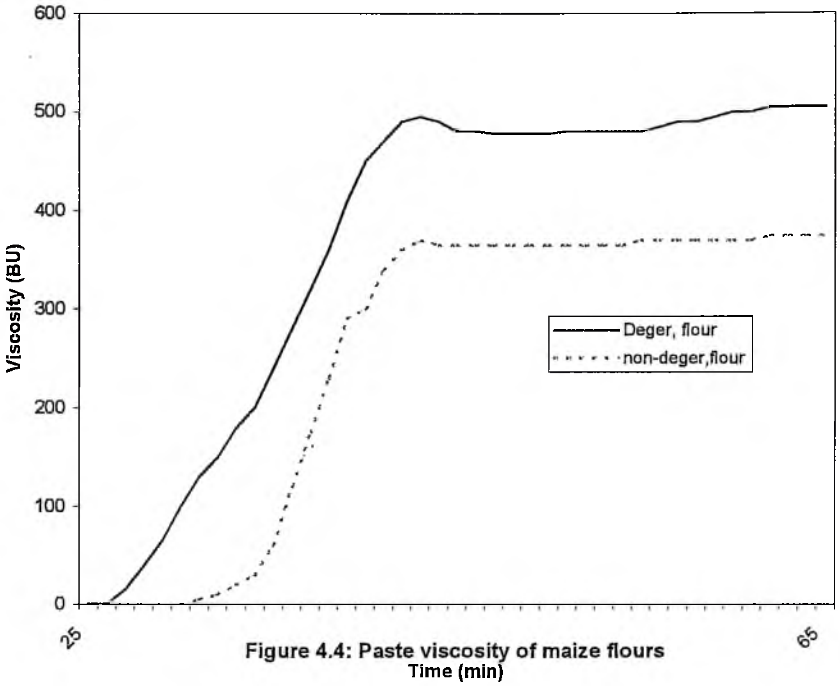

Figure 4.4: Paste viscosity of maize flours

4.2 Moisture sorption properties of degermed and non -degermed maize flour

4.2.1 General observations over the moisture equilibrium

Isotherm data are based upon the moisture content of a sample in equilibrium with a known Aw, and because that sufficient time was allowed for complete equilibration between the samples and the Relative Humidities . It was observed that the equilibrium time for Degermed maize flour sample (DF) was 15 days while Non-Degermed maize flour sample (nDF) took only 12 days to reach equilibrium.

It was also observed that during the experiment, no yeast or mould growth occurred except for samples exposed to Aw = 0.93 at 30 °C. Apart from the microbial growth, there were physical changes such as caking, discoloration and loss of free flowing properties of both maize flour samples exposed to Aw = 0.93.

4.2.2 The moisture Sorption Isotherm

A useful approach to the study of the adsorption of moisture by solid substances, such as cereal flour is given by means of sorption isotherm.

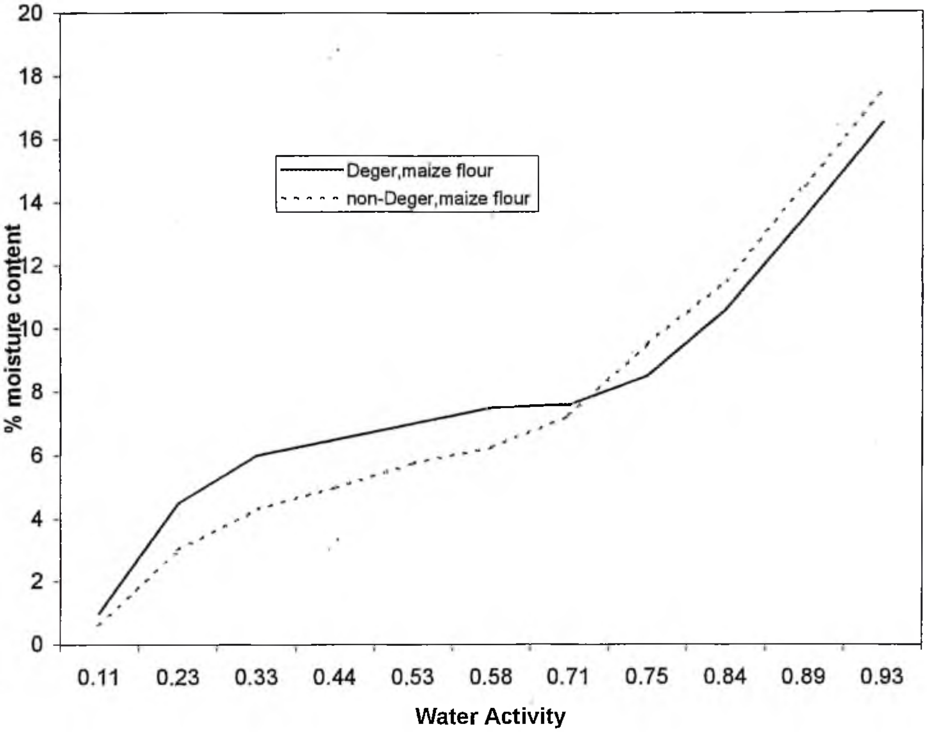

Figure:4.5 : Sorption isotherm of the flour samples at 29 1°C

A moisture sorption isotherm is a curve describing the amount of moisture adsorbed by a substance at a particular constant temperature; as a function of the equilibrium vapour pressure, water activity or relative humidity.

The isotherm of Degermed maize flour (DF) and Non-Degermed maize flour (nDF) studied (Figure 4.5) can be classified as belonging to BET type II isotherms (Labuza, 1984). A portion of the total water content present in food is strongly bound to specific sites. These sites include hydroxyl groups of polysaccharides, the carbonyl and amino groups of proteins, and others on which water can be held by hydrogen bonding, ion-dipole bonds, or other strong interaction., (Owen *et al.*, 1976).

Comparing moisture adsorption of DF and nDF it was noticed that the moisture uptake by DF was higher than the moisture uptake by nDF for the water Activity (Aw) 0.11 to 0.71 indicating that the DF was more hygroscopic, whereas nDF registered relatively higher amounts of moisture uptake for Aw between 0.71 to 0.93. This moisture uptake pattern of the two (2) flour samples for the Aw between 0.11 and 0.71 can be explained based on the fact that the particle size of the DF are finer therefore exposing a larger surface area for moisture absorption than nDF whose particle size are less fine. Figure 4.1 shows that only DF particle were able to pass through the smallest sieve with aperture 0.063 mm.

This variation can also be attributed to the difference in carbohydrate content (79.96% and 74.14 % for DF and nDF respectively). Within this low Aw range (0.11 - 0.71) a higher content of hydrophilic macromolecular materials usually leads to higher uptake of moisture (Johnson, 1996). But the reverse tendency observed after Aw 0.71 to 0.93 could be attributed to the difference in fibre content of the two (2) fours samples. DF contains less fibre (0.51%) than nDF (1.84%). The relatively higher fibre content of nDF means that there are more voids, crevices and holes where free water molecules can be mechanically entrapped (Johnson, 1996). Based on these sorption isotherm results obtained from this study and according to the reaction rates in food as function of water activity (Owen, *et al.*, 1975), we can affirm that water activity for good storage of the DF and nDF should be maintained under condition such that Aw is between 0.33 ant 0.84 corresponding to water content between 6 % to 10.6% for DF and 4.3 % to 11.5 % for nDF respectively; in order to avoid lipid oxidation mainly for nDF and also avoid moulds and yeast that start to grow at Aw between 0.7 and 0.8. However, due to the rapid absorption after Aw = 0.71 it would be safer to keep the Aw of the flour not exceeding 0.71.

4.2.3 Estimation of monolayer capacities using the BET plot, and further processing of sorption data.

The BET (Brunauer - Emmett - Teller) equation is an indispensable tool used to calculate the monolayer value of foods stuffs. Although the BET analysis is based on over simplified assumptions (Labuza, 1968,) it is certainly expected to hold for water sorption in foods. The monolayer concept is useful because of its relationship with several aspects of the physical and chemical deterioration in dehydrated foods. (Iglesia & Chirife, 1976). In addition the BET monolayer calculation is an effective method for estimating the amount of water bound to specific polar sites in dehydrated food systems. The BET equation was used to obtain the BET plots from which the slopes C - 1/mC and intercepts 1/mC were calculated (Figure 4.6.). In accordance with the usual practice, water sorption data at water activity 0.0 to 0.5 were used for the BET analyses. The monolayer capacities were then estimated for the flour samples It was found that the monolayer values for DF and nDF were 3.9 and 2.98 g/100g solid matter respectively at 30 ^{O}C.

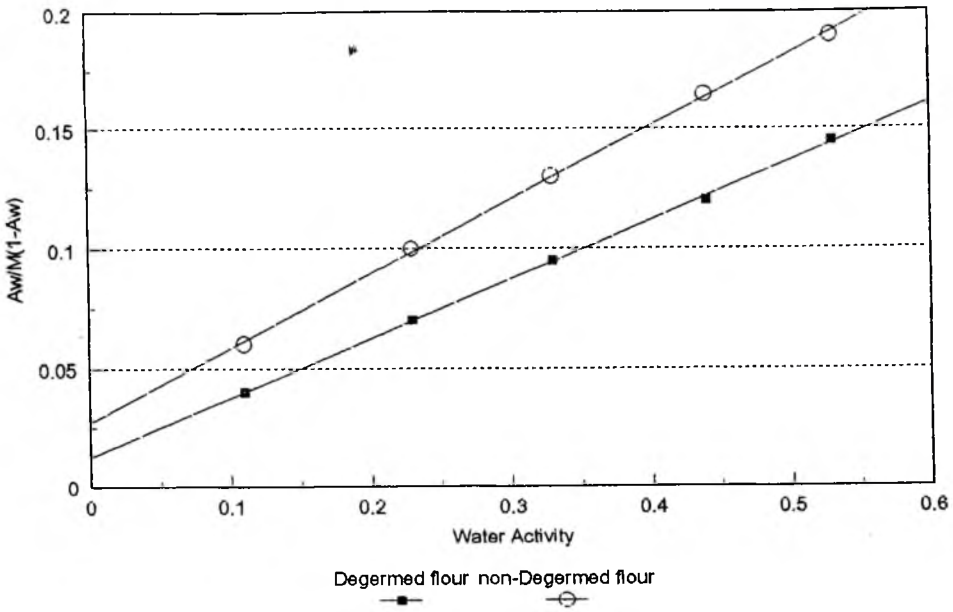

Figure 4.6 : BET plot for maize flours

Table 4.4 : BET indices of flour samples

Sample	Intercept 1/mc	Slope c-1/mc	C (constant)	m (mono-layer g/100g
NDF	0.025	0.31	13.4	2.98
DF	0.016	0.24	16.0	3.90

4.2.4 Treatment of data

4.2.4.1 Calculation of monolayer value (m)

(i) Degermed maize flour sample (DF)

From the straight line $1/mC = 0.016$ imply $mC = 62.5$

$C - 1/mC = 0.24$ imply $C-1 = 0.24\ mC$

$C-1 = 0.24 \times 62.5$

$C = 16$

If $mC = 62.5$ and $C = 16$ therefore **m = 3.9 g/100 solid matter**

(ii) Non-Degermed maize flour sample (nDF)

From the straight line $1/mC = 0.025$ imply $mC = 40$

$C - 1/mC = 0.31$ imply $C-1 = 0.31\ mC$

$C-1 = 0.31 \times 40$

$C = 13.4$

If $mC = 40$ and $C = 13.4$ therefore **m = 2.98 g/100 g solid matter**

The reason for the lower monolayer value for the nDF as compared to DF may be attributed mainly to the lower carbohydrate content of nDF . Apart from the proteins, the charge on polar groups of the polysaccharide are the binding sites for the monolayer water molecules (Johnson., 1998). Therefore, in term of shelf life DF with a higher monolayer value can be kept longer because it binds more of its water therefore making it unavailable to both microbes and enzymes reactions.

4.2.4.2 Heat of sorption (QS)

It was observed that from Aw of 0.11 to 0.23 there were sharp increases in total heat of sorption (Figure 4.7). This could be due to the fact that the sample at this Aw has water molecules tightly bound in a layer by strong hydrogen bounds. (Johnson, 1996). A sharp decrease was observed at Aw between 0.23 to 0.33. This is because the water molecules are less firmly held since the water molecules sorb near or on top of the first layer of molecules. The water molecules are held in solid matrix by capillary condensation or multilayer adsorption (Johnson, 1996).

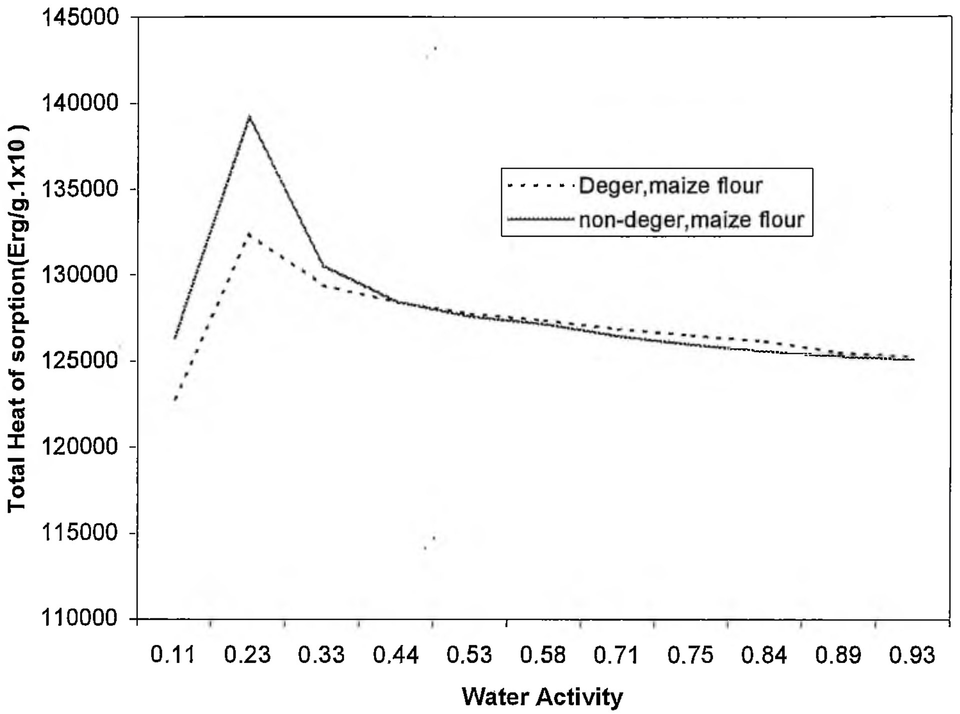

Figure 4.7: Effect of water activity on heat of Sorption at 30 C

The gradual decrease observed after this stage (Aw = 0.33 to 0.93) emphasises the fact that the sample was by then accessed by much more water hence the amount of energy required to remove the water molecule is less.

Zuritz *et al.*, (1985) agreed that the heat of sorption decreases with increased moisture concentration, provided no biological, chemical, or any other changes occur during sorption. The decrease in the isoteric heat with amount of water sorbed can be qualitatively explained considering that initially, sorption occurs on the most active available sites, giving rise to the greatest interaction energy. As these sites become occupied, sorption occurs on the less active sites giving lower heats of sorption. At lower Aw ranging for 0.11 to 0.44 the curve showed that, (Figure 4.7) the total heat of sorption of nDF is higher than heat of sorption of DF. This observation does not correlate with the fact that the monolayer moisture content of DF is higher than that of nDF. It was expected that within Aw range of 0.11 to 0.44, the more the water molecules the higher the total heat of sorption, since the monolayer water molecule are strongly bound to the food particles. Iglesias & Cherife (1976) have explained that because of changes in constitution, dimensions and other properties, during the sorption process, it is generally difficult to interpret the causes of heat of sorption within this Aw range.

At the high water activity, heat evolved was less because the water molecules are not firmly bound, but entrapped in capillaries with water molecules held together by weak Van der Waal forces, hence less heat was evolved as water molecules are entrapped.

4.2.4.3 Specific Surface

The surface area per unit mass is called the specific surface (Sp). The specific surface of the sample studied was calculated according to Labuza.,(1968); Ayernor, (1976). See section 3.3.5.4.

Specific Surface for degermed maize flour sample (DF) and the non-Degermed maize flour (nDF) were found to be 0.1378×10^3 and 0.1053×10^3 m^2 respectively. This indicates that the DF has a larger surface area than the nDF emphasising the finer particles obtained in the DF compared with nDF. This resulted in the higher hygroscopicity pattern for the DF at Aw 0.11 to 0.71 as observed in the sorption isotherm (Figure 4.5).

4.3 Water vapour permeability of selected packaging material

Permeability test (Figure 4.8) was conducted in order to know the rate of transmission of Water vapour through the following packaging materials : High density polyethylene (HD), Low density Polyethylene (LD), and Polypropylene (PP).

There was not much difference between the rate of water transmission for HD and PP (0.021 and 0.022 g/h respectively) (Figure 4.8) . The LD showed a higher transmission rate compare to PP and HD, recording a water vapour transmission rate of 0.04g/h. Heiss and Munich.,(1970) has reported a similar observation where HD and PP film had a lower permeability to both water vapour and gas than LD by a factor of about 2 - 3 times.

Based on this result HD and PP were chosen as suitable packaging material for the storage study because of their lower rate of transmission of water vapour.

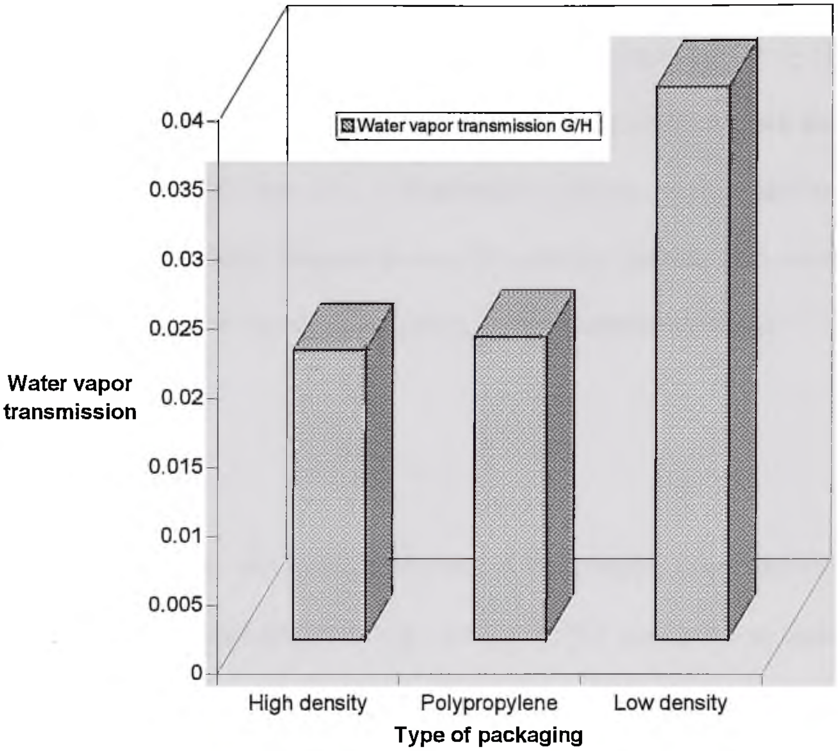

Figure 4.8:Water vapor Permeability of the packaging materials used

4.4 Effect of storage conditions and suitable packaging materials on the physico-chemical and microbiological indices of the degermed maize flour during storage

The storage conditions and packaging were as defined in materials section (materials and methods) .The flour samples were packaged into High Density Polyethylene (HD) and Polypropylene (PP) and kept at 29 ± 1 ° C corresponding to room temperature for six (6) months, moisture, pH, titratable acidity, crude fat, free fatty acid, cooked paste viscosity, mould, and bacterial counts were the indices measured over the storage period. The results are discussed below. (See Appendices Tables 1-6 for numerical details)

4.4.1. Moisture

A general increase in the moisture content of the samples dried and stored in the different packaging materials was observed. This increase was significant between 0 and 2 months storage for both flour samples (Figure 4.9a , 4.9b and appendix, Table 1) A slight variation was observed after 2 months up to the 6 months of storage period.

Analysis of variance of the data for each flour samples showed that storage time significantly affected ($P \leq 0.05$) the moisture content of the flours.

The packaging materials used (HD, and PP) had no significant effect on the overall moisture content ($P > 0.05$). This confirms the results obtained from water vapour permeability test where HD and PP were almost the same with low rate water vapour transmission.(4.2.6).

However Figure 4.9a , 4.9b show that moisture picked up within the first 2 months was faster in HD than in PP . This may be attributed to the fact that PP has better moisture barrier than HD (Saravacos, 1995). Johnson (1998) also found a similar trend with dehydrated plantain slices packaged in PP and Polytene porches. After 2 months storage, the moisture content of the packaged samples are comparable because equilibrium has been achieved. There is a decrease in driving potential for moisture transfer which is the difference between the activities of the combined air and flour inside the packaging and the immediate surrounding air outside the packaging (Johnson 1998).

Also the moisture uptake by the oven dried samples was higher than solar dried samples mainly between 0 month and 2 months of storage. Analysis of variance on the data showed significant differences ($P \leq 0.05$) between drying methods and moisture content. This may probably be due to the fact that the oven-dried samples with initial low moisture content has the ability of quickly variance on the data showed significant differences ($P \leq 0.05$) between drying methods and moisture content. This may probably be due to the fact that the oven-dried samples with initial low moisture content has the ability of quickly taking up more moisture than solar-dried samples during the initial storage period before equilibrium period.

Even though differences were observed in moisture content of the flour samples, after 6 months storage, the highest moisture content of the samples was 12.37 % which was less than 13 % for storage of cereal flours. (Kent, *et al.*, 1970).

OD HD is : Sample Oven Dried (OD) and packaged in High density polyethylene (HD)

OD PP is : Sample Oven Dried (OD) and packaged in polypropylene (PP)

SD HD is : Sample Solar dried (SD) and packaged in High density polyethylene (HD)

SD PP is : Sample Solar Dried (SD) and packaged in polypropylene (PP)

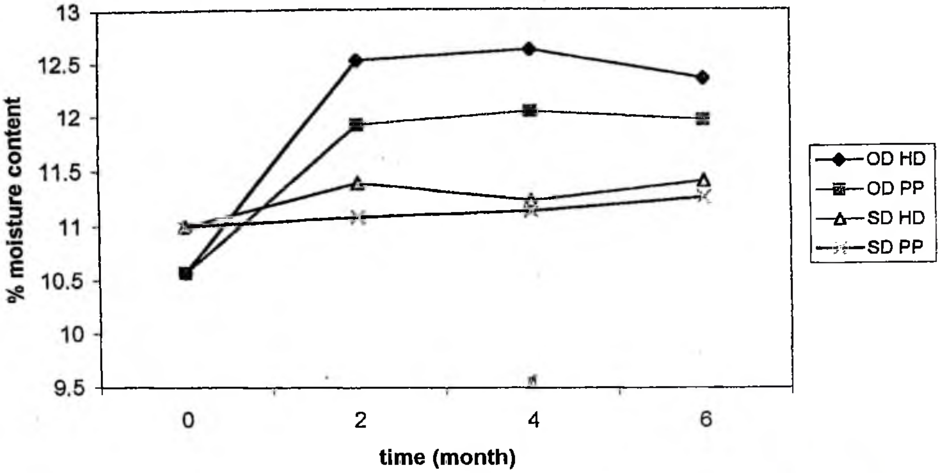

Figure 4.9a : Percentage moisture content of degermed maie flour during storage

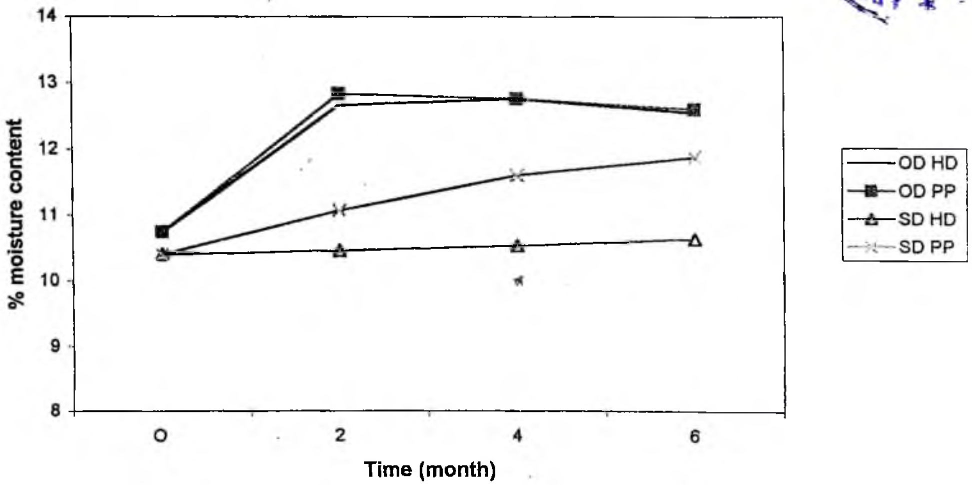

Figure 4.9b : Percentage moisture content of non-degermed maize flour during storage

4.4.2 pH and Titratable Acidity

The pH of the flour samples was weakly acidic over the storage period even though it was relatively high at 2 months (Figure 4.10a and 4.10b, and Appendix, Table 2). There were some slight variations between months 2 to 6 Percentage increases in titratable acidity (Figure 4.11a, 4.11b and Appendix, Table 3) of the flour samples correlates with decreases of the pH for both flour samples studied. The increase in acidity and decrease in pH over the storage period could be due to break down /dissociation of lactic acid as well as increase of Free Fatty acid in the flour samples as the moisture content of the flour also increased during storage time (between 2 and 6 months). Similar observation was reported by Afoakwa., (1996), when working on storage studies of cowpea fortified maize dough.

Analysis of variance on the data showed that storage time and flour type significantly ($p \leq 0.05$) affected the pH and acidity levels in all samples (Appendix, Table 8 and 9). Dzokoto, (1982) observed that acidity increases as pH falls during fermentation..

Also, it was observed that the percent acidity of non-degermed flour samples over the storage time was higher compared to degermed maize flour samples.

These could be attributed to the difference in fat content of the two types of the flour. Non-degermed maize flour contains more crude fat (5.76%) than Degermed maize flour (1.57 %) and this usually leads to oxidative or hydrolytic rancidity of the fat in the non-degermed flour.

OD HD is : Sample Oven Dried (OD) and packaged in High density polyethylene (HD)

OD PP is : Sample Oven Dried (OD) and packaged in polypropylene (PP)

SD HD is : Sample Solar dried (SD) and packaged in High density polyethylene (HD)

SD PP is : Sample Solar Dried (SD) and packaged in polypropylene (PP)

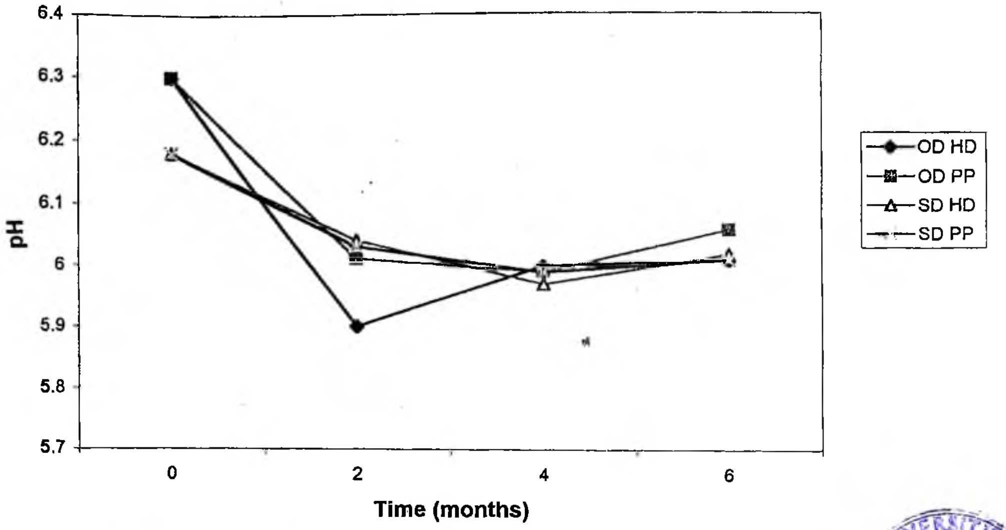

Figure 4.10a : pH of degermed maize flour during storge

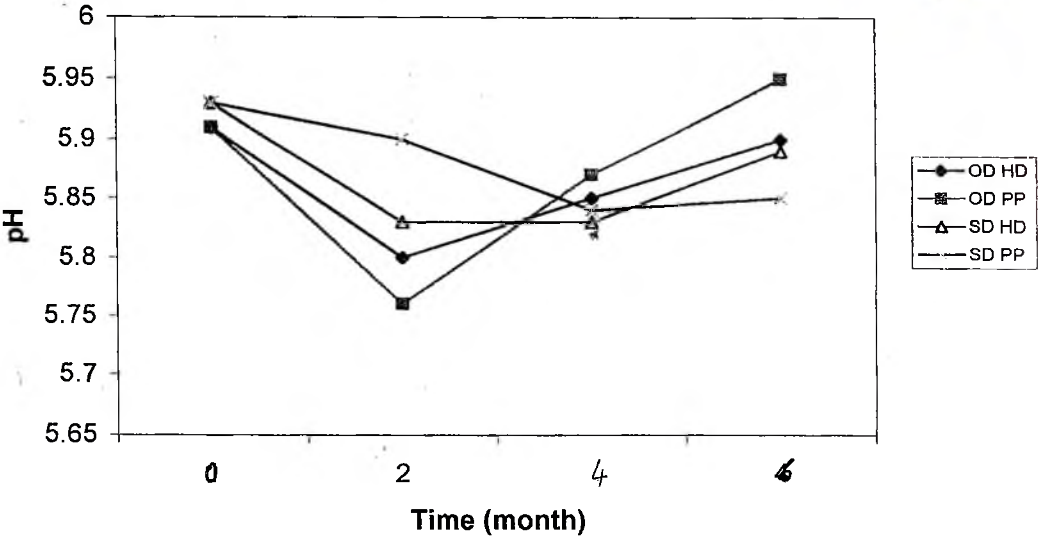

Figure 4.10b : pH of non-degermed maize flour during storage

OD HD is : Sample Oven Dried (OD) and packaged in High density polyethylene (HD)

OD PP is : Sample Oven Dried (OD) and packaged in polypropylene (PP)

SD HD is : Sample Solar dried (SD) and packaged in High density polyethylene (HD)

SD PP is : Sample Solar Dried (SD) and packaged in polypropylene (PP)

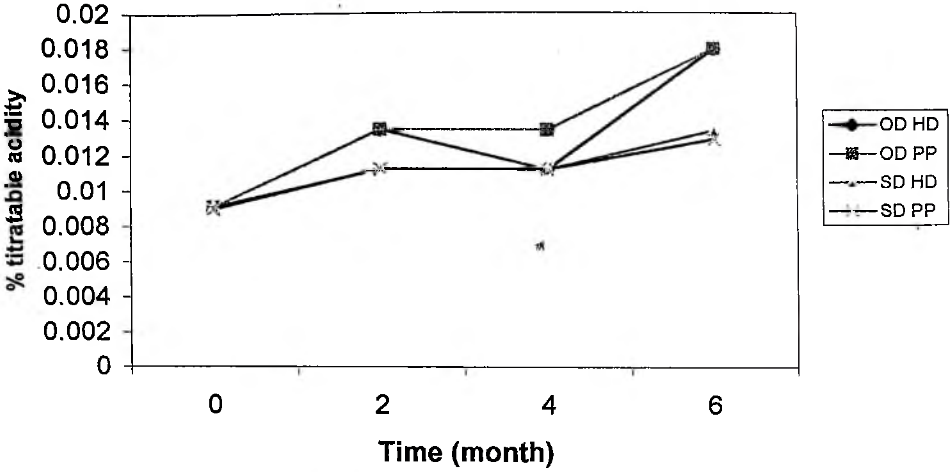

Figure 4.11a : Percentage Titratable acidity of degermed maie flour during storage

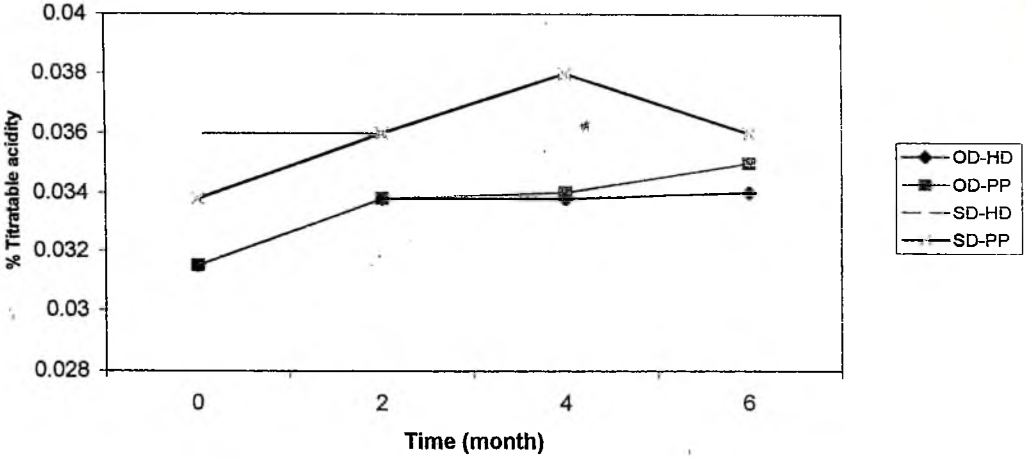

Figure 4.11b : Percentage titratable acidity of non-degermed flour during storage

4.4.3 Fat and Fatty acid

A percentage fat content of the two flour samples decreased after 2 months in storage and showed slight fluctuations for the rest of the storage period (Figure 4.12a and 4.12b, and appendix, Table 4) while the percentage fatty acid (Figure 4.13a 4.13b, and appendix, Table 5) on the other hand increased during the storage period.

The differences of the fat and free fatty acid levels observed after 2 months in storage could be attributed to the initial difference of the fat content of the two samples. The statistical analysis showed that the storage time and type of the flour had significant effect ($P \leq 0.05$) on the fat and free fatty acid levels (Appendix, Table 10 and 11). Obviously the non-degermed flour sample showed high percentage free fatty acid content as compared to degermed maize flour samples owing to the initial differences of fat content of the flour samples. Though the maximum level of free fatty acid recorded (0.54 %) after 6 months storage fell within the acceptable level which should not be more than 1% as lactic acid in corn flour (Matz, 1969). But with the storage time beyond 6 months non-degermed maize flour has higher probability of getting spoilt faster than degermed maize due to lipid oxidation.

OD HD is : Sample Oven Dried (OD) and packaged in High density polyethylene (HD)

OD PP is : Sample Oven Dried (OD) and packaged in polypropylene (PP)

SD HD is : Sample Solar dried (SD) and packaged in High density polyethylene (HD)

SD PP is : Sample Solar Dried (SD) and packaged in polypropylene (PP)

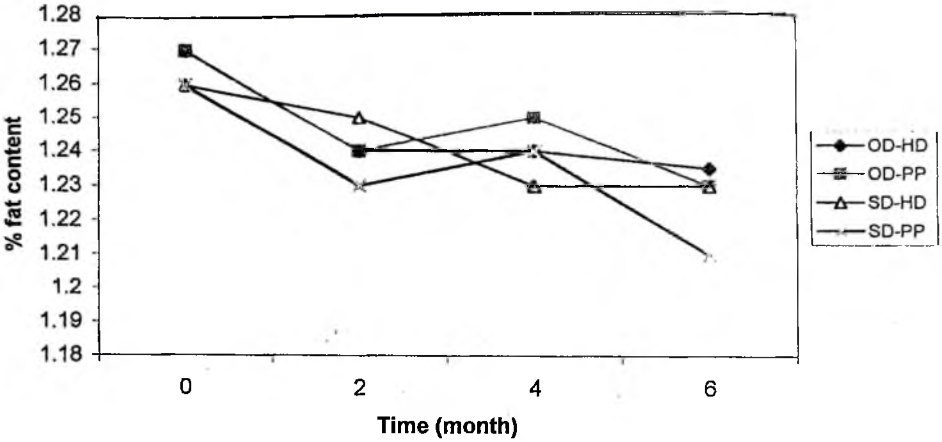

Figure 4.12a : Percentage Fat content of degermed maize flour during storage

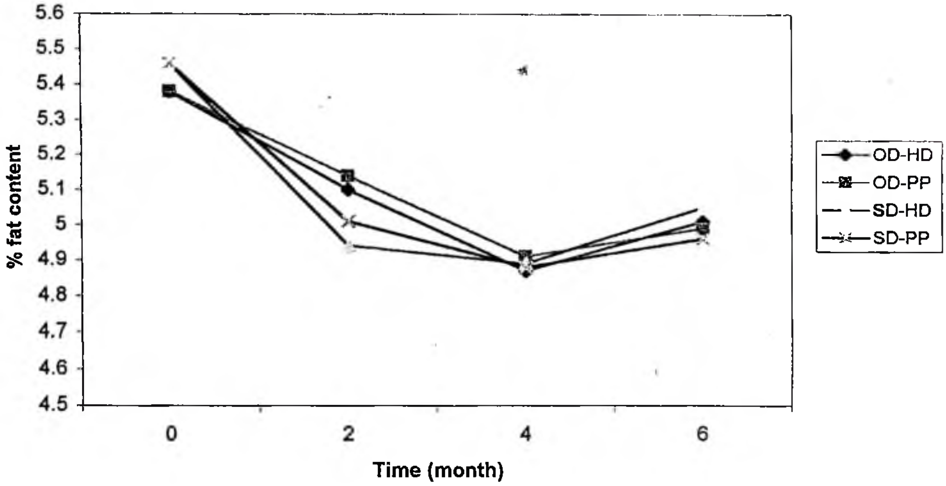

Figure 4.12b : Percentage Fat content of non-degermed maie flour during storage

OD HD is : Sample Oven Dried (OD) and packaged in High density polyethylene (HD)

OD PP is : Sample Oven Dried (OD) and packaged in polypropylene (PP)

SD HD is : Sample Solar dried (SD) and packaged in High density polyethylene (HD)

SD PP is : Sample Solar Dried (SD) and packaged in polypropylene (PP)

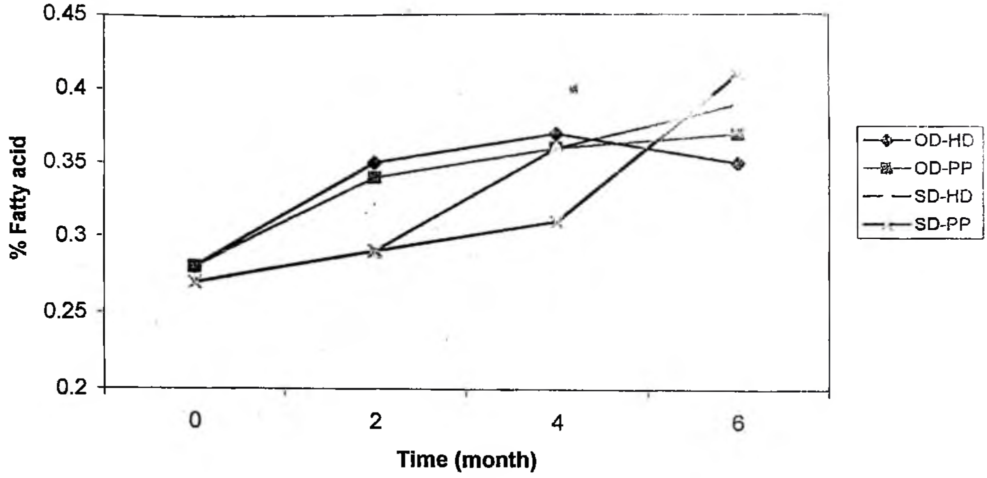

Figure 4.13a : Percentage Fatty acid of degermed maize flour during storage

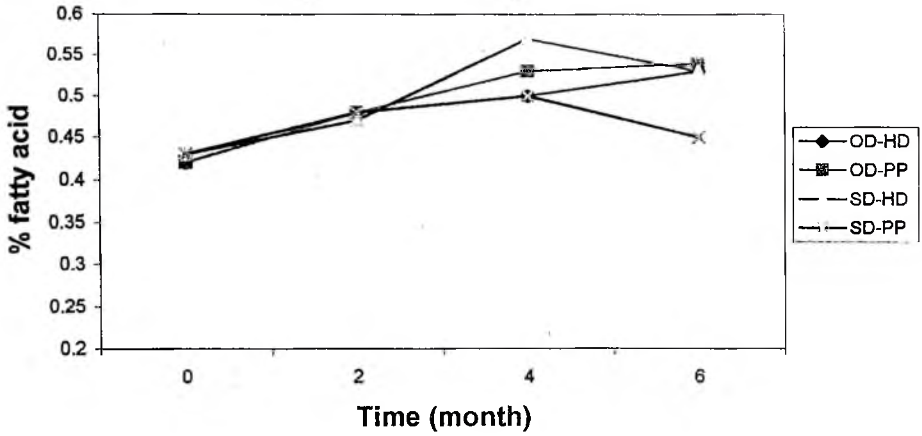

Figure 4.13b : Percentage Fatty acid of non-degermed maize flour during storage

4.4.4 Microbiological Analysis

Foods are normally contaminated with micro-organisms since the entire environment in which we live is colonised by them. However the microbial population of a food sample is affected by many factors. The results throughout this study (Table 4.5 and 4.6) indicated a slight increase in the number of micro-organisms from the initial time of production (0 month) to the final period of the storage (6 months). The number of micro-organisms in the different drying methods of samples (solar dried and oven dried) were similar.

Also, not much difference was observed in terms of number of micro-organisms in Polypropylene and High density polyethylene packaging materials.

In general the number of micro-organisms (bacterial and mould) counted were low per gram sample. This could be probably attributed to low levels of contamination and acceptable moisture content which was 12.37% maximum of the packaged flour samples during storage.

Table 4.5: Total Bacterial count (per. Gram) of the flours packaged into selected packaging material during the storage period

Period	Degermed maize flour				Non degermed maize flour			
	Oven dried		Solar dried		Oven dried		Solar dried	
	HD	PP	HD	PP	HD	PP	HD	PP
* 0 month	72 ± 14	72 ± 14	58 ± 4	58 ± 4	34 ± 6	34 ± 6	25 ± 6	25 ± 6
2 months	76 ± 22	81 ± 13	66 ± 9	72 ± 4	41 ± 4	34 ± 2	66 ± 7	36 ± 13
4 months	32 ± 6	64 ± 8	94 ± 16	54 ± 11	70 ± 14	55 ± 18	44 ± 6	48 ± 6
6 months	59 ± 11	70 ± 12	86 ± 8	75 ± 6	65 ± 10	54 ± 13	53 ± 15	40 ± 9

* Fresh sample (just before the flour has been packaged.)

Table 4.6: Mould count (per. Gram) of the flours packaged into selected packaging material during the storage period.

Period	Degermed maize flour				Non degermed maize flour			
	Oven dried		Solar dried		Oven dried		Solar dried	
	HD	PP	HD	PP	HD	PP	HD	PP
* 0 month	47 ± 11	47 ±11	57 ± 5	57 ± 5	41 ± 13	41 ± 13	40 ± 12	40 ± 12
2 months	59 ± 13	76 ± 10	65 ± 13	73 ± 9	44 ± 9	37 ± 8	38 ± 8	36 ± 6
4 months	74 ± 11	75 ± 14	80 ± 8	78 ± 15	46 ± 13	50 ± 4	34 ± 13	45 ± 14
6 months	65 ±10	79 ± 8	73 ± 5	80 ± 6	49 ± 11	55 ± 11	44 ± 12	41 ± 13

* Fresh sample (just before the flour has been packaged.)

4.4.5 Brabender Visco-Amylograph Viscosity indices.

Visco-amylograph viscosity indices (pasting temperature, peak viscosity, viscosity at 95°C) values recorded over the storage period are shown in Figure 4.14a, 4.14b and Appendix 6.

Pasting temperature was indicated by the temperature at which the first detectable viscosity was measured by the amylograph. This index is characterised by initial change in viscosity due to the swelling properties of the starches. Pasting temperature of freshly prepared degermed maize flour (DF) and non-degermed maize flour (nDF) samples were 70.5^{0}C and 79^{0}C respectively. The difference observed for DF samples and nDF sample might be due to the differences in carbohydrate content of the samples. This implies DF samples would be easier to cook since it requires less heat for gelatinization to start. However during the storage period no wide variations in pasting temperatures were observed within the DF and nDF samples. This implies that the pasting temperature of the different flour samples were quite stable during storage.

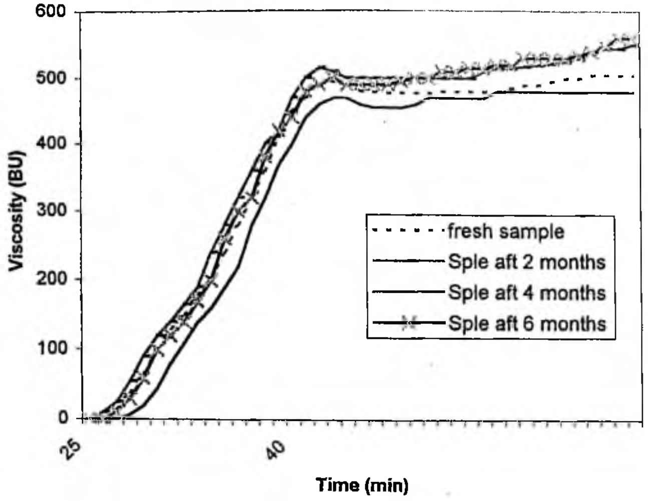

Figure 4.14a : Paste viscosity of degermed maize flour during storage

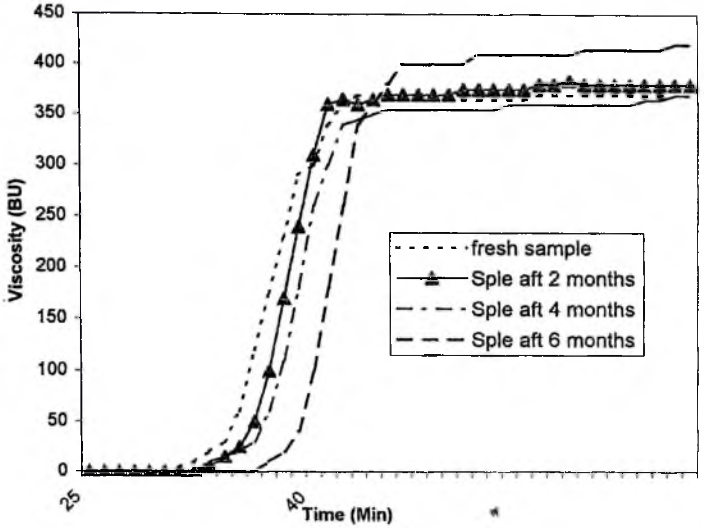

Figure 4.14b : Paste viscosity of non-degermed maize flour during storage

Peak viscosity is linked to the ease of cooking of sample analysed. It is measured as highest value of viscosity attained by the paste during heating (25^0C - 95^0C). The peak viscosity observed for DF samples was higher than nDF samples with values of 505BU and 370BU respectively.

During storage of the samples, only slight variations were observed in peak viscosity of DF and nDF samples analysed.

The viscosity attained by the samples after cooking to 95^0C gives an indication of the ease of cooking the samples. Similar to the observation made for the peak viscosity of the samples, the viscosity at 95^0C for DF were higher than nDF samples with values of 495 BU and 360 BU respectively. However during storage only slight variations were noted within both samples. The results revealed that there is not much difference between peak viscosity and viscosity at 95^0C within the DF and nDF samples during storage. However the differences observed between the DF and nDF samples might be due to the fact that the nDF sample has a higher percentage fat content which could lead to lower frictional force during the testing process and probably result in emulsification, thereby lowering the viscosity. Also the high fibre content of the nDF may have contributed to the lower viscosity by reducing the starch cohesiveness.

5. Conclusion and Recommendations

5.1 Conclusion

Based on the specific objectives and the results of the study, the following conclusions can be drawn.

i . The physico-chemical and functional properties of the maize flour can be modified by dehulling and degerming maize. This was shown as increase in water absorption, swelling capacity, peak viscosity, and viscosity at 95°C for degermed maize compared to non-degermed maize flour. Dehulling and degerming processes caused reductions when compared to non-degermed maize flour in crude fat reduction (76%) and crude fibre reduction (72%) content of degermed maize flour.

ii . (a) The moisture sorption isotherm of degermed maize flour (DF) and non-degermed maize flour (nDF) followed the type (II) isotherm pattern. Moisture sorption pattern of DF and nDF in relation to the various Aw was higher for DF than that of nDF at Aw between 0.11 to 0.11 indicating DF was more hygroscopic, whereas nDF registered relatively higher amounts of moisture uptaake for Aw between 0.71 to 0.71.

(b) The monolayer moisture content of the nDF and DF studied obtained indicate the moisture content at which the rate of quality loss is negligible. The less the monolayer value the less stable the product. The DF showed a higher monolayer value compared to nDF. Therefore DF can be kept longer than nDF because it binds more of its water.

(c) The heat of sorption of DF and nDF decreases with increased moisture concentration. But at low Aw ranging from 0.11 to 0.44 the total heat of sorption of nDF is higher than heat of sorption of DF.

iii . The packaging materials (HD and PP) and storage conditions used preserved the quality of dried maize flour over the period of storage.

iv. Based on the results obtained the degermed maize flour can be stored for at least 6 months with minimal changes in quality; and that the degermed maize flour has a higher potential for long term storage than the non-degermed maize flour.

5.2 Recommendations

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

i. There is the need to study the efficacy of the dehulling and degerming machine in order to improve the yield of the flour.

ii. There is also the need to carry out tests on the baking properties' of the degermed maize flour to determine its use for bakery.

iii. Further work need to be done on the degermed maize flour in order to find out the effect of storage under different temperature conditions .

iv. The above recommendations for further studies would better improve distribution, marketing, and utilisation of degermed maize flour.

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APPENDICES

Appendix 1 : Percentage moisture content of the flours packaged into selected packaging material during the storage period

	Degermed maize flour				Non degermed maize flour			
	Oven dried		Solar dried		Oven dried		Solar dried	
Period	HD	PP	HD	PP	HD	PP	HD	PP
* 0 month	10.57 ± 0.78	10.57 ±0.78	11± 0.6	11± 0.6	10.74 ±0.87	10.74 ± 0.87	10.39 ± 0.49	10.39 ± 0.49
2 months	12.53 ± 0.04	11.93 ±0.70	11.40 ±0.62	11.09 ±0.13	12.67 ±0.06	12.84 ±0.16	10.45 ±0.70	11.07 ± 0.53
4 months	12.63 ±1.01	12.06 ±0.19	11.24 ±0.23	11.15 ±0.01	12.76 ± 0.25	12.76 ± 0.56	10.53 ±0.12	11.61 ±1.73
6 months	12.37 ± 0.31	11.98 ± 0.24	11.42 ± 0.45	11.27 ± 0.48	12.55 ± 0.36	12.61 ± 0.77	10.63 ± 0.14	11.88 ± 0.05

* Fresh sample (just before the flour has been packaged.)

Appendix , 2: pH of the flours packaged into selected packaging material during the storage period

Period	Degermed maize flour				Non degermed maize flour			
	Oven dried		Solar dried		Oven dried		Solar dried	
	HD	PP	HD	PP	HD	PP	HD	PP
* 0 month	6.3 ± 0.014	6.3 ± 0.014	6.18± 0.11	6.18± 0.11	5.91± 0.007	5.91± 0.007	5.93± 0.42	5.93± 0.42
2 months	5.97± 0.042	6.01± 0.014	6.04± 0.028	6.03± 0.035	5.80 ±0.06	5.76 ±0.13	5.83± 0.113	5.9± 0.028
4 months	6.0 ± 0.07	5.99 ±0.21	5.97± 0.035	5.99± 0.056	5.85± 0.028	5.87± 0.028	5.83± 0.028	5.84± 0.063
6 months	6.01 ±0.01	6.06± 0.05	6.02± 0.1	6.01± 0.0	5.90 ±0.05	5.95± 0.07	5.89± 0.01	5.85± 0.0

* Fresh sample (just before the flour has been packaged.)

Appendix,3: Titratable acidity of the flours packaged into selected packaging material during the storage period

Period	Degermed maize flour				Non degermed maize flour			
	Oven dried		Solar dried		Oven dried		Solar dried	
	HD	PP	HD	PP	HD	PP	HD	PP
* 0 month	0.0091 ± 0.00	0.0091 ±0.00	0.0091 ± 0.00	0.0091 ± 0.00	0.0315 ± 0.63	0.0315 ± 0.63	0.0338 ± 0.0	0.0338 ± 0.0
2 months	0.0135 ± 0.0	0.0135 ± 0.00	0.0113 ±0.32	0.0113 ±0.32	0.0338 ± 0.32	0.0338 ± 0.32	0.036 ±0.00	0.036 ±0.0
4 months	0.0113 ±0.32	0.0135 ±0.00	0.0113 ±0.32	0.0113 ±0.32	0.0338 ± 0.32	0.034 ± 0.95	0.038 ±0.63	0.0383 ±0.95
6 months	0.018 ±0.0	0.018 ±0.0	0.014 ±0.06	0.014 ±0.06	0.034 ± 0.06	0.035 ± 0.06	0.036 ±0.0	0.036 ± 0.0

* Fresh sample (just before the flour has been packaged.)

Appendix, 4 : Percentage of Fat content of the flours packaged into selected packaging material during the storage period

	Degermed maize flour				Non degermed maize flour			
	Oven dried		Solar dried		Oven dried		Solar dried	
	HD	PP	HD	PP	HD	PP	HD	PP
* 0 month	1.27 ± 0.09	1.27 ± 0.09	1.26± 0.34	1.26± 0.34	5. 38 ± 0.32	5. 38 ± 38	5.76± 0.63	5.76± 0.63
2 months	1.24 ± 0.03	1.24 ± 0.05	1.25± 0.12	1.21± 0.04	5.1 ± 0.28	5.14 ± 0.007	4.94± 0.5	5.01± 0.05
4 months	1.24 ± 0.028	1.25 ± 0.07	1.23± 0.014	1.24± 0.07	4.87 ± 0.19	4.91 ±0.26	4.79± 0.26	4.88± 0.18
6 months	1.23± 0.03	1.23± 0.007	1.23± 0.06	1.21± 0.14	5.01 ± 0.028	5.00 ± 0.068	5.05 ± 0.06	4.96 ± 0.063

* Fresh sample (just before the flour has been packaged.)

Appendix 5: Fatty acid content (% as lactic acid) of the flours packaged into selected packaging material during the storage period

Period	Degermed maize flour				Non degermed maize flour			
	Oven dried		Solar dried		Oven dried		Solar dried	
	HD	PP	HD	PP	HD	PP	HD	PP
* 0 month	0.28 ± 0.00	0.28 ± 0.00	0.27± 0.014	0.27± 0.014	0.42 ± 0.00	0.42 ± 0.00	0.43± 0.056	0.43± 0.056
2 months	0.35 ± 0.00	0.34 ± 0.02	0.29± 0.0	0.29± 0.0	0.48 ± 0.06	0.48 ± 0.06	0.47± 0.00	0.48± 0.06
4 months	0.37 ± 0.00	0.36 ± 0.00	0.36± 0.049	0.31± 0.028	0.5 ± 0.056	0.53 ± 0.00	0.57± 0.00	0.5± 0.056
6 months	0.35 ± 0.0	0.37 ± 0.0	0.39 ± 0.05	0.41 ±0.0	0.53± 0.0	0.54± 0.0	0.54± 0.0	0.45± 0.13

* Fresh sample (just before the flour has been packaged.)

Appendix, 6: Visco-amylograph analyses of degermed and non-degermed maize flour over the storage period

	Degermed maize flour			Non degermed maize flour		
Indices Period	Gelling tempt °C	Peak viscos BU	Viscos at 95 °C	Gelling tempt °C	Peack viscos BU	Viscos at 95 °C
0 month	70.5	505 BU	495 BU	79	370 BU	360 BU
2 months	70.5	555 BU	515 BU	81.5	380 BU	365 BU
4 months	71.3	480 BU	470 BU	81.7	370 BU	340 BU
6 months	70.5	560 BU	500 BU	82	420 BU	360 BU

Appendix, 7 : ANOVA Summary Table for Moisture

Sce of varia	Sum of Sq	d.f	Mean square	F-ratio	Sig . level
Main effects	15.669738	6	2.6116229	46.750	0.0000
Storage	7.792375	3	2.5974583	46.497	0.0000
Flourtype	0.004050	1	0.0040500	0.072	0.7948
Drytype	7.840800	1	7.8408000	140.357	0.0000
Package	0.032513	1	0.032513	0.582	0.4671
Residual	0.7262250	13	0.0558635		
Total	21.997600	31			

Appendix, 8 : ANOVA Summary Table of Variance for pH

Sce of varia	Sum of Sq	d.f	Mean square	F-ratio	Sig . level
Main effects	0.4453437	6	0.0742240	61.010	0.0000
Storage	0.1414844	3	0.471615	38.765	0.0000
Flourtype	0.3022531	1	0.3022531	248.444	0.0000
Drytype	0.009031	1	0.009031	0.742	0.4136
Package	0.0007031	1	0.0007031	0.578	0.4671
Residual	0.158156	13	0.0012166		

Appendix, 9 : ANOVA Summary Table for Titratable acidity

Sce of varia	Sum of Sq	d.f	Mean square	F-ratio	Sig . level
Main effects	0.0041243	6	0.0006874	1000.000	0.0000
Storage	0.0000868	3	0.0000289	62.025	0.0000
Flourtype	0.0040365	1	0.0040365	1000.000	0.0000
Drytype	0.0000006	1	0.0000006	1.296	0.2754
Package	0.0000003	1	0.0000003	0.686	0.4313
Residual	6.06750E-006	13	4.66731E-007		

Appendix , 10 : ANOVA Summary Table for Crude fat

Sce of varia	Sum of Sq	d.f	Mean square	F-ratio	Sig . level
Main effects	118.82349	6	19.80392	1000.000	0.0000
Storage	0.35756	3	0.11919	80.216	0.0000
Flourtype	118.46453	1	118.464553	1000.000	0.0000
Drytype	0.00138	1	0.00138	0.928	0.3632
Package	0.00003	1	0.00003	0.019	0.8941
Residual	0.01993156	13	0.0014858		

Appendix , 11: ANOVA Summary Table for Fatty acid

Sce of varia	Sum of Sq	d.f	Mean square	F-ratio	Sig . level
Main effects	0.2377625	6	0.0396271	48.201	0.0000
Storage	0.0472375	3	0.0157458	19.153	0.0000
Flourtype	0.1891125	1	0.1891125	230.032	0.0000
Drytype	0.008000	1	0.008000	0.973	0.3523
Package	0.006125	1	0.006125	0.745	0.4127
Residual	0.0106875	13	8.22115E-004		