INFLUENCE OF MOISTURE ON SOME ENGINEERING PROPERTIES OF BUSH MANGO SPECIES' [*Irvingia gabonensis* AND *Irvingia wombolu* (HOOK, F.)] SEED AND KERNEL

BY

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ABSTRACT

Irvingia gabonensis and *Irvingia wombolu* are species of bush mango commonly found in Africa whose kernel are processed into soup. Literature generally abounds on the nutritional composition of the fruits and kernel but there is dearth of information on the engineering properties which are very important in the design of processing equipment and machines. This study was designed to investigate the influence of moisture on some engineering properties of seeds and kernels of *I. gabonensis* and *I. wombolu*.

Irvingia gabonensis sourced from Oyo, Ogun, Osun and *Irvingia wombolu* sourced from Edo, Ondo and Imo states, Nigeria were used for the study. Based on moisture content at harvest and storage, their seeds were conditioned to moisture content of 10.0%, 20.0%, 30.0%, 40.0% and 50.0% and kernel to 2.2%, 3.7% and 5.3% (dry basis) using ASABE method. Properties studied include dimension, sphericity, true and bulk densities, porosity and angle of repose on commonly used material such as plywood, glass and steel for seed and kernel. Deformation, rupture force, failure stress, stiffness and Young's moduli for seed were determined. Specific heat, thermal conductivity and diffussivity of kernel were studied. All properties were evaluated using ASABE standards and data analysed using ANOVA at $p = 0.05$.

Kernel length, width, thickness and sphericity increased respectively from 25.9 to 30.4 mm, 15.7 to 19.2 mm, 3.5 to 4.3 mm and 43.3 to 44.6% with increase in moisture content. Length and width of seed decreased from 53.5 to 34.7 mm and 38.4 to 30.3 mm respectively with increase in moisture content while, thickness and sphericity increased from 3.5 to 4.2 mm and 66.7 to 78.0% respectively, indicating that seeds swell only in the lateral direction. Sphericity of seed was high indicating tendency to roll easily while low sphericity of kernel indicates sliding on structural surfaces. True density increased from 825.6 to 1216.4 kgm^{-3} and 697.7 to 1092.0 kgm^{-3} for seed, and kernel respectively. Their densities appear close to that of water hence may be difficult separating them using water. Angle of repose increased from 30.4 to 52.9^{o} and 18.9 to 29.0^{o} for seed and kernel respectively and was significantly affected by moisture content and species. Based on existing design, hopper and inclined discharge chute can be used for seed and flat bed for kernel. Deformation and Young's modulus increased linearly from 1.4 to 3.9 mm and

5978.0 to 26098.0 Nmm^{-2} respectively for seed and were significantly affected by moisture and species. Specific heat and thermal conductivity of the two species increased with moisture and those of *I. wombolu* (982.8 JkgK^{-1}, 0.2 Wm^{-1}K^{-1}) were significantly higher than *I. gabonensis* (795.9 JkgK^{-1}, 0.1 Wm^{-1}K^{-1}) kernel. Thermal diffussivity also increased with moisture content and was significantly higher in *I. wombolu* than *I. gabonensis*; hence *I. wombolu* kernels will dry faster.

Mechanical properties of the seeds evaluated at the selected moisture content showed that more energy would be required in cracking of *Irvingia wombolu* during kernel extraction than the same quantity of *Irvingia gabonensis* at the same processing condition.

Keywords: Bush mango, Moisture content, Engineering properties

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DEDICATION

I dedicate this achievement to Almighty Allah (SWT), for making this feat achievable for me.

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CERTIFICATION

I certify that this work was carried out by Taibat Olusola IKOTUN in the Department of Agricultural and Environmental Engineering, Faculty of Technology, University of Ibadan.

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NOMENCLATURE

a: the length is the dimension along the longest axis, mm;

b: the width is the dimension along the longest axis perpendicular to a, mm;

c: the thickness, mm; is the dimension along the longest axis perpendicular to both a and b, mm;

C: Specific heat

d: diameter of the cone, m;

h: height of the cone, m;

K: Thermal conductivity

M_1: initial moisture content of sample, d.b. %;

M_2: desired moisture content of sample, d.b. %;

M_b : bulk mass of seed, kg;

M_s: seed mass, kg;

W_2 : mass of distilled water, kg;

W_1 : initial mass of sample, kg;

ρt : true density, kgm^{-3};

V_s: seed volume, m^3;

ρ_b : bulk density, kgm^{-3};

V_b: bulk (cylinder) volume of seed, m^3;

μ_m : coefficient of friction on material surface,

α: Thermal diffussivity

θ : angle of repose,

Φ: sphericity

β: angle of inclination, degree;

Ψ: Porosity

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Bush mango *(Irvingia species*) belongs to the group of important multipurpose indigenous food tree species widely cultivated in West and Central African countries (Ngondi *et al*., 2005). *Irvingia species* is indigenous to the humid forest zone of the Gulf of Guinea from Western Nigeria to the Central African Republic, Angola and the Western part of DR Congo; it also occurs in Sao Tome et Principe. Significant phonological, morphological and genetic variation correlated to geographical distance were detected among populations across West and Central Africa as observed in Table 1.1 (Leakey *et al*., 2000). However quantitative data relative to this variation have only been obtained from Central Africa (Lowe *et al*., 2000).

It is better adapted to utisol soils in high rainfall areas than less acidic soils (Nzekwe *et al*., 2005) but within those areas the two species of bush mango differs. Lowe *et al*. (2000) stated that *Irvingia gabonensis* prefer well drained sites, while *Irvingia wombolu* thrives in wetter conditions. Both species were found growing wild in the humid lowland forest of tropical Africa but it is widely planted in Central and Western Africa (Leakey *et al*., 2000). The preferred habitat of *Irvingia gabonensis* is moist lowland tropical forest below 1000 m altitude and with annual rainfall of 1500–3000 mm and mean annual temperatures of 25–32°C. *Irvingia gabonensis* is better adapted to acid utisols in high-rainfall areas than to less acidic Alfisols; it prefers well-drained sites. Often 2–3 trees grow together and in some areas it is reported to be gregarious. The presence of *Irvingia gabonensis* is often associated with former human habitation. *Irvingia wombolu* however occurs in dry land forest with more than 1500 mm annual rainfall. In some locations it grows in seasonally flooded forest and on river banks. It is adapted to a wider rainfall range than other *Irvingia* species.

The geographic range of *Irvingia wombolu* is from Senegal to Uganda while that of *Irvingia gabonenesis* is from Nigeria to Congo (Simons and Leakey, 2004).
Figure 1 is a distribution maps for the two species, created from the NTFP database. The two species are found in the Southern States of Nigeria (Nzekwe *et al*., 2005). *Irvingia gabonenesis* is found mostly in the Western states of Nigeria while *Irvingia wombolu* range from the lower region of the Middle Belt states to the Eastern States of Nigeria (Lowe *et al*., 2000). *Irvingia gabonensis* and *I. wombolu* are planted and maintained on farms throughout their range in Central and Western Africa. Planting is common in Nigeria and is more predominantly on outlying farms than on compound farms (Okafor, 1987).

The fruits of *Irvingia wombolu* and *Irvingia gabonensis* are similar in appearance to that of cultivated mango (*Magnifera indica*) and their colour varies from green to yellow when mature. *Irvingia gabonensis* flowers in February to March and fruits during the rainy season (July – September) while *Irvingia wombolu* flowers in October and fruits during the dry season, (January – March). The fruits of *Irvingia gabonensis* have a fleshy mesocarp with a sweet taste when eaten by animals and humans, hence it is locally called sweet bush mango. On the other hand, the fruits and mesocarp of *Irvingia wombolu* are fleshy, with a bitter taste, hardly eaten by animals and humans, and locally called bitter bush mango (Nkwatoh, 2010). The domestication of indigenous fruit trees and their integration into diverse agro forests have been identified as important components of a strategy for the improvement of land use in Africa (Simons and Leakey, 2004). In West Africa, *Irvingia* species top the list of non-timber forest products being clamored for domestication (Leakey *et al*., 2005), and are fast becoming the trees of choice in agroforestry practices. However, previous studies on fruit and seed characteristics which would stimulate domestication of the trees also did not take into account the potential differences between *I. gabonensis* and *I. wombolu* (Anegbeh *et al*., 2003).

Table 1.1: Species and growing countries of bush mango

Species	Countries
Irvingia gabonensis Baill (Aubry-Lecomte ex O'Rorke)	Cameroon, Central Africa Republic, Congo, Gabon, Ivory Coast, Nigeria and Zaire
Irvingia grandiflora (Engl.)	Cameroon, Central Africa Republic, Gabon, Congo, Nigeria and Zaire
Irvingia malayana Olivex AW Benn	Vietnam and Malaysia
Irvingia robur Mildbr	Congo, Cameroon and Gabon
Irvingia smithii Hook F.	Nigeria and Zaire
Irvingia wombolu (Aubry-Lecomte ex O'Rorke)	Nigeria, Congo and Cameroon
Irvingia excelsa Mildbr	Cameroon, Gabon and Congo

Adapted from: Nkwatoh, 2010

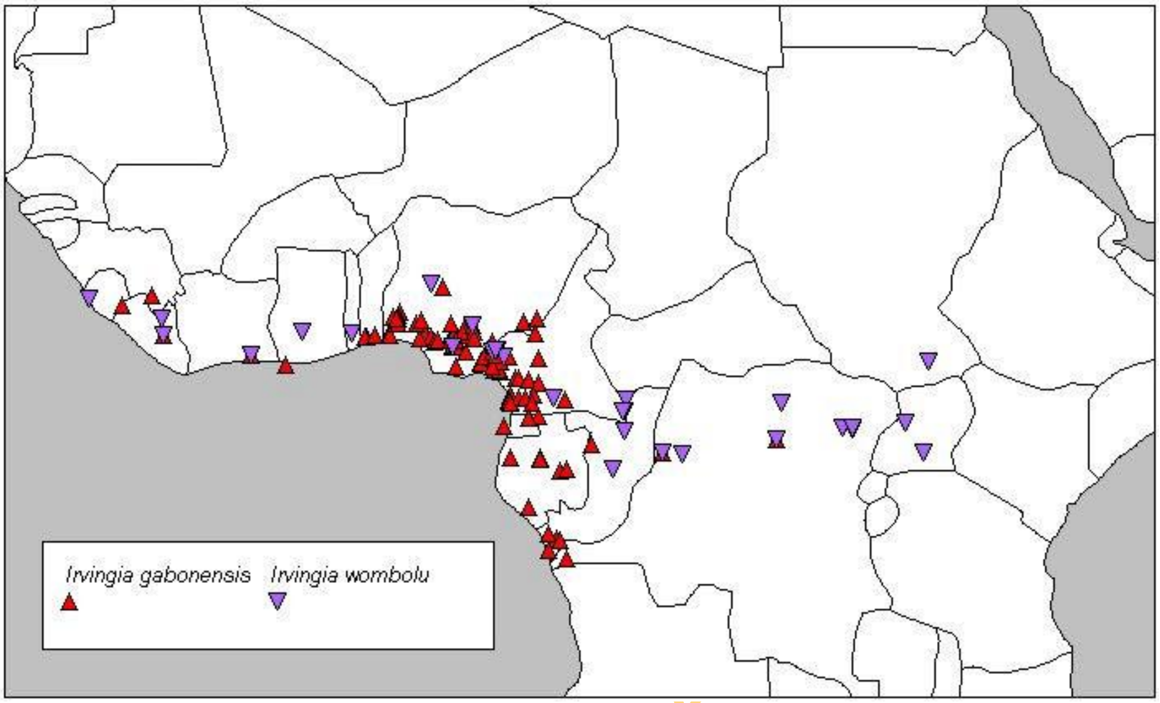


Figure 1.1: Distribution of herbarium collections of *Irvingia gabonensis* and *Irvingia wombolu*

Source: Lesley and Brown (2004)

1.2 Taxonomy and local names of bush mango

Irvingia gabonensis and *I. wombolu* are important high-value indigenous multi-purpose tree species found in West and Central Africa (Atangana *et al*., 2002). Prior to 1975, *Irvingia gabonensis* and *Irvingia wombolu* were clumped together as one species, *Irvingia gabonensis*, (Aubry-Lecomte ex O'Rorke). However, a distinction was made between the two forms of *Irvingia gabonensis* by Okafor (1975) who recognised *I. gabonensis* var. *gabonensis* as having a sweet edible pulp, and *I. gabonensis* var. *excelsa*, having a bitter inedible pulp. Following this distinction, Harris (1996) revised the taxonomy of the Irvingiaceae, splitting *I. gabonensis* (var *excelsa*), described by Okafor (1975) as the bitter variety, from *I. gabonensis* (var *gabonensis*), the sweet variety, to create *Irvingia wombolu* Vermoesen. The sweet variety is now simply named *Irvingia gabonensis* while the bitter one is *Irvingia wombolu*. *Irvingia gabonensis* and *Irvingia wombolu* look very similar, and indeed are often difficult to tell apart from herbarium specimens alone (Harris, 1996). However, there are characteristics that distinguish the two, most noticeably the edibility of the fruit mesocarp. Studies on *Irvingia* have often failed to identify which species is being analyzed, therefore in some cases figures given for *Irvingia gabonensis* are actually for *Irvingia gabonensis* var. *excelsa* (*Irvingia wombolu*) (Atangana *et al*., 2002). *Irvingia gabonensis* and *Irvingia wombolu* are also called bush mango or African mango because the trees bear mango-like fruits (Leakey and Tchoundjeu, 2001). The fruits are broadly ellipsoid, green when unripe and yellow when ripe with a fleshy mesocarp. The onset of ripening predisposes the fruits to postharvest spoilage microorganisms such as *Aspergillus* and *Botrytis* species, whose actions on the fruit produce the brownish-black rot disease symptoms (Etebu, 2012). Although the fresh fruits of *Irvingia* species have long been known to have a short shelf life after harvest (Joseph and Aworh, 1992), a systematic assessment of postharvest spoilage of *Irvingia* fruits has been done only recently (Etebu, 2012), but this study did not take into account the potential differences between *Irvingia gabonensis* and *Irvingia wombolu.*

Irvingia species are commonly known as African mango, wild mango and bush mango, while it is known as *manguier sauvage* in French speaking African countries. There are many local names for *Irvingia gabonensis* and *Irvingia wombolu*, some of which are listed in Table 1.2. Their kernels also have various local names: in Nigeria, they are referred to as *ogbono* in Ibo and *apon* in Yoruba.

1.3 Uses of Bush Mango

1.3.1 Fruits

Bush mango (*Irvingia gabonensis*) is very valuable for its edible yellow mango-like fruit (Lowe *et al*., 2000). The juicy fruit pulp of *Irvingia gabonensis* is rich in vitamin C and is widely reported to be consumed as a dessert fruit or snack throughout Western and Central Africa (Ladipo and Boland, 1994). *Irvingia gabonensis* pulp can be used for making jam, jelly and juice and the sugar concentrate of the juice is comparable with that of pineapple and orange (Lowe *et al*., 2000). The fruit pulp of *Irvingia wombolu*, however, is bitter and tastes of turpentine, so it is not edible (Ejifor, 1994).

Bush mango fruit (*Irvingia gabonensis)* has some nutritive value that makes it good for human consumption. It is good source of energy, vitamin A and C, protein, fibre, fat, minerals and essential oils as shown in Table 1.3. The main flavour components of the fruit pulp are zingiberene and α-curcumene, ethyl and methyl esters of cinnamic acid, dodecanal and decanol imparting spicy-earthy, fruity and wine-yeast flavour notes. The pulp yields about 75% juice (Tchoundjeu and Atangana, 2007). Wine produced from it was found to be of good colour, mouth feel, flavour and generally acceptable.

Composition of the bush mango kernel is given in Table 1.4. Fat content of kernels (*Irvingia gabonensis* and *Irvingia wombolu*) also varies between trees and is 37.5–75 g/100 g; the approximate fatty acid composition is: lauric acid 20–59%, myristic acid 33–70%, palmitic acid 2%, stearic acid 1% and oleic acid 1–11%. Physicochemical properties of bush mango fat as shown in Table 1.5 reflect the potential to use it in different pharmaceuticals confectionery and cosmetic uses. The residue obtained after separation from the fat is suitable for processing in the food industry.

Table 1.2: Local names for Bush mango

Local Name	Tribe/Country
Ewewe	Bolon Gabu
Moboulou	Bibaya Pygmies
Ogwi	Benin/ Nigeria
Borburoi	Cote D’ivoire
Bulukutu	Cameroun
Ebi	Central African Republic
Eniok	Congo
Miba	Donali
Mwiba	Bassi/Cameroun
Ogbono	Ibo/Nigeria
Ogwe	Nigeria
Oro	Yoruba/Nigeria
Oro Apon	Yoruba/Nigeria
Orogbiye	Yoruba/Nigeria
Uyo	Efik/Nigeria

Adapted from: Leakey *et al*., 2005

Table 1.3: Nutritive value of bush mango fruit pulp per 100g

Parameter	Value
Water (g)	81
Energy (kJ)	255
Protein (g)	0.9
Fat (g)	0.2
Carbohydrate (g)	15.7
Vitamin A (mg)	67
Vitamin C (mg)	65.3
Minerals	Mg, Ca, P, Cu, Zn, Ni, Fe and Co

Source: Tchoundjeu and Atangana, 2007

Table 1.4: Nutritive value of bush mango kernel per 100g

Parameter	Values
Water (g)	4
Energy (kJ)	2918
Protein (g)	8.5
Fat (g)	67
Carbohydrate (g)	15
Minerals	Mg, Ca, P, Cu, Zn, Ni, Fe and Co

Source:Tchoundjeu and Atangana, 2007

Table 1.5: Physicochemical properties of bush mango fat

Parameter	Value
Melting point (^{o}C)	39-40
Saponification value (^{o}C)	212-220
Smoking point (^{o}C)	213-210
Free fatty acid value (%)	0.25-0.30
Iodine Value (mg/gm)	3.5-4.2
Peroxide value (mg/gm)	1.95-1.99
Acid value (mg/gm)	13.6
Total Lipid content (%)	71

Source: Omogbai, 1990

1.3.2 Seeds

The kernels of *Irvingia gabonensis* and *Irvingia wombolu* are classed as oilseeds. They are ground with a pestle and mortar or on a stone into a paste or cake called 'dika bread', which is used as a soup, stew or sauce additive, for flavouring and thickening (Leakey *et al*., 2005). Dika bread may be sun-dried so that it can be stored. Okafor (1975) notes that whilst kernels from both *Irvingia* species are used in soup making, *I. gabonensis* kernels can only be used when fresh since they become too slimy over time. *Irvingia* kernels form an important part of the West and Central African diet, providing carbohydrate and protein (Leakey *et al*., 2005).

Agbor (1994) reports that the kernels may be roasted to enhance their flavouring effect, and that crushed pieces of the roasted kernels may be used in frying vegetables. The kernels of *Irvingia wombolu* are consumed by the Baka pygmies in South-east Gabon and have a slightly bitter after-taste, although their overall flavour is not unpleasant (Omogbai, 1990).

Flour can be produced from the kernel, but degrades within 6-9 months unless defatted. Defatted flour is still accepted in terms of its color, taste and a texture after 9 months stored in ambient conditions and is more viscous, with greater emulsifying properties than undefatted flour (Leaky *et al*., 2005). Due to its ability to form gels at a lower concentration than many other oil seeds flours, bush mango kernel flour can be very effective in many industrial food applications that required a thickening agent (Agbor, 1994).

Ejifor (1994) and Anegbeh *et al*. (2003) recommends using flour produced by milling the seed testa in formulating feeds for livestock. Improvements in sliminess and possible storage time have enabled the flour to be considered for a range of processed products, particularly *Ogbono* cubes. These are produced by cubing and packaging the flour, thus giving them a longer shelf life, and are sold as a convenient cooking ingredient.

1.3.3 Timber and wood

Bush mango wood is used locally for construction (Festus and Nwala, 2012). It is a fine grained, hard, heavy timber (Ayuk *et al*,, 1999), conferring strength and durability.

The wood is also used for making poles and stakes while the live branches are made into walking sticks or thatched roof supports (Agbor, 1994). Dead branches are used as firewood (Ayuk *et al.*, 1999).

1.3.4 Other uses of bush mango

Leaky *et al*. (2005) stated that the roots, leaves and bark of bush mango are used as medicine. *Irvingia gabonensis* bark when mixed with palm oil can be used in the treatment of diarrhea and is also taken by women to shorten their breast feeding period (Ndoye *et al.*, 1998). An anti-diarrheic and anti-ulcer property has been reported in *Irvingia species* (Ayuk *et al.*, 1999). It is also administered for colic and dysentery as well as for hernias, yellow fever and as an antipoison. Ndoye *et al*. (1998) report that the bark has antibiotic properties for healing scabby skin, particularly when boiled; it can be given as a painkiller for toothache. Ejifor (1994) documents that stems from *Irvingia gabonensis* are among several species that can be used as 'chewing-stick' which is chewed to help keep their teeth clean. Farmers may collect leaves from bush mango trees as fodder for their animals (Ayuk *et al*., 1999). Anegbeh *et al*. (2003) also reported that extract of the polysaccharides from bush mango kernel and analysis of their properties concluded that they have potentials as an industrial gum. Bush mango flour (dika) was also found to be effective in treatment of diabetics.

1.3.5 Potential uses

Much of the potential for *Irvingia gabonensis* and *Irvingia wombolu* lies in the expansion of current uses, particularly of the kernels, to industrial levels. There are, however, some novel applications that have been suggested by researchers. *Irvingia gabonensis* fruit can produce a good quality wine, comparable in colour, flavour, sweetness and general acceptability with a selected German wine. The wine had 8.12% alcohol content after 28 days fermentation in a trial set up by Ndoye *et al*. (1998). This seems like a viable future product of bush mango, particularly after the success of other African alcoholic drinks made from native fruits, such as 'Amarula' made from Sclerocarya birrea fruits. Ayuk *et al.* (1999) lists the potential industrial applications of bush mango kernel fat, including cooking oil, margarine, perfume, soap and pharmaceuticals. He notes that once the fat has been extracted from the kernels, the residue still possesses the consistency and thickening properties required for soup-making, so there are no wasteful by-products from the fat extraction process, both the fat and the residue can be used. Aside from its role as a thickener, the residual kernel cake could also be used as a binder in food or pharmaceutical products (Ndoye *et al.*, 1998). Anegbeh *et al*. (2003) extracted the polysaccharides from *Irvingia* kernels and from an analysis of their properties concluded that they have potential as an industrial gum.

Irvingia gabonensis (known as ‘dikanut’ in these studies) has been studied as a dietary fibre for reducing the hyperglycemic effects and lipid metabolism disruption caused by diabetes mellitus. Adamson *et al*. (1986) found that giving diabetic patients a dose of dikanut preparation daily for 4 weeks reduced blood glucose levels to normal and additionally increased the activity of three ATPases, which usually fall significantly below regular levels in diabetics. Dikanut could therefore be a suitable alternative to Guar, another viscous dietary fibre that has been shown to have similar effects but is unacceptable to patients at the dosage necessary. These dietary fibres work by delaying gastric emptying and thus reducing the intestinal sugar absorption rate. This reduced rate improves the sensitivity of the tissues to insulin, resulting in increased glucose uptake. Omoruyi and Adamson (1994) tried to work out how *Irvingia gabonensis* alters the lipid metabolism of diabetics. Adamson *et al*. (1986) had previously found that the blood glucose and lipid levels of type II diabetic patients could be improved by a dose of 4g of dikanut per 100 g of food. Omoruyi and Adamson (1994) examined the plasma and liver lipids of streptozotocin-induced diabetic rats after 4 weeks in a dikanut -supplemented diet. They found that the dikanut affected phospholipid distributions and concluded that this may be how it helps in the hepatic control of plasma lipids. Joseph (1995) also notes that dikanut could be employed as a substitute for easily hydrolyzed carbohydrates in diabetic foods.

1.4 Processing and Storage of Bush Mango

There are several reported methods of obtaining the kernel from the bush mango seed. The fruits are piled up in heaps and left to ferment before the seeds are extracted (Nkwatoh, 2010). The seeds can either be taken out wet from the fermented fruits, or the fruit may be sun dried first. Alternatively, the fresh fruit can be split open with a cutlass to reveal the kernel inside (Ayuk *et al.*, 1999). The fermented seeds can either be taken out wet or sun dried before cracking to extract the kernel. However, the seeds of *Irvingia gabonensis* can also be collected after the fruits had been eaten to extract the kernel. Once the seeds have been collected they are dried, either in the sun or over a fire. The seeds can be cracked open and a knife used to remove the two white cotyledons (kernels). The kernels can further be dried to reduce the moisture before it is stored or processed as food. It is important that the kernels are fully dried, unless they are being used immediately, because fresh kernels quickly discolour and turn mouldy. In South-west Nigeria, bush mango kernels are normally taken fresh from the fruit, before drying (Ladipo and Boland, 1994). In Cameroon, often 3 or 4 women meet to process the kernels (Ayuk *et al.* 1999), which are extracted from the fruits once they have already been dried, so little further drying is necessary. The dried kernels are ground with a pestle and mortar before being added to food (Agbor, 1994). Potential industrial applications of *Irvingia* kernels require that they are ground and that the fat is extracted and on an industrial scale (Leakey *et al.*, 2005). Grinding and fat extraction would involve processing machinery.

The fresh fruits of *I. gabonensis* have a shelf life of less than 2 days if picked when ripe and not more than 10 days if harvested at the mature green stage due to high respiration rate, moisture loss and microbial attack (Joseph and Aworh, 1992). Poor storage conditions and handling, as well as pest attack, diseases and deterioration contribute to high losses of saleable fruit. Stored *Irvingia* seeds keep for up to a year ((Ndoye *et al*., 1998), but are susceptible to pests. One major pest is the merchant grain beetle (*Oryzaephilus mercator*) which lays its eggs between the testa and cotyledons of the seed or in cracks in the cotyledons; so that when the larvae hatch they can consume the cotyledons (Dudu *et al.*, 1998b). The testa could be fully removed to reduce the number of preferred ovipositor sites, but this may allow other pests to attack. More careful handling of the seeds to prevent cracks will both help to prevent grain merchant beetle infestation and keep the value high, since damage reduces sale price. Dudu *et al.* (1998a) suggest that a diethyl ether extract of *I. gabonensis* could be used to attract the beetle, either to detect it or to attract it away from stored oilseeds, including *Irvingia* seeds themselves. The various products of *Irvingia* kernels have differing length shelf lives. The sauce made from fresh kernels can be kept for 3 or 4 days, while *dika bread* paste made from crushed, dried kernels can be stored for over a year ((Ndoye *et al.*, 1998). *I. gabonensis* fat, extracted from the kernels, has been stored for more than a decade with no adverse changes in it properties because it contains natural anti-oxidants that hinder oxidative decay (Ndoye *et al.*, 1998).

1.5 Justification of the Study

The kernel of bush mango are commercialized at local, regional and international levels (Leaky and Tchoundjeu, 2001), indicating that demand is likely to increase. It is ranked as an important non-timber forest product for its food and commercial value in West African Countries including Nigeria (Ladipo and Boland, 1994). The cracking of the bush mango seed and oil extraction from the kernel are still being done manually, therefore there is need to develop equipment that will remove drudgery involved in the cracking and oil extraction.

In other to have a good design of machine for handling, drying, cracking and processing knowledge of the engineering properties of the agricultural crop is necessary. Engineering properties of biological materials such as bush mango seed and kernel have unique characteristics which set them apart from other engineering materials. The irregular shape of most agricultural materials complicates the analysis of their behaviour. Also due to the increasing importance of agricultural products together with the complexity of modern technology for their production, processing and storage, a better knowledge of their engineering properties is necessary. The engineering properties of bush mango are pre requisites in the designing of equipment for handling, storage, mechanical extraction of oil and other processes. It is therefore essential to determine the relevant characteristics of bush mango which appears to be lacking in literature. More so that emphasis is now being placed on production of non-timber forest products.

1.6 Objectives of the Study

This work is aimed at studying some engineering properties of two species of bush mango (*Irvingia gabonensis and Irvingia wombolu*) seed and kernel at different moisture levels, obtained from six southern states of Nigeria. The specific objectives are:

1) To determine the effect of moisture content and species on physical properties of bush mango seed and kernel
2) To determine the effect of moisture content and species on frictional properties of bush mango seed and kernel

3) To determine the effect of moisture content and species on mechanical properties of bush mango seed.
4) To determine the effect of moisture content and species on thermal properties of bush mango kernel.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Physical properties

Planting, harvesting, threshing, separating, cleaning, sorting, sizing, grading, drying, conveying, packaging, storing, heat and air flow studies, seed purity determination, maturity and quality evaluation, marketing etc. are among other agricultural engineering problems of importance. Proper design of machines and processes to handle, store and process agricultural products and to convert them into food and feed requires an understanding of their physical properties. Physical properties are important in many problems associated with design of a specific machine or analyzing the behaviour of the product in handling agricultural materials. These properties include size, shape and density, deformation in response to applied static and dynamic forces, moisture absorption and desorption characteristics, thermal properties, frictional characteristics, flow properties, aerodynamic and hydrodynamic properties, and response to electromagnetic radiation (Stroshine and Hamann, 1995). The solution to these problems involves the knowledge of physical properties data such as shape and size (axial dimensions), equivalent diameters and sphericity, density (bulk and true density), porosity weight and volume (Irtwange, 2002). Also the knowledge of physical properties constitutes an important and essential engineering data in the design of machines, storage structure and processing (Esref and Halil, 2007).

The size, shape, density and aerodynamic properties of kernels and plant parts are important for the proper design of combines which thresh the kernels from the plants and separate kernels from the straw and chaff. Knowledge of frictional properties and the characteristics from flow of chutes and orifices are needed for the design of handling equipment. Physical properties are also useful when designing and sizing machine components such as those used for metering seeds into the soil (Stroshine and Hamann, 1995). Due to the mostly non-uniform dimensions of agricultural products, the use of average measurements in their analysis and description becomes necessary. Length, width and thickness measurements are usually replicated several times due to their irregular nature. Because of the irregular nature of the shape and sizes of agricultural products, coefficient of variation (CV) may be used to characterize the quality of dispersion to the measured parameters about their means, low CV's indicate more uniform dispersions (Eke *et al*., 2007).

According to Stroshine and Hamann (1995), the dimensions of agricultural materials also vary widely with growing season, growing location and variety. Therefore it is best to perform measurements on a large number of specimens from the particular variety grown under cultural practices typical of the region. Various types of grading and separation equipment are designed on the basis of their physical properties (Teye and Abano, 2012).

2.1.1 Size and Shape

Length, width and thickness determination is useful in the design of seed metering devices, sorting sieves, pneumatic conveying systems and planters attached to combine harvesters. Clearance between the cylinder and the concave of a combine harvester is also reliant on size and shape dimensions (Stroshine and Hamann, 1995). The major diameter, length, is the longest dimension of the longest projected area. The minor diameter, thickness, is the shortest dimension of the minimum projected area. The intermediate diameter, width, is the minimum diameter on the maximum projected area and is often assumed to be equal to the longest diameter of the minimum projected area (Stroshine and Hamann, 1995).

Shape is exploited singly or together with other characteristics to determine the free flowing or bridging tendencies of a seed mass in many separators used in seed cleaning, (Eke *et al*., 2007). Differences in size and shape can be used to improve the quality of grains by removing foreign materials and damaged particles. Seeds may be separated into size categories before being sold in the market. Shape is important in orienting fruits and vegetables prior to mechanize operations such as peeling, removal of cores and pits, or positioning for machine assisted packing. Proper performance of machine vision systems for sizing and quality evaluation will also depend on proper orientation. For example, the bottom part of pears is ellipsoidal but the upper portion is conical, hence the centre of gravity is nearer the bottom. When pears fall into the notch of a belt roller, they assume a position in which their centre of gravity is as low as possible and therefore their stem ends point upwards, good for separation purposes (Stroshine and Hamann, 1995). The application of physical properties such as shape which is an important parameter for stress distribution in materials under load is important in developing sizing and grading machines and for analytical prediction of its drying behaviour (Chukwu and Sunmonu, 2010).

Size refers to the characteristics of an object which determines how much space it occupies and within limits can be described in terms of length, width and thickness, (Asoegwu *et al*., 2006). In fruit and vegetable packing operations, size is a grading factor used to establish economic value while shape may be used to achieve a desirable orientation. The packing coefficient of agricultural products is also dependent on the size. The market price of fresh fruits and vegetables are often influenced by their sizes. In packing operations, smaller sizes can be diverted for use in juicing or canning processes (Stroshine and Hamann, 1995).The average size of popcorn seed was determined by Karababa (2006) using a sample of 100 seeds randomly picked. The length, width and thickness were measured using a micrometer screw gauge with accuracy of 0.01mm. The length, width and thickness of pistachio nut and kernel were measured with micrometer to an accuracy of 0.01 mm by Polat *et al.* (2007). The dimensions of cashew nut were determined using a venier caliper. The study was carried out with 100 seeds selected randomly from the bulk of the seed by Seifi and Alimardani (2010). The width and thickness were measured perpendicular to the major axis. Saeeid *et al*. (2009) also used digital caliper with accuracy of 0.02 mm to measure the length, width and thickness of groundnut kernel.

Principal axial dimensions of rough rice grains are useful in selecting sieve separators and in calculating power during the seed milling process. They can also be used to calculate surface area and volume of kernels which are important during modeling of grain drying, aeration, heating and cooling. According to Stroshine and Hamann (1995), knowledge of seed size is also helpful in selecting the flexible tubing used to transport simulated seeds to the drop point. The number of seeds per unit volume could be used to size the hopper on the planter which holds the seeds prior to planting.

According to Baryeh (2002), for millets, all the dimensions increased with grain moisture content up to 25% moisture content. Dimensional changes are important in designing drying and storage bins and seed pod threshers (Karimi *et al*., 2009).

2.1.2 1000 Grain Mass

This refers to the mass of 1000 grains and includes the dry matter and the moisture present within the grains. The moisture present however is dependent on the water holding ability of the grain and void spaces. The 1000-grain weight is a good indicator of grain size, which can vary relatively to growing condition and maturity, even for the same variety of of a given crop. Generally, this is measured by taking the weight of 1000 grain kernel. A model study of the effect of barley grain moisture content on the distribution of horizontal and vertical pressures in a silo by Teye and Abano (2012), showed that in the course of storage of both wet and dry barley grapotatoes in, the horizontal and vertical pressures are subject to change and also the increased moisture content and longer storage time cause pressure values to increase. Pressure values increase due to an increase in the dimensional measurements of individual grains caused by an increase in weight from moisture absorption. This provides useful information in the design of silos taking into consideration weight increase and volumetric expansion.

The 1000 grain mass of cereal grains is a useful index to *milling outturn* in measuring the relative amount of dockage or foreign material in a given lot of grain, and the amount of shriveled or immature kernels (Varnamkhasti *et al.*, 2008). Coskun *et al*. (2005) found that the 1000-seed weight of sweet corn increase linearly with increasing moisture content. The variation of 1000 grain mass with moisture content was found to increase linearly for category B cocoa beans from 1125.02 g to 1247.19 g at moisture contents ranging between 7.56% and 19.00% (w.b.) (Bart-Plange and Baryeh,2002). Izil *et al*. (2009) also observed a linear relationship between kernel weight of rapeseed and its moisture content in the range 8.0 – 20.0%. The mass of 1000 grains has been found to increase linearly with an increase in moisture content for spinach seeds (Kilickan *et al*., 2010).

2.1.3 Sphericity and geometric mean diameter

One commonly used technique for quantifying differences in shapes of fruits, vegetables, grains and seeds are to calculate sphericity. Sphericity can be defined in several ways, but the one most commonly used is based on the assumption that the volume of the solid can be approximated by calculating the volume of a triaxial ellipsoid with diameters equal to the major, minor and intermediate diameters of the object (Stroshine and Hamann, 1995). Sphericity is defined as the ratio of this volume to the volume of a sphere which circumscribes the object (ie. a sphere with diameter equal to the major diameter of the object). Sphericity can also be defined as the ratio of the surface area of a sphere which has the same volume as that solid, to the surface area of the solid.

$$\text{Sphericity} = \frac{[Volume\ of\ ellipsoid\ with\ equivalent\ diameters]^{1/3}}{Volume\ of\ cicumscibed\ sphere}$$

The geometric mean diameter or equivalent diameter can be calculated from equation (2.1) according to (Mohsenin, 1986).

$$D_p = (abc)^{1/3} \qquad 2.1$$

Where, the major, minor and intermediate diameters are respectively a, b and c.

The degree of sphericity is then calculated using equation 2.2 (Mohsenin, 1986)

$$\Phi = \frac{(abc)^{1/3}}{a} \text{ X } 100 \qquad 2.2$$

$$\Phi = \frac{D_p}{a} \text{ X } 100 \qquad 2.3$$

Burubai *et al.* (2007) also found that African nutmeg had sphericity of less than 0.75, which explained the difficulty in getting the seeds to roll The sphericity of melon seeds increased linearly with increased moisture content from 5.21% to 6.33% (Davies, 2009). Razavi (2006) determined size and shapes of three dried water melon seed varieties using the above equations. Similar methods were used by other researcher such as Zewdu and Solomon (2007), Aseogwu *et al.* (2006) and Said and Pradhan (2013).

2.1.4 Bulk density

This is the ratio of the mass of grains to the volume including the space of void. The bulk density is determined by measuring the weight of a sample of known volume. The sample is placed in a container of regular shape, and the excess on the top of the container is removed by sliding a string or stick along the top edge of the container. After the excess is removed completely the weight of the sample is measured. The bulk density of the sample is obtained by dividing the weight of sample by the volume of the container (Agbetoye *et al.*, 2007). The bulk density may also be done using the air comparison pycnometer. This method was used by Baryeh and Mangope (2002) in the determination of some physical properties of QP-38 variety pigeon pea. Bulk density can also be determined with a weight per hectoliter tester, which is calibrated in kg per hectoliter. This has a predetermined volume and a measure of the weight easily enables the researcher to determine the bulk density. This method has been used by several researchers including Shirkole *et al.* (2011) for soybeans and Isil *et al*. (2009) for rapeseed. The bulk density gives a good idea of the storage space required for a known quantity of a particular crop.

According to Kibar *et al.* (2010), the bulk density decreases as the moisture content increases up to 25%, beyond which it does not change appreciably. A decrease in bulk density as moisture content increases has been reported by Al-Mahaseneh and Rababah (2007) for green wheat; Dursun and Dursun (2005) for caper seeds and Bart-Plange *et al*. (2012) for cashew nut and kernel. Koocheki *et al.* (2007) studied physical properties of water melon seed as a function of moisture content and variety and concluded that standard bulk densities were significantly different among the varieties and increased with increase in moisture content.

In precision agriculture, diverse approaches are used to determine the volume of the existing grain in a combine hopper. To determine the weight of product in the hopper, knowledge of bulk density is necessary. The bulk density of grains is also useful in the design of silos and storage bins (Varnamkhasti *et al*., 2008). Densities of liquid foods are important in separation by centrifugation and sedimentation and in determining flow properties and power requirements. When grains and other particulate solids are transported pneumatically or hydraulically, the design fluid velocities are related to both density and shape (Stroshine and Hamann, 1995). In such sorting systems, fruits are placed in solutions like salt brine or alcohol-water. The specific gravity of the solution is adjusted to a value, which will differentiate between those fruit which are desirable and those, which are not. Problems to be overcome include contamination of the solution by dirt which causes an accompanying change in solution density (Mohsenin, 1986). Wilhelm *et al*. (2004) said that density of food materials is useful in the mathematical conversion of mass to volume and also influences the amount and strength of packaging material. The percent voids of an unconsolidated mass of materials such as grain, hay and other pawns materials are often needed in air flow and heat flow studies (Mohsenin, 1986).

2.1.5 True Density

The true density is the weight per unit volume of an individual seed. The true density is defined as the ratio between the mass of seeds and the true volume of the seeds excluding void spaces, and determined using the toluene (C_7H_8) displacement method. Toluene is used instead of water because it is absorbed by seeds to a lesser extent. The volume of toluene displaced is found by immersing a weighted quantity of seeds in the measured toluene (Tavakoli *et al*., 2009). The true density of rice was measured using toluene displacement method by Kibar *et al*. (2010). 50 grains of rice were weighed using a digital scale with accuracy of 0.01 mm and poured into a scaled burette containing toluene. The level of toluene displaced was equal to the volume of rice. Similar method was used by Razavi and Taghizadeh, (2007).

Kernel and bulk density data have been used in research to determine the dielectric properties of cereal grains (Karimi *et al*., 2009) and for determining volume fractions for use in dielectric mixture equations (Karimi *et al*., 2009). Pneumatic sorting tables are used to separate seeds of cereal crops by true density. Seeds of various impurities such as centourea, rye grass, field mustard and wild oats greatly differ in true density from the seeds of cereal crops. The true density of grain mixtures is determined either in solution or in suspension (Tavakoli *et al*., 2009).

The true density increases nonlinearly from 0.75 to 1.21 g/mm3 as the seed moisture content increases from 5% to 25% for pigeon pea (Baryeh and Mangope, 2002). Linear increase of seed density as the seed moisture content increases has *been* found by Burubai *et al*. (2007) for African nutmeg and Al-Mahaseneh and Rababah (2007) for green wheat. Bulk and true densities are essential in knowing the weight of the crop per unit volume and useful in handling operations (Akaaimo and Raji, 2006).

Gursoy and Guzel (2010), evaluated volume, kernel and bulk densities, weight loss and colour for the variation of physical properties of wheat, barley, chickpea and lentil. Shirkole *et al*. (2011) used spherical shape, equivalent diameters, particle density and other parameters to investigate particle trajectory for grain classifier and selected the length and breadth of the separation chambers. Pod size, true and bulk densities, porosity and moisture content were used by Atiku *et al*. (2004) as relevant for investigating bulk handling and processing of bambara groundnut by a nut sheller. Physical properties of cheat, such as dimension, weight, and shape and bulk density were used by Hauhouot-ihara *et al*. (2000) to establish machine design and operating variables for rollers and hammer mills, selecting the optimum gap between rolls and optimum screen opening size for the hammer mill. Aseogwu (2006) stated that in the physical characterization of oil bean seed, it is important to have an estimate of shape, size, volume, size and bulk densities and other physical parameters for that product.

2.1.6 Porosity

This is defined as the percentage of the total container volume occupied by air spaces between the particles. Porosity can be determined using the air comparison pycnometer and is calculated as the ratio of the volume of the air to the total volume of the chamber. The pycnometer is constructed of two air-tight chambers of nearly equal volumes V1 and V2 connected by small diameter tubing. The valves isolate the chambers from each other and the outside atmosphere (Fig 2.1). The material to be measured is placed in the second tank. In a similar measurement sequence the sample is placed in chamber 2, and valves 2 and 3 are closed. Valve 1 is opened and the gauge pressure P1 in chamber is increased to 700-1000Pa. Valve 1 is closed the pressure P1 is recorded and the valve 2 is opened.

Porosity depends on true and bulk densities and hence its magnitude of variation depends on these factors and is different for each seed or grain. The porosity which is the percentage of air space in particulate solids, affects the resistance to airflow through bulk solids. Airflow resistance in turn affects the performance of systems designed for forced convection drying of bulk solids and aeration systems used to control the temperature of stored bulk solids (Stroshine and Hamann, 1995).

Porosity increases nonlinearly with increase in seed moisture content from 8% porosity at 5% seed moisture content to 28% porosity at 25% seed moisture content for pigeon pea (Baryeh and Mangope, 2002). Kibar *et al.* (2010) and Gursoy and Guzel (2010), found the porosity of rice and sunflower seeds, respectively, to increase with increase in moisture content. Koocheki *et al.* (2007) and Said and Pradhan (2013), however found porosity to decrease linearly with an increase in moisture content for water melon and *Lagenaria siceraria* seeds, respectively. Baryeh (2002) also reports a non-linear increase in porosity from 38% at 5% grain moisture content to 43% at 20% moisture content and then decreases non-linearly to 40.5% at 35% moisture content for millet grains. According to Bart-Plange and Baryeh (2002), high porosity at high moisture content indicates that less number of beans can be stored at high moisture content than at low moisture content due to increase in inter-bean voids when the porosity is high for cocoa beans. The porosity is the most important factor for packing and affects the resistance to airflow through bulk seeds (Tavakoli *et al*., 2009).

Grain bed with low porosity will have greater resistance to water vapor escape during the drying process, due to the reduction in pore spaces which may lead to higher power to drive the aeration fans (Karimi *et al.*, 2009). Hence in the design of postharvest drying equipment, knowledge of porosity of crops is essential when designing fans. A relationship between the porosity, amount of power required driving a specific volume of air through a specific volume and mass of grains and the time taken to carry out this action in order to bring grains to some particular moisture content is necessary in designing storage aeration fans. Porosity, on the other hand, allows gases, such as air and liquids to flow through a mass of particles in aeration, drying, heating, cooling and distillation operations (Karimi *et al*., 2009).

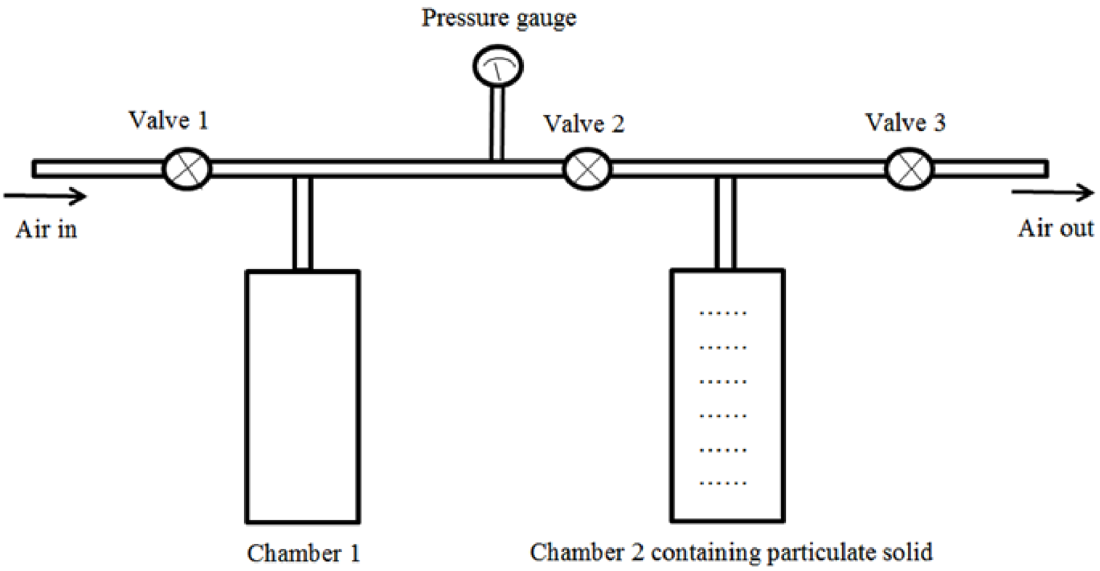


Figure 2.1: Air comparison pycnometer (Source: Stroshine and Hamann, 1995)

2.2 Friction Properties

2.2.1 Angle of repose

This includes the filling angle of repose and the emptying angle of repose. It is affected by the surface characteristics, shape and the moisture content of the grains. The filling angle of repose is the angle with the horizontal at which the material will stand when piled. When grains are removed from an opening in the bottom or the side of a bin, the angle which the grain surface assumes with the horizontal is called the emptying or funneling angle of repose. These angles are very useful for calculating the quantity of granular materials which can be placed in piles or flat storages (Stroshine and Hamann, 1995). The increasing trend of repose angle with moisture content occurs because surface layer of moisture surrounding the particle holds the aggregate of grain together by the surface tension (Tavakoli *et al*., 2009). The angle of repose is also important in designing the equipment for mass flow and structures for storage. The angle of repose is particularly useful for calculating the quantity of granular materials which can be placed in piles or flat storages (Stroshine and Hamann, 1995).

Flow ability of agricultural grains is usually measured using the angle of repose. This is a measure of the internal friction between grains and can be useful in hopper design, since the hopper wall‘s inclination angle should be greater than the angle of repose to ensure the continuous flow of the materials by gravity (Gharibzahedi *et al*., 2010). Low angle of repose of cocoa beans is often advisable during belt conveying while high angle of repose is more desirable when unloading onto a horizontal surface. Hence low moisture content is advisable for belt conveying, while high moisture content is advisable when unloading for the beans (Bart-Plange and Baryeh, 2002).

A linear increase in angle of repose as the seed moisture content increases has been reported by Zewdu and Solomon (2007) for tef seeds, Baryeh and Mangope (2002) for pigeon pea, Bart-Plange and Baryeh (2002) for cocoa beans and Kabas *et al.* (2007) for cowpeas. The angle of repose is useful in hopper design for gravity flow since the angle of inclination of the hopper wall should be greater than the angle of repose to ensure continuous flow of material, (Omobuwajo *et al*., 2000). Mohsenin (1986) said that data on the coefficient and hence, the angle of internal friction of material are very important in calculating their resultant lateral pressure on the returning walls of bins by using the Rankine equation. Akaaimo and Raji (2006) stated that coefficient of internal friction is important in studying the compressibility of the material and determining methods of compressing and packaging. Aseogwu (2006) found that the angle of repose of oil bean was considerably higher than for soybean, corn and wheat. This might be due to the smothness of the surface of oil bean seed which makes it easy for the seed to slide on each other.

Selvi *et al*. (2006) determined the effect of moisture on angle of repose of linseed, at 5 moisture levels. Results show that angle of repose increased with increasing moisture content in all species. This was also confirmed by Koocheki *et al*. (2007) with water melon seed.

2.2.2 Coefficient of Static Friction

Coefficient of static friction is determined by the use of a tilting table and a lifting screw mechanism. It is calculated as the tangent inverse ($\tan^{-1}$) of the angle which the tilting table makes with the horizontal when grains just start moving along the table. An increase in the coefficient of static friction with moisture content has been observed by Tavakoli *et al.* (2009) for barley grains using glass, galvanized iron sheet and plywood; Baryeh (2002) for millets using plywood, galvanized iron and aluminum; Zewdu and Solomon (2007) for tef seeds using plywood, mild steel and glass; Kabas *et al.* (2007) for cowpeas using rubber, plywood and galvanized sheet; Aviara *et al.* (2005) for sheanut using metal sheet, formica and plywood.

The materials used for the experiment were considered because they are commonly used in the handling and processing of grains and construction of storage and drying bins. The reason for the increased friction coefficient at higher moisture content may be owing to the water present in the grain. The grains also possibly become rougher on the surface as the moisture content increases making the coefficient of friction increase (Baryeh and Mangope, 2002). The friction coefficient is important in the design of conveyors because friction is necessary to hold cocoa beans to the conveying surface without slipping or sliding backward. If a rubber surface is to be used for conveying cocoa beans, it will be advisable to roughen the surface to increase friction between the beans and the surface. On the other hand, discharging requires less friction to enhance the discharging process (Bart-Plange and Baryeh, 2002). The knowledge of coefficient of friction of food grains on various structural surfaces is necessary in analysis and design of post-harvest equipment such as grain bins, silos, conveyors. A machine can only be started or stopped if forces of static friction or dynamic friction are overcome by a power source. Therefore, information on both static and dynamic coefficient of friction is vital in estimating the power requirement of machines (Nwakonobi and Onwualu, 2009). The friction coefficient is important in the design of conveyors because friction is necessary to hold grains to the conveying surface without slipping or sliding backward (Tavakoli *et al*., 2009).

Kibar *et al*. (2010) determined the static coefficient of friction and angle of repose of rice to facilitate the development of equipment for processes such as threshing. In the moisture range of 10 to 14% (d.b.) the static coefficient of friction varied from 0.76 to 0.97, 0.52 to 0.70 and 0.58 to 0.76 for concrete, galvanized steel and wood surfaces. Said and Pradhan (2013), determine friction properties like angle of repose and coefficient of friction on plywood, galvanized steel and glass surface of *Lagenaria siceraria* seeds. Angle of repose and coefficient of was observed to be increasing with increase in moisture content. Shirkole *et al*. (2011) stated that friction coefficient increases with increasing moisture content of soyabean against galvanized steel, plywood, mild steel, stainless steel, aluminium and rubber surfaces.

2.3 Mechanical properties

Mechanical properties of biological materials are the behaviour of the materials under applied forces. The study of mechanical is needed for textural analysis and better understanding of the product quality. Force –deformation testing of agricultural materials can be used to study the damage which occurs during harvesting and handling of crops. The mechanical properties that are of interest are the compressive force, deformation, toughness, and modulus of stiffness and young’s modulus.

Mamman and Umar (2005) studied the effects of moisture content and loading orientation on the mechanical properties of balanities nuts. The six mechanical properties investigated were modulus of elasticity, bioyield point, bioyield stress compressive strength, rupture strength and modulus of stiffness. Results show that values of the six properties decreased with increase in moisture content.

The effect of loading direction and nut size of walnuts was studied by Burubai *et al*. (2008). He reported that the large size of walnuts required higher cracking force and experienced more deformation than small ones. Burubai *et al*. (2008) also found that the difference between kernel and African nutmeg cracking deformation is a dependable indicator for predicting the effect of moisture content and compression magnitude on kernel damage. Olajide and Bamgboye (2014) studied the effect of moisture content on rupture force and energy, deformation, normal and shear stress of locust bean on quasi-static loading. They found out that all the factors examined had significant effect on the deformation, normal and shear stress.

Ahmadi *et al.* (2009) said that determination of engineering properties of agricultural products under loading is aimed at textural measurement and the reduction of mechanical damage to agricultural produce during postharvest handling, processing and postharvest systems. Kibar *et al.* (2010) observed that Poisson and lateral pressure ratio of rice grain decreased with increase in moisture content. Shirmohammadi and Yarlagadda (2012) found out that the rupture force, toughness and firmness of flesh of pumpkin were lower than that of the unpeeled sample.

Ahmadi *et al.* (2009) found that rupture force on both the seed length and width sections decreased log metrically with moisture content in the moisture range of 6.78 to 21.67% (d.b). Ogunsina *et al.* (2008) observed that the compressive force required to crack dika nut increased with nut diameter and that the force is lower when applied in the transverse direction. The cracking force is highest on the vertical direction, followed by loading on the vertical while it smallest on thickness of locust bean seed as reported by Ogunjimi *et al.* (2002). Burubai *et al.* (2008) stated that the African nutmeg seeds loaded in the axial position required lower force to cause seed coat rupture than those loaded laterally. In the case of shea nut it best crack along the vertical loading position since it required lesser energy as reported by Olaniyan and Oje, (2002).

Orhevba *et al.* (2013) observed that it would be economical to load dika nut in the longitudinal direction to reduce energy demand to fracture or compress the nut. Bart-Plange *et al.* (2012) reported that the compressive strength, deformation and Young's modulus of cashew kernel and nut increased progressively with increase in moisture content from 5.0 to 9.0% w.b. Mechanical properties of sunflower such as rupture force, elasticity modulus and hardness were higher in the horizontal loading position than the vertical as observed by Bagvand and Lorestani, (2013).The rupture force of locust bean seed decreased linearly from 214.40 to 129.86 N as the moisture content of the seed increased in the range of 5.9 to 28.2% (d.b), while the deformation decreased from 0.98 to 0.97 mm at 11.1% and increased to 1.61 mm at 22% before it finally dropped at 28.2% to 1.13 mm. (Olajide and Bamgboye 2014). The average cracking force required to break the dura and tenera varieties of oil palm were 2301 N and 1149 N, respectively which implies that greater force is required in breaking the dura variety when compared to the tenera variety as reported by Owolarafe *et al.* (2007). The Poisson ratio and lateral pressure ratio of rice grain decreased with increase in moisture content as observed by Kibar *et al.* (2010).

The Young's modulus, rupture force and energy of caper were reported to be 0.247 Gpa, 164.00 N and 620.93 Nmm respectively by Ali, (2012). Ogbonnaya and Sunmonu, (2010) reported that the compressive strength, tensile strength, hardness, abrasive strength, shear strength and torsion strength Tvx variety of cowpea were greater than those of sampea 7 variety.

Table 2.1: Static coefficient of friction of some materials on some selected surfaces

Material	Type of Surface	Moisture Content	Static Coefficient of Friction
Barley	Concrete, wood float finish	12.3	0.52
Oats	Concrete, wood float finish	13.0	0.44
Soybeans	Concrete, wood float finish	12.2	0.52
Corn shelled	Concrete, wood float finish	13.9	0.54
Wheat	Concrete, wood float finish	11.2	0.51

Source: Stroshine and Hamanna, 1995

2.4 Thermal properties

Agricultural and food materials undergo heating or cooling during processing and storage. Heating comes in the form of drying, evaporation, sterilization, pasteurization, baking, etc., whereas cooling comes in the form of chilling or freezing. The response of a material during the heating and cooling process is dependent on its thermal properties. During processing and storage heat may be transferred by conduction, convection or radiation. Conduction is the predominant mode of heat transfer, as such, information on the thermal properties of materials related to conduction is important.

Heat conduction is either molecular interchange of kinetic energy or electron drift. In molecular interchange, the molecules of the materials are set into motion as they heated. In electron drift, heat conduction is primarily associated with the mobility of free electrons. In both cases, heat is transferred. Thermal conductivity is a measure of a material's ability to transmit heat. It is the proportionality factor in the heat conduction equation (equation 2.4)

$$\frac{dQ}{dt} = kA\frac{dT}{dx} \qquad 2.4$$

where:

Q = heat, j

t = time, s

T = temperature. ^{o}K

A = cross sectional area. m^2

x = length, m

k = thermal conductivity, Js^{-1} m^{-1}K^{-1}

The values of thermal conductivity and diffusivity vary with the chemical composition, physical structure, the state of the substance and temperature. Thermal conductivity values are low for low density organic gases and vapors, medium for higher density liquids and porous solids, and highest for pure metals of the highest density.

Moisture content affects the thermal conductivity of a material. During heating of a material, moisture migration occurs if the material is moist and permeable or porous.

Moisture migration involves evaporation in the warm region, transmission of the vapor by diffusion to the cooler region and condensation in the cooler region. Latent heat is transferred by this mechanism in addition to the conduction heat transfer. Thermal conductivity is affected by this phenomenon. Therefore, the use of conductivity measurement methods involving long heating periods are not suitable for agricultural and food materials.

Olajide and Bamgboye (2014) determined the thermal conductivity of locust bean (*Parkia biglobosa*) using the steady-state heat flow method. Measurements were made using digital ammeter, voltmeter and thermometer. Samples at specified moisture content were put in a 75 mm diameter, circular plastic ware plate and 10 mm thickness. The samples assumed the size of the plate. The probe thermocouple pierced through the cylinder bottom and through the plastic but slightly penetrating into the sample to avoid touching the hot plate directly. The plastic dish containing the sample was placed at the base of the cylinder. The hot plate was lowered down the cylinder gently until it touched the sample. The temperature of the hot plate was pegged around 70 ^{o}C. The fluctuations in temperature of the hot plate and the changes in temperature of the samples were monitored and recorded for one hour at five minutes interval. At equilibrium conditioned, the temperature difference and heat flux were recorded and used in calculating the thermal conductivity of the sample from equation 2.5.

$$q = \frac{KdT}{L} \qquad 2.5$$

Where q = heat flux, Wm^{-2}

dt = temperature difference at equilibrium condition, ^{o}C

K = thermal conductivity, Wm^{-1o}C^{-1}

L = length of sample, m

Alagusundaram *et al.* (1991) measured the thermal conductivity of bulk barley, lentils and peas using the line heat source methodology. Sample moistures used were: (a) 9.7 to 22.8% w.b. for barley; (b) 10.2 to 21.2% for lentils; and (c) 10.2 to 21.3% for peas. Temperature ranges were: (a) -28 to 29 °C for barley; and (b) -21 to 28 °C for lentils and peas. The samples were placed in an aluminum cylinder with a diameter of 150 mm and a height of 300 mm. A 250 mm long 31-gauge chromel wire was used as the line heat source with a resistance of 0.0274 mm^{-1}. A DC power supply with constant current input of 544 mA through the line heat source was used. They recommend the use of the slope method in calculating the thermal conductivity.

Bart-Plange *et al.* (2012) measured the thermal conductivity of cashew kernel using the line heat source method. The moisture content of cashew kernel was 5 to 9% w.b. The samples were placed in a cylinder at a particular bulk density. The plastic cylinder was sealed at the top and bottom with wooden plugs. A constant D.C. power source of 3V and a current of 1 A were supplied to Nichrome wire stretching between two ends of the plastic cylinder as the heat input source. The probe was inserted through the center of the sample mass to take the temperature readings. During the heating process, the temperature of the sample was recorded as a function of elapse time at the interval of 30 seconds with the help of a digital time recorded. Recorded temperature values were then plotted against the natural logarithm of elapse time and subsequently thermal conductivity was calculated by using equations 2.6 and 2.7.

$$K = \frac{Q\ In\left({}^{t_2}/{}_{t_1}\right)}{4\pi(T_2 - T_1)} \qquad 2.6$$

$$Q = \frac{VI}{L} \qquad 2.7$$

Q = heat supply

t_2 = final time

t_1 = initial time

V = electrical voltage, volts

I = current, amps

T_1 = initial temperature

T_2 = final temperature

K = thermal conductivity

A guarded hot-plate apparatus with steady the state heat flow method was used to measure the thermal conductivity of sheanut kernel (Aviara and Haque, 2001). The apparatus consisted of an upper (hot) plate and a lower (cold) plate, all made of brass.

The upper plate was 85 mm in diameter and 39 mm thick. It was surrounded by a guard ring of 139 mm diameter and 25 mm thickness. The gap between them was filled Teflon spacer at both the top of the plate and the sides to a thickness of 2 mm. The lower plate had a diameter of 85 mm and a thickness of 20 mm. It was surrounded by a ring of 139 mm diameter and 25 mm thickness, from which it was separated by Teflon spacer to a thickness of 2 mm. The upper plate was heated electrically and this was controlled using a power stabilizer. Measurements were made using an indicating digital ammeter and voltmeter. The temperature of the plates was measured with 0.2 mm copper-constantan thermocouples. To determine the thermal conductivity of ground sheanut kernel, a sample at specified moisture content was obtained using an open-ended cylinder made of polythene with a diameter of 85 mm and length of 2 mm. The polythene cylinder was placed on the lower plate and filled with ground kernel from a height of 15 cm. The surface was leveled off and the device adjusted to lower the upper plate on the sample. The polythene cylinder was carefully torn off prior to the heating of the upper plate. Most of the measurements were made using samples of 2 mm thickness. At the equilibrium condition, the temperature difference and heat flux were recorded and used in calculating the thermal conductivity of the sample from the equation 2.5.

The thermal conductivity of banana was determined using the line heat source probe method based on non-steady heat conduction (Bart-Plange *et al.*, 2012). The apparatus consist of an ammeter and voltmeter for the recording of current voltage respectively. A direct current (DC) power source was used to provide the heat source. Current and voltage of 0.7 A and 4.5 ± 0.5 V respectively were used throughout the experiment. In the set-up was a rheostat to vary the resistance in the circuit in order to achieve the desired current for the experiment. The conditioned samples of specific moisture content were allowed to warm up to room temperature. After weighing, it was it was put in a sample holder of diameter 2 cm. A heating coil was placed in the middle of the sample and connected externally to the power source. The temperature meter was inserted into the sample holder and then the switch turned on. The current and voltage readings were adjusted to 0.7 A and 4.5 ± 0.5 V respectively and used as heat source for the sample. The experiment was replicated four times at each moisture content level and recorded. A graph of temperature difference at the intervals considered T_2-T_1 was plotted against the natural logarithm of the corresponding time ratio $\left[In\frac{\theta_2}{\theta_1}\right]$. The slope (S) of the graph was determined from the straight line portion of the graph which is given as

$$S = \frac{Q}{4\pi K} \qquad 2.8$$

Hence, thermal conductivity was determined from equation 2.10

$$K = \frac{Q}{4\pi S} \qquad 2.9$$

The thermal conductivity of cylindrical shaped potato slices were determined by utilizing their time-temperature data (Califano and Calvelo, 1991). Temperatures of 50 to 100 °C were used during measurement. The potato cylinders measuring 1 cm diameter and 6 cm long were cut from potatoes having a density of 1070 $\mathrm{kgm^{-3}}$ and moisture of 80%. Each sample was immersed in a temperature-controlled oil bath until it reached uniform temperature. A thermocouple wire was placed in the center of the sample. The sample was transferred to another temperature-controlled oil bath having a temperature of 10 °C higher than the other bath. The temperature was recorded at intervals of 5 s. The time-temperature data were fitted through a numerical solution to the heat transfer equation for an infinite cylinder at initial temperature T_0, immersed in a well-stirred bath at temperature, T_f, with convective boundary condition. Thermal conductivities were calculated using an iterative least squares procedure. 100 g of water was transferred from the conical flask to thermos flask and the temperature was recorded with digital thermometer with an accuracy of ± 0.1 °C. After 10 min, 40 g of encapsulated sample in two small thin wall glass bottles was dropped into the thermos flask and the temperature recorded at 1 min intervals initially, then at 5 min intervals. The equilibrium temperature was determined by graphical method described by Mohsenin (1986), to reduce the error due to thermal leakage. The degree of mixing was improves by slight shaking of the flask by hand. The water equivalent of the flask was determined using 40 g of water at a known temperature. The sample and the thermos flask were equilibrated at the same room temperature to reduce the error. The method was calibrated by measuring the specific heat of water.

Yang *et al.* (2002) used bare-wire transient method to determine thermal conductivity of borage seeds. It consisted of a bare-wire thermal conductivity apparatus, a 80 mm (inner diameter) cylindrical air conduct, an air conditioning system, a circulating system, a data acquisition system comprising of a Campbell 21X Micro logger

(Campbell Scientific Inc., UT) and a personal computer. The bare-wire thermal conductivity apparatus consisted of a brass cylindrical sample tube 58.6 mm in inner diameter and 240 mm in length, with a removable top cover and a fixed bottom base. A 0.254 mm (diameter) constantan heater wire (10.07 Ωm^{-1}, 210 mm in length) was connected to a constant d.c. current (1.000 ± 0.004 A) power source. Pre-calibration type T thermocouples were installed for measuring the core temperature and the outer surface temperature of the sample tube. The thermocouples were connected to data acquisition system by a thermocouple extension wire.

Specific heat of banana was determined using the method of mixtures by Tansakul and Lumyong (2008). The method employed the following assumptions: (a) Heat loss as a result of transfer of product from the heated chamber to calorimeter is negligible and (b) loss of evaporation during equilibration period is negligible.

The heat capacity of calorimeter was determined experimentally: a known quantity of hot water at a temperature of (85^0) was added to the calorimeter containing a known quantity of water at a lower temperature. The heat capacity of the calorimeter was determined using equation 2 as reported by Mortaza et al. (2008).

$$C_c = \frac{M_{hw}(t_{hw}-t_e)-M_{cw}C_w(t_e-t_{cw})}{M_{ht}(t_e-t_1)} \qquad 2.10$$

The specific heat of aluminum foil was also determined experimentally. The foil with a known mass and high temperature was put into a calorimeter that contains a known quantity of distilled water at a known low temperature (room temperature). The system was assumed to be adiabatic. Therefore, the specific heat capacity of the foil was calculated from equation (2.11) Mortaza *et al*. (2008).

$$C_s = \frac{(M_c C_c+M_t C_t)(t_t-t_e)}{M_s(t_e-t_s)} \qquad 2.11$$

To determine the specific heat of banana, a sample of known weight and temperature was wrapped in aluminum foil and heated in a heating chamber for one hour and the final temperature recorded. The sample was quickly removed and dropped into a calorimeter containing water of known quantity and temperature. The mixture was stirred continuously with a glass rod in order to obtain a uniform mixture. At equilibrium, the final temperature was recorded and the specific heat of sample calculated using the equation reported by Mortaza *et al*. (2008) as follows:

$$C_b = \frac{(M_c C_c + M_w C_w)(t_t - t_e) - M_f C_f}{M_b (t_e - t_f)} \qquad 2.12$$

Yang *et al.* (2002) used differential scanning calorimetry method to determine the specific heat of borage seeds. A single borage seed, weighed to ± 0.001 mg, was hermetically sealed in a 40 µl standard aluminum crucible, and loaded in the DSC 30 cell of a TC 10 thermal analyser, Mettler TA 3000 (Mettler Instrumente AG, Switzerland). The specific heat measurement were made between 5 and 20 ^{o}C temperature at a heating rate of 5 Kmin^{-1} against a pre=recorded blank compensation curve (the baseline when an aluminum crucible contained no sample).

Thermal diffusivity is a derived property involving a high time and is always associated with unsteady or transient heat flow. Thermal diffusivity has dimension of length squared divided by time (m^{2}s^{-1}). The inverse of thermal diffusivity in units of sm^{-2} is a measure of the time required temperature level. The ratio of heating times of two materials of the same thickness will be inversely proportional to their respective diffusivities: Thermal diffusivity α is the ability of a material's to conduct heat relative to its ability to store heat. It is the ratio of thermal conductivity k to the product of density ρ and specific heat C_p

$$\alpha = \frac{k}{\rho C_p} \qquad 2.13$$

where:

A = thermal diffusivity in m^2 s^{-1}

ρ = bulk density in kgm^{-3}

C_p = specific heat capacity of sample in Jkg $^{-1}$K^{-1}

K = thermal conductivity in Wm^{-1}k^{-1}

The thermal diffusivity of sheanut kernel and borage seeds increase with increase in moisture content as reported by Aviara and Haque (2001) and Yang *et al.* (2002). Mariani *et al.* (2008) observed that the thermal diffusivity of millet grains and flours and banana, respectively, decreased with increase in moisture content. Also Aviara *et al.* (2008) reported that thermal diffusivity of guna seed and kernel decreased with increase in moisture content and increased with increase in temperature.

2.5 Water Properties

Three concepts are important in the discussion of moisture in agricultural materials and food products: equilibrium moisture content, water activity and water potential. Equilibrium moisture describes the final moisture reached during drying of lower moisture agricultural materials and food products. Water potential describes the effect of moisture loss or gain on both volume changes and force deformation behaviour of fruits and vegetables (Stroshine and Hamann, 1995).

Water potential is the potential energy of water per unit volume relative to pure water in reference conditions. Water potential quantifies the tendency of water to move from one area to another due to osmosis, gravity, mechanical pressure, or matrix effects such as surface tension (Taiz and Zeiger, 2002). When the moisture content (M_w) of agricultural material and food products are described by the percentage of total weight (W_t), it is called wet basis moisture content. However if it is expressed as the percentage equivalent to the ratio of weight of water only (W_w) to the weight of dry matter (W_d) it is called the dry basis moisture content. They are described by the following formulas;

$$M_w = 100\frac{W_w}{W_t} = 100\frac{W_w}{W_w + W_d} \qquad 2.14$$

$$M_d = 100\frac{W_w}{W_d} \qquad 2.15$$

$$M_w = 100\frac{M_w}{100 + M_d} \qquad 2.16$$

$$M_d = 100\frac{M_d}{100 - M_w} \qquad 2.17$$

W_w = weight of water in the material

W_d = weight of dry matter in the material

W_t = total weight of sample = Ww + Wd

M_w = moisture content expressed in wet basis

M_d = moisture content expressed in dry basis

The amount of dry matter in a sample is assumed to be constant. The amount of dry matter is calculated from initial weight and initial moisture content (m.c.). The dried or rewetted sample will contain the same amount of dry matter (Stroshine and Hamann, 1995).

2.5.1 Properties of Water in Foods

According to Taiz and Zeiger (2002), despite having the same chemical formula (H_2O), the water molecules in a food product may be present in a variety of different molecular environments depending on their interaction with the surrounding molecules. The water molecules in these different environments normally have different physiochemical properties namely:

Bulk water - Bulk water is free from any other constituents, so that each water molecule is surrounded only by other water molecules. It therefore has physicochemical properties that are the same as those of pure water, *e.g.*, melting point, boiling point, density, compressibility, heat of vaporization, electromagnetic absorption spectra.

Capillary or trapped water - Capillary water is held in narrow channels between certain food components because of capillary forces. Trapped water is held within spaces within a food that are surrounded by a physical barrier that prevents the water molecules from easily escaping, *e.g.*, an emulsion droplet or a biological cell. The majority of this type of water is involved in normal water-water bonding and so it has physicochemical properties similar to that of bulk water.

Physically bound water - A significant fraction of the water molecules in many foods are not completely surrounded by other water molecules, but are in molecular contact with other food constituents, *e.g.* proteins, carbohydrates or minerals. The bonds between water molecules and these constituents are often significantly different from normal water-water bonds and so this type of water has different physicochemical properties than bulk water.

Chemically bound water. Some of the water molecules present in a food may be chemically bonded to other molecules as water of crystallization or as hydrates, *e.g.* $NaSO_4.10H_20$. These bonds are much stronger than the normal water-water bond and therefore chemically bound water has very different physicochemical properties to bulk water. In addition, foods may contain water that is present in different physical states: gas, liquid or solid.

2.5.2 Moisture Measurement

A number of techniques have been developed for measuring the moisture content of agricultural materials and food products. Moisture content often varies slightly when different methods are used for the determination. The reason may be that some of the water may actually be chemically bound as a constituent of the product itself or heating may decompose some of the constituents and water may be one of the products of the decomposition. An accurate determination of moisture is dependent upon proper sampling procedures. Moisture content can be determined by either the direct or indirect methods. Direct methods are simpler and accurate but time-consuming. Indirect methods such as chemical and electrical methods are convenient and quick but less accurate (Stroshine and Hamann, 1995).

2.5.2.1 Direct Measurement

Water content is determined by removing moisture and then by measuring weight loss. Direct methods are considered to provide true measurements of moisture content, and are used to calibrate more practical and faster indirect methods. Direct methods are mainly devoted to research purposes because they require special equipment (e.g. an oven and analytical balance), and measurements can only be implemented in laboratories. They are also time-consuming (Stroshine and Hamann, 1995).

2.5.2.2 Indirect Measurement

An intermediate variable is measured and then converted into moisture content such as electrical conductivity (Stroshine and Hamann, 1995).

2.5.3 Moisture Meters

All commonly used methods are based on electrical property of grains. An electrical current unit, resistance or capacitance, is measured and then converted into moisture content.

1. Resistance: the meter measures the electrical resistance of grains when a current is applied between two electrodes. Grains are placed in a constant and known volume.

2. Capacitance: the meter measures an electrical current between two plates of a condenser which constitute the walls of a recipient. A precise weight of sample is required.

In both techniques, temperature corrections are required for accurate measurements. Most moisture meters are equipped with temperature correction software.

Limits of the method

Calibration charts must be established for each grain type. This means that a meter must be calibrated separately for robusta beans and arabica beans, but also for cherries and parchment to obtain accurate measurements. Accurate measurements are obtained within a range given by the manufacturer (Stroshine and Hamann, 1995).

2.5.4 Moisture Content Determination Techniques

2.5.4.1 Electrical Method

An awareness of the effect of moisture on the electrical properties of resistance and capacitance led to the development of electrical moisture meters. In meters which use the principle of conductance, the sample is compressed by two plates made of conducting material and connected in series to a source of electric current. The current is measured with a galvanometer. A series of fixed resistors may be included in the circuit to increase the sensitivity of the galvanometer. The resistance of the sample is dependent on the pressure which the plates apply to the sample. The capacitance type acts as a dielectric material when placed between two plates or concentric metal cylinders which form a capacitor (Stroshine and Hamann, 1995).

2.5.4.2 Hygrometers

These devices measure the relative humidity in the air space between grains. Values given by these meters refer to water activity of grains and are useful for microbiological purposes. The accuracy of measurements depends on the uniformity of the distribution of moisture in the sample and equilibration must be achieved to have reliable measurements. For high moistures, equilibration time may take few hours.

2.4.4.3 Evaporation Method

This method relies on measuring the mass of water in a known mass of sample. The moisture content is determined by measuring the mass of a food before and after the water is removed by evaporation:

$$\%Moisture \ = \frac{M_{initial} - M_{dried}}{M_{dried}} \times 100 \qquad 2.18$$

Here, M_{initial} and M_{dried} are the mass of the sample before and after drying, respectively. The basic principle of this technique is that water has a lower boiling point than the other major components within foods, *e.g.*, lipids, proteins, carbohydrates and minerals. Sometimes a related parameter, known as the *total solids*, is reported as a measure of the moisture content. The total solids content is a measure of the amount of material remaining after all the water has been evaporated:

$$\% \text{ Total Solids} = \frac{M_{dried}}{M_{intial}} \times 100 \qquad 2.19$$

Thus, %Total solids = (100 - %Moisture).

2.5.4.4 Hot-air Oven Method

The sample is weighed and heated in an insulated oven to constant weight. The difference in weight is the water that has evaporated. The sample is usually weighed in a flat-bottomed, shallow dish (made of material that will not react with food nor pick up moisture readily). The oven must be thermostatically controlled and usually set at 105 ± °C. The size, weight, etc., of the sample is very critical. To help fast and uniform drying, the sample should be disintegrated into fine particles. Very often, an internal fan is also fitted in the oven to circulate the hot air. This method is suitable for nuts, flour, powders, meat and meat products, and most fruits and vegetables.

Advantages

i. Precise
ii. Relatively cheap
iii. Easy to use
iv. Officially sanctioned for many applications
v. Many samples can be analysed simultaneously

Disadvantages

i. Destructive
ii. Unsuitable for some types of food
iii. Time consuming

2.5.4.5 Distillation Method

Distillation methods are based on direct measurement of the amount of water removed from a food sample by evaporation: %Moisture = 100 ($M_{water}/M_{initial}$). Basically, distillation methods involve heating a weighed food sample ($M_{initial}$) in the presence of an organic solvent that is immiscible with water. The water in the sample evaporates and is collected in a graduated glass tube where its mass is determined (M_{water}).

Dean and Stark Method

A known weight of food is placed in a flask with an organic solvent such as xylene or toluene. The organic solvent must be insoluble with water; have a higher boiling point than water; be less dense than water; and be safe to use. The flask containing the sample and the organic solvent is attached to a condenser by a side arm and the mixture is heated. The water in the sample evaporates and moves up into the condenser where it is cooled and converted back into liquid water, which then trickles into the graduated tube. When no more water is collected in the graduated tube, distillation is stopped and the volume of water is read from the tube.

Advantage

i. Suitable for application to foods with low moisture contents
ii. Suitable for application to foods containing volatile oils, such as herbs or spices, since the oils remain dissolved in the organic solvent, and therefore do not interfere with the measurement of the water
iii. Equipment is relatively cheap, easy to setup and operate
iv. Distillation methods have been officially sanctioned for a number of food applications.

Disadvantages

i. Destructive
ii. Relatively time-consuming

iii. Involves the use of flammable solvents
iv. Not applicable to some types of foods.

2.5.4.6 Chemical Reaction Methods

Reactions between water and certain chemical reagents can be used as a basis for determining the concentration of moisture in foods. In these methods a chemical reagent is added to the food that reacts specifically with water to produce a measurable change in the properties of the system, e.g. mass, volume, pressure, pH, colour or conductivity. Measurable changes in the system are correlated to the moisture content using calibration curves. To make accurate measurements it is important that the chemical reagent reacts with all of the water molecules present, but not with any of the other components in the food matrix.

2.5.5 Rewetting

2.5.5.1 Methods of Rewetting

Several methodologies have been used in literature for preparing rewetted materials and among which the following are commonly utilized. Grain particles are often rewetted by immersion in water during different periods of time depending on the initial moisture content that must be attained. Other researchers rewet particles by contacting the mass of grains to be rewetted with the exact amount of water required to reach the desired initial moisture content. Another methodology used considers rewetting of the particles by placing them within an environment of saturated air for the time necessary for them to reach the moisture content of interest (Ruiz *et al.*, 2007). Soaking is a slow process controlled by the diffusion of water in the grain (Bello *et al.*, 2004). Thus soaking at room temperature may provoke microbial contamination, which affects quality attributes (such as colour, taste and flavour) of the product (Bello *et al.*, 2004). Warm water soaking is a common method to shorten the soaking time, because higher temperature increases hydration rate (Kashaninejadl and Kashiri, 2007).

Moisture content each time after soaking is calculated based on the increase in the sample weight at corresponding times. For this purpose, at regular time intervals, kernels are rapidly removed from test tubes and superficially dried on a large filter paper, to eliminate the surface water. The kernels are then weighed to determine the moisture uptake. The samples are subsequently returned to water via wire mesh baskets, and the process is repeated until the kernels moisture content attains a saturation moisture content, (i.e., when three successive weight measurements differ from the average value in less than ±1%) (Resio *et al*., 2005).

2.5.5.2 Importance of Rewetting

In the canning industry, knowledge in hydration characteristics of grains prior to further processing is necessary to know the changes such as leaching losses, and grain expansion in the can during a thermal process. In order to control and predict the process, optimizing the hydration condition is vital since hydration governs the subsequent operations and the quality of the final product (Kashaninejadl and Kashiri, 2007). The wetting process is commonly applied in cereal and other crop grains. It is used as a preliminary process (e.g. before hulling) during processing of leguminous plant seeds. Wetting plays an important role at preparing the seeds for milling. Properly performed it has a significant influence on extract index value for white flours and the quality of the obtained milled products. Moreover, it ensures the optimum working conditions for a grinding device resulting in a uniform condition of the seeds by improving such traits as endosperm tenderness as well as ductility and elasticity of cover (Chemperek and Rydzak, 2006).

Kibar *et al.* (2010) found that field rewetting increased the number of cracked rice kernels, and that the percentage of cracks increased with the duration of exposure to moisture. The level of rewetting which is based on the moisture content of kernels can then be used to determine the degree of cracking, hence a relation between rewetting and cracking. Depending on the moisture level, an estimate can be given for the number of cracked kernels which would lead to a reduction in cracked kernels or increase in head rice yield for industrial processing.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

For the experiment, the two species of bush mango seed and kernel were sourced from six states in the South-western and South- eastern parts of Nigeria where the fruit is grown. The grains were already clean from chaff and other foreign materials. The edible fruits (*Irvingia gabonensis*) were obtained from Omi- Adio in Oyo state, Idowa in Ogun state and Ife in Osun state. The bitter fruits (*Irvingia wombolu*) were obtained from Owo in Ondo state, Auchi in Edo state and Mbano in Imo state. The fruits were removed to obtain the seed and kernel samples which are shown in (Plate 3.1).

3.2 Materials

Ceramic weighing pans, Venier caliper, Measuring cylinder, Beaker, Distilled water, Electronic balance, Toluene (C_7H_8), Circular wooden plate, Protractor, Coefficient of friction apparatus (tilting table mechanism), Thermometers, Copper calorimeter, Improvised Leeds disc apparatus, Glycerin.

3.3 The Physical Properties

Length, width and thickness measurements

Geometric Mean Diameter, Sphericity, 1000 Grain Mass

Bulk Density, True Density, Porosity

Angle of Repose, Static Coefficient of Friction

3.4 Methods

3.4.1 Moisture content determination

The initial moisture content of the seed after harvest was determined by using the standard hot air oven method at $105 \pm 1\ ^{o}C$ for 24h. (ASAE, 2002). Five samples each was placed in the oven. After this, the moisture content on dry basis was determined by dividing the

Irvingia wombolu seed

Irvingia gabonensis seed

Irvingia wombolu kernel

Irvingia gabonensis kernel

Plate 3.1: Samples of Bush mango seed and kernel

mass of moisture evaporated from the sample by the final weight of the samples. The average was then recorded. Also the moisture content of the dried seed was determined after 30 days of storage at atmospheric conditions. The kernels were removed from the seeds using the traditional method by cracking using knife to remove the kernel. The initial moisture content of the kernel was immediately determined and dry moisture content obtained by drying the kernel for 10 hours at 70 ^{o}C. (Zewdu and Solomon, 2007). Data obtained was used as a guide in the selection of moisture levels.

The size and principal axes of the seeds and kernel (minor, intermediate and major) were determined using a BILTEMA venier caliper of precision 0.01 mm, model Art.16-1140. The mass of seeds was determined by using a Mettler Toledo ADP 2100 electronic balance of maximum allowable mass 400 g (Mettler Toledo GmbH, Greifensee, Switzerland) to an accuracy of 0.0l g. The moisture content was determined using a Memmert drying oven model 854 Schwabach, made in Germany.

3.4.2 Rewetting

Several methodologies have been used in literature for preparing rewetted materials. Grain particles are often rewetted by immersion in water during different periods of time depending on the initial moisture content and required moisture content. This was used by Aviara *et al*. (2005), and involved the soaking of different bulk samples of Bambara groundnuts in clean water for a period of one to four hours, followed by spreading out in a thin layer to dry in natural air for about eight hours. After this, the samples were sealed in polyethylene bags and stored in that condition for a further 24 hours to achieve a stable and uniform moisture content of the samples.

However, for this study, samples were conditioned to moisture contents in the range of 10% - 50% for the seeds and 2.18% - 5.32% for the kernel by adding calculated amount of distilled water (Eqn. 3.1), sealing in low density polythene bags and stored in a refrigerator at a temperature of 5 degrees for 72 hours (Coskun *et al*., 2005). This was done to create a favourable environment for the absorption of water by the seed and kernel and also to prevent the action of microbes on the moist seeds.

Before starting a test, the required quantities of the samples were taken out of the refrigerator and allowed to warm up to the room temperature for about 2 hours.

$$Q = \frac{W_1(M_i - M_f)}{100 - M_f} \qquad 3.1$$

Where:

Q: mass of distilled water, kg;

W_i: initial mass of sample, kg;

M_i: initial moisture content of sample, d.b. %;

M_f: desired moisture content of sample, d.b. %

3.4.3 Drying

To decrease the moisture content of seeds and kernels to a lower one after rewetting, sun drying was carried out for about 6 hours. Grains were spread out evenly on polythene bags and regularly stirred to ensure uniform drying. Samples were taken at regular time intervals and moisture content determination carried out. The seeds were allowed to cool down to room temperature for about 2 hours before beginning each experiment.

3.5 Dimensional Properties

The dimensions of agricultural materials vary widely with growing season, growing location and variety. Therefore it is best to perform experiments on a large number of specimens from the particular variety grown under cultural practices typical of the region. The mean and standard deviation determined can be compared to other means and standard deviations of other sample. The average size was determined based on 100 randomly selected seeds and kernels. An electronic venier caliper of precision 0.01 mm, model Art.16-1140, was used to measure the axial dimensions of the seeds and kernels; length (a), width (b) and thickness (c) as shown in Plates 3.2 and 3.3. The axial dimensions were determined at five moisture levels for the seed and three moisture levels for the kernel.

Plate 3.2: Shape and dimensions of bush mango seed

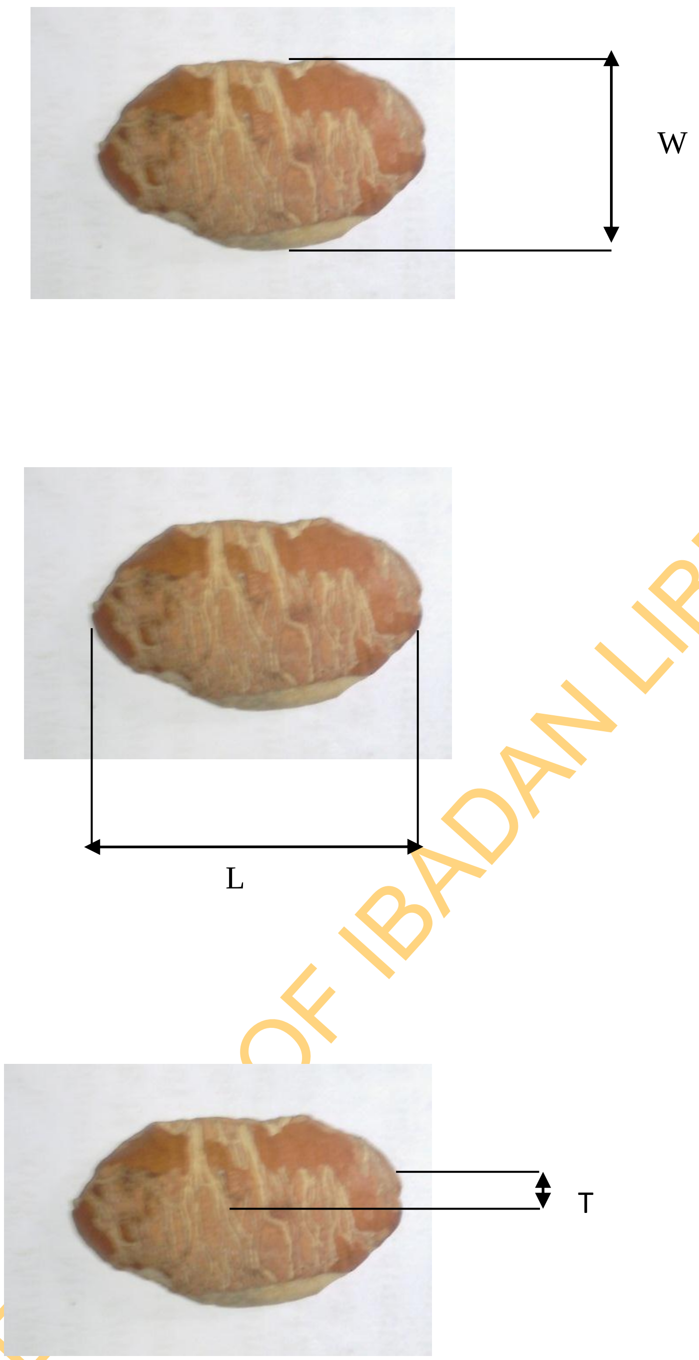


Plate 3.3: Shape and dimension of bush mango kernel

3.6 Geometric Mean Diameter and Sphericity

The length, width and thickness dimensions were recorded by carefully placing each single seed and kernel within the venier caliper. Based on measurements of the length, width and thickness, data for the geometric mean diameter, sphericity, volume and surface area were determined using the mathematical equations 3.2, 3.3, 3.4 and 3.5 respectively

$$D_p = (\mathrm{abc})^{\frac{1}{3}} \qquad \text{(Mohsenin,1986)} \qquad 3.2$$

Where:

a = the length: it is the dimension along the longest axis in mm;

b = the width: it is the dimension along the longest axis perpendicular to a in mm

c = the thickness: it is the dimension along the longest axis perpendicular to both ‘a’ and ‘b’ in mm.

The sphericity Φ was determined by using the formular given by Mohsenin (1986)

$$\Phi = \frac{(abc)^{1/3}}{a} \qquad 3.3$$

3.7 1000 seed weight

Five replications of 100 seeds and kernels were picked at random from each of the two species and weighed on an electronic balance to 0.01 g accuracy. The weight was then multiplied by 10 to give the 1000 grain mass and the average mass was recorded. Similar methods have been used by Wang *et al.* (2007) for Fibered Flaxseed; Tunde-Akintunde and Akintunde (2007) for beniseed; Igbozulike and Aremu (2009) for garcinia kola seeds; Tavakoli *et al.* (2009) for barley grains and Gharibzahedi *et al.* (2010) for pine nut.

3.8 True density, Bulk density and Porosity

True density was obtained by using the toluene displacement method (Zewdu and Solomon, 2007). Toluene was used in place of water because the former is absorbed by seeds to a lesser extent. Also, its surface tension is low, so that it fills even shallow dips in a seed and its dissolution power is low (Kabas *et al*., 2007). Similar methods have been used by Tavakoli *et al.* (2009) for barley grains; Ozturk *et al.* (2009) for new common beans and Khodabakhshian *et al*. (2010) for sunflower seeds and kernels. A known mass of seed was poured into an improvised Eureka can and the volume of toluene displaced measured using the density measuring cylinder. The process was replicated 10 times for each species at of the seed at five moisture levels. The true density calculated from Equation 3.4

$$\rho_t = \frac{M_s}{V_s} \qquad \text{(Tavakoli } et\ al., \text{ 2009)} \qquad 3.4$$

Where

ρ_t is the true density in kgm^{-3}

M_s is the seed mass in kg

V_s is the seed volume in m^3

The experiment was repeated for the bush mango kernel at three moisture contents.

The bulk density was determined using the standard test weight procedure. A standard container (beaker) of known weight and volume of 150 ml was filled with seeds from a height of 150 mm at a constant rate. The grains were then leveled by striking off the top of the container (Koocheki *et al*., 2007). No additional manual compaction was done. The total weight of seeds and cylinder was recorded. Bulk density was determined as the ratio of the mass of seeds only to the volume occupied by the seeds (volume of container). The bulk density was calculated using equation 3.4 for the seed and kernel.

The porosity of the grains was calculated from the values of the bulk and particle densities using the mathematical expression

$$\Psi = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \qquad 3.5$$

Where ρ_t is the true density and $\rho_b$is the bulk density

3.9 Angle of repose

The measurement of the angle of repose was done by using an open ended cylinder of 15 cm diameter and 50 cm height (Ozturk *et al*., 2009).The cylinder was placed at the centre of a circular plate having a diameter of 35 cm and was filled with the bush mango seed. The angle of repose was measured on three structural material, galvanized steel, wood and mild steel. The cylinder was raised slowly until it formed a cone of the seeds on the circular plate. The height of the cone was recorded by using a moveable pointer fixed on a stand having a scale of 0-1 cm precision. The angle of repose θ was calculated using eqn. 3.7

$$\theta = tan^{-1}\frac{2h}{d} \quad \text{(Tavakoli } et\ al.\text{, 2009)} \qquad 3.6$$

where:

h = height of the cone in m
d = diameter of the cone in m

This was done in five replicates and average angle of repose calculated. The procedure was repeated for the calculation of angle of repose for the accessions of the kernel at three different moisture contents. Similar methods have been used by Bart-Plange and Baryeh (2002) for category B cocoa beans and Bart-Plange *et al*. (2005) for obatanpa maize variety.

3.10 Static coefficient of friction

The coefficient of friction for the seed was determined with respect to five structural materials: glass, galvanized steel, plywood, stainless steel and mild steel using the Inclined Plane Apparatus as described by Faleye et al. (2013). The table was gently raised and the angle of inclination to the horizontal at which the sample started to sliding was read off the protractor attached to the apparatus as shown in Plate 3.4. The tangent of this angle was reported as coefficient of friction (Zewdu and Solomon, 2007).

$$\mu_m = \tan \beta \qquad 3.7$$

Where

μ_m is coefficient of friction on material surface
β is angle of inclination.

The experiment was repeated five times for each mentioned surface, and the average values reported.

Plate 3.4: Set up for determination of static coefficient of friction

3.11 Determination of mechanical properties

Quasi – static compression tests were performed with an instron universal testing machine equipped with a 50 kN compression load cell and an integrator. A deformation rate of 20 mm/min was used as recommended by ASAE S368 (2002). Deformation was automatically obtained from the recorder chart. Individual bush mango seed was loaded between two parallel plates. The effect of loading position was determined by loading the seeds in three directions. Fifty seeds and kernel of each species at the different moisture levels were determined. Mean values were recorded as data obtained.

3.12 Thermal properties

3.12.1 Thermal conductivity

In order to determine the thermal conductivity of bush mango kernel, Lee's disc apparatus in the steady state heat flow was used. The apparatus consist of three cylindrical blocks of copper 30 mm in diameter x 13 mm thick, drilled radially to take thermometers. Between the first and second block was inserted a small electric heater which is suitable for operation from 4 to 6 V. The bush mango kernel was prepared to form a thin disc of the same diameter with copper block and 2 mm thick. The sample was inserted between the second and third blocks, and the whole was clamped together as shown in Plate 3.5. The heater was connected to a 6 V power supply, the current I, and the potential difference across the coil V is measured. The heat generated by the heating element was conducted through the discs to the sample. The discs ensure uniform distribution of heat. After sometime when the steady state is reached the temperatures of the three discs and the room temperature close to the equipment were measured. The temperatures recorded and emissivity area of the discs and the sample were used in the following equations to determine the thermal conductivity of the sample.

Let A_1, A_2, A_3, A_X, be emissive areas of the discs and sample respectively.
t_1, t_2, t_3, be the thermometric readings
t be the laboratory temperature
V be the voltage across the heater
I be the current in amperes

Plate 3.5: Thermal conductivity set up

c be the thickness of sample under test
e be the emissivity
k be thermal conductivity constant

Then

$$VI = e\{A_1(t_1 - t) + A_2(t_2 - t) + A_3(t_3 - t) + A_x[(t_2 + t_3)/2 - t]\} \qquad 3.8$$

and hence e

If A_x is the cross sectional area of sample,

$$K\,A_x/2[(t_2 + t_3)/2 - t] = e\{A_x/2\,[(t_2 + t_3)/2 - t] + A_3/2\,(t_3 - t)\} \qquad 3.9$$

The thermal conductivity of the bush mango kernel was calculated from the two equations. The experiment was replicated three times and average value reported.

3.12.2 Specific heat

The specific heat of bush mango kernel was determined using the method of mixtures using toluene as the liquid (Tansakul and Lumyong, 2008). In this method the following assumptions were made: Heat loss during transfer of sample from the hot air oven to the calorimeter and evaporation loss in the calorimeter during equilibration period were negligible.

The heat capacity of the calorimeter and toluene were determined experimentally .A known quantity of distilled water at a known temperature was added to the calorimeter containing a known quantity of distilled water at a lower temperature. The heat capacity of the calorimeter was determined using the equation (3.10):

$$C_c = \frac{M_{hw}C_w(t_{hw}-t_e)-M_{cw}C_w(t_e-t_{cw})}{M_{ht}(t_{ht}-t_e)-M_{ct}(t_e-t_1)} \quad \text{(Tansakul and Lumyong, 2008)} \qquad 3.10$$

Where :

C_c = specific heat of calorimeter kJ kg^{-1} K^{-1}
M_c = mass of calorimeter in kg
M_{hw} = mass of hot water in kg
M_{cw} = mass of cold water in kg
t_{hw} = temp. of hot water in K
t_{cw} = temp. of cold water in K
t_e = equilibrium temp of mixture K
C_w = specific heat capacity of water kJ kg^{-1} K^{-1}

The heat capacity of toluene was also determined. A known weight of toluene at high temperature was poured into the calorimeter that contains a known weight of toluene at a lower temperature (room temperature). The system was assumed to be adiabatic. Therefore the heat capacity of toluene was calculated thus:

$$C_t = \frac{M_c C_c (t_e - t_t)}{M_{ht}(t_{ht} - t_e) - M_{ct}(t_e - t_1)} \quad \text{(Tansakul and Lumyong, 2008)} \quad 3.11$$

Where :

C_c = specific heat of calorimeter kJ kg^{-1} K^{-1}

M_c = mass of calorimeter in kg

M_{ht} = mass of hot toluene in kg

M_{ct} = mass of cold toluene in kg

t_{ht} = temp. of hot toluene in K

t_t = temp. of cold toluene in K

t_e = equilibrium temp of mixture K

C_t = specific heat capacity of toluene kJ kg^{-1} K^{-1}

To determine the specific heat of the bush mango kernel, a known weight of the sample, temperature and moisture content was dropped into the calorimeter containing a known quantity of toluene which is at higher temperature. The mixture was stirred continuously using a copper stirrer. The temperature of the mixture was recorded at interval of 1s. At equilibrium, the final temperature was recorded and the specific heat of the sample was calculated using the equation (3.12):

$$C_s = \frac{(M_c C_c + M_t C_t)(t_t - t_e)}{M_s(t_e - t_s)} \quad \text{(Tansakul and Lumyong, 2008)} \quad 3.12$$

Where

C_s = specific heat of bush mango kernel in kJ kg^{-1} K^{-1}

M_s = mass of bush mango kernel in kg

t_s = temp. of bush mango kernel in K

t_e = equilibrium temperature of mixture in K

M_t = mass of toluene in kg

M_c = mass of calorimeter in kg

t_t = temp. of toluene in K

C_c = specific heat of calorimeter in kg

The experiment was replicated three times for kernel at the three moidture levels.

3.12.3 Thermal diffusivity

Relationship between specific heat capacity, thermal conductivity and density was used to calculate the thermal diffussivity (Eqn. 3.13).

$$\alpha = \frac{k}{\rho_b C_p} \qquad \text{(Tansakul and Lumyong, 2008)} \qquad 3.13$$

Where :

α = thermal diffusivity in $m^2 s^{-1}$

ρ_b = bulk density in kgm^{-3}

C_p = specific heat capacity of sample in $Jkg^{-1}K^{-1}$

k = thermal conductivity in $Wm^{-1}k^{-1}$

3.13 Experimental Design and Data Analysis

All tests were conducted at five levels of moisture content with three replications at each level. The experimental design used was the completely randomised design (CRD). The relationship between physical properties of bush mango seed and kernel and levels of moisture content were determined. Analysis of variance (ANOVA) was carried out on the data using Microsoft Excel version 2010 at a significance level of 5%. The Least Significant Difference (LSD) was determined where a significance difference existed between treatments means. The Regression Coefficient (R^2), the mean square error (MSE) and the variation of predicted values (SS) were used to evaluate the fitness of models to the experimental data.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Linear Dimensions

The linear dimensions, including length (a), width (b) and thickness (c) of the different species of bush mango seed with respect to moisture content are as presented in Table 4.1 while detail data are given in the Appendix A. As moisture content increased from 10 to 50% (d.b.), seed length and width decreased for the two species while the thickness increased. The length, for *Irvingia gabonensis* seed decreased from 38.51 to 34.70 mm, the width from 31.28 to 30.26 mm. and thickness increased from 19.69 to 20.17 mm. The length for *Irvingia wombolu* seed, decreased from 53.53 to 40.71mm, the width decreased from 38.40 to 31.34 mm, and the thickness increased from 22.00 to 24.97 mm. This implies that the seed swells up in the lateral direction. Similar trend was reported by Sacilik et al. (2003) for hemp seeds.

The analysis of variance (Table 4.2) shows that the seed length, width and thickness are significantly ($p<0.05$) affected by the species of the bush mango and moisture content. The interaction between the species and moisture content of the seed also significantly ($p<0.05$) affect the linear dimensions. The length, width and thickness of *Irvingia wombolu* seed are significantly different at the five levels of moisture. However the width and thickness are not significantly different while the length is significant for *Irvingia gabonensis* seed at the five levels of moisture. The independent samples t-test shows that the linear dimensions of *Irvingia wombolu* seed is significantly higher than that of *Irvingia gabonensis* seed at the five levels of moisture content as observed in Appendix A.

The linear dimensions of bush mango kernel with respect to moisture content are shown in Table 4.1 while the detail data are shown in Appendix B. As the moisture content increased from 2.18 to 5.32% (d.b.), kernel length, width and thickness increased for the two species. The length, for *Irvingia gabonensis* kernel increased from 25.91 to 27.17 mm, the width increased from 15.67 to 16.86mm and the thickness increased from 3.47 to 3.84 mm. The length for *Irvingia wombolu* kernel increased from 28.51 to 30.43, the width increased from 17.36 to 19.16 mm and the thickness increased from 3.85 to 4.28 mm.

Table 4.1: Average linear dimensions of bush mango seed and kernel

(a) Seed

Specie	Moisture Content	Length (a) mm	Width (b) mm	Thickness (c) mm
Irvingia gabonensis	10%	38.51(2.90)*	31.28(2.06)	19.69(1.42)
	20%	37.56(2.58)	30.93(2.13)	19.71(1.53)
	30%	37.04(2.39)	30.85(1.85)	19.79(1.82)
	40%	36.03(2.46)	30.65(2.00)	19.81(1.50)
	50%	34.70(1.92)	30.26(2.68)	20.17(2.37)
Irvingia wombolu	10%	53.53(5.64)	38.40(4.93)	22.00(2.88)
	20%	51.71(6.33)	36.56(5.59)	23.62(2.51)
	30%	51.38(5.68)	36.11(3.66)	24.36(3.49)
	40%	50.17(5.27)	35.91(5.02)	24.42(3.27)
	50%	40.71(4.47)	31.34(3.83)	24.97(3.43)

* Values in brackets are standard deviation

(b) Kernel

Specie	Moisture Content	Length (a) mm	Width (b) mm	Thickness (c) mm
Irvingia gabonesis	2.18%	25.91(1.48)*	15.67(1.39)	3.47(0.44)
	3.65%	26.38(2.15)	16.20(1.21)	3.67(0.47)
	5.32%	27.17(2.02)	16.86(1.29)	3.84(0.44)
Irvingia wombolu	2.18%	28.51(3.91)	17.36(2.14)	3.85(0.53)
	3.65%	29.19(2.93)	17.70(1.87)	4.22(0.65)
	5.32%	30.43(2.43)	19.16(1.73)	4.28(0.57)

* Values in brackets are standard deviation

Table 4.2: Analysis of variance table for axial dimensions of bush mango seed

(a) Length (mm)

Source of Variation	SS	Df	MS	F	P-value	F crit
Treatment		9				
Species	40263.34	1	40263.34	2228.632**	1.1E-255	3.850869
Moisture content	8196.933	4	2049.233	113.4279**	1.23E-79	2.380921
Interaction (Sp x m.c)	2821.496	4	705.374	39.04344**	2.22E-30	2.380921
Error	17885.72	990	18.06639			
Total	69167.49	999				

(b) Width (mm)

Source of Variation	SS	df	MS	F	P-value	F crit
Treatment		9				
Species	5477.098	1	5477.098	406.3515**	5.47E-76	3.850869
Moisture content	1755.846	4	438.9615	32.56701**	1.56E-25	2.380921
Interaction (Sp x m.c)	995.0727	4	248.7682	18.45637**	1.22E-14	2.380921
Error	13343.93	990	13.47872			
Total	21571.95	999				

(c) Thickness (mm)

Source of Variation	SS	df	MS	F	P-value	F crit
Treatment		9				
Species	4078.582	1	4078.582	629.7552**	5.9E-108	3.850869
Moisture content	337.4973	4	84.37434	13.02785**	2.41E-10	2.380921
Interaction (Sp x m.c)	208.028	4	52.00699	8.030162**	2.26E-06	2.380921
Error	6411.692	990	6.476457			
Total	11035.8	999				

** Highly significant

This was also reported for some seeds such as Koocheki et al. (2007) for water melon seeds and Zewdu and Solomon (2007) for tef seeds. The linear dimensions of bush mango seeds were observed to be greater than that of melon seeds (Koocheki *et al.*, 2007), cashew nuts (Bart-Plange, 2012) and lower than that of guna seeds (Aviara *et al.*, 2005). The kernel dimensions were however lower than that of cashew kernel (Bart-Plange, 2012).

The ANOVA Table 4.3 showed that the effect of species and moisture content were highly significant ($p<0.05$) on the linear dimensions of bush mango kernel. The interaction between moisture content and species of the bush mango kernel significantly affect the width of the kernel while it was not significant on the length and thickness. The length, width and thickness of kernel were significantly different at the three levels of moisture content for the two species. The two tailed samples t-test of the difference between the two species of bush mango kernel showed that the linear dimensions of *Irvingia wombolu* were significantly higher than that of *Irvingia gabonensis* as presented in Appendix B. The regression equations of the linear dimensions of bush mango seed in the moisture range of 10 -50% (d.b) and kernel in the moisture range of 2.18 – 5.32% are presented in Table 4.4.

The linear dimensions are important in the selection of sieve or screen size in the design of separating, dehulling and decorticating equipment and in the sizing of the hopper. Principal axial dimensions of seeds are useful in selecting sieve separators and in calculating power during the seed milling process. They can also be used to calculate surface area and volume of kernels which are important during modeling of seed, drying, aeration, heating and cooling (Ghasemi *et al.*, 2008). The result of the analysis shows that different screen size will have to be used for the two species of bush mango seed and kernel. Also the same screen size cannot be used for the same species at different moisture content for both the seed and kernel.

The frequency distribution curves for the bush mango seed are shown in Figures 4.1 and 4.2 while that of the kernel are shown in Figure 4.3 and 4.4. The curves generally approximate to normal distribution for the two species and for all the moisture content levels and the individual linear dimensions. The peaks of the curves are generally around their means. Thus, normal distribution tables can reasonably use to predict the distribution at various confidence levels

Table 4.3: Analysis of variance for axial dimensions of bush mango kernel

(a) Length (mm)

Source of Variation	SS	Df	MS	F	P-value	F crit
Treatment		5				
Species	1252.447	1	1252.447	184.7255**	7.91E-37	3.857161
Moisture content	260.0069	2	130.0034	19.17442**	8.52E-09	3.010892
Interaction (sp x m.c)	11.72233	2	5.861163	0.864472^{NS}	0.421803	3.010892
Error	4027.348	594	6.780047			
Total	5551.524	599				

(b) Width (mm)

Source of Variation	SS	df	MS	F	P-value	F crit
Treatment		5				
Species	503.3816	1	503.3816	187.2669**	2.99E-37	3.857161
Moisture content	237.4884	2	118.7442	44.17495**	1.3E-18	3.010892
Interaction (sp x m.c)	17.40431	2	8.702157	3.237357*	0.039961	3.010892
Error	1596.698	594	2.688044			
Total	2354.972	599				

(c) Thickness (mm)

Source of Variation	SS	df	MS	F	P-value	F crit
Treatment		5				
Species	31.16496	1	31.16496	114.2924**	1.62E-24	3.857161
Moisture content	16.97954	2	8.489768	31.13483**	1.38E-13	3.010892
Interaction (sp x m.c)	0.818564	2	0.409282	1.500974^{NS}	0.223757	3.010892
Error	161.9705	594	0.272678			
Total	210.9335	599				

** Highly significant

* Significant

^{NS} Not Significant

Table 4.4: Regression equations for linear dimensions of bush mango seed and kernel

(a) Seed

Property	Species Irvingia gabonensis Equations	R^2	Irvingia wombolu Equations	R^2
Length (mm)	39.513 – 0.915M	0.9784	57.612 – 2.718M	0.7270
Width (mm)	31.490 – 0.232M	0.9548	40.085 – 1.537M	0.8769
Thickness (mm)	19.515 + 0.107M	0.7576	21.882 + 0.674M	0.8552

(b) Kernel

Property	Species Irvingia gabonensis Equations	R^2	Irvingia wombolu Equations	R^2
Length (mm)	25.229 – 0.6289M	0.9798	27.449 + 0.9637M	0.9726
Width (mm)	15.043 + 0.5999M	0.9967	16.277 + 0.8985M	0.8838
Thickness (mm)	3.293 + 0.1838M	0.9996	3.680 + 0.2181M	0.8613

M = moisture content, % d.b

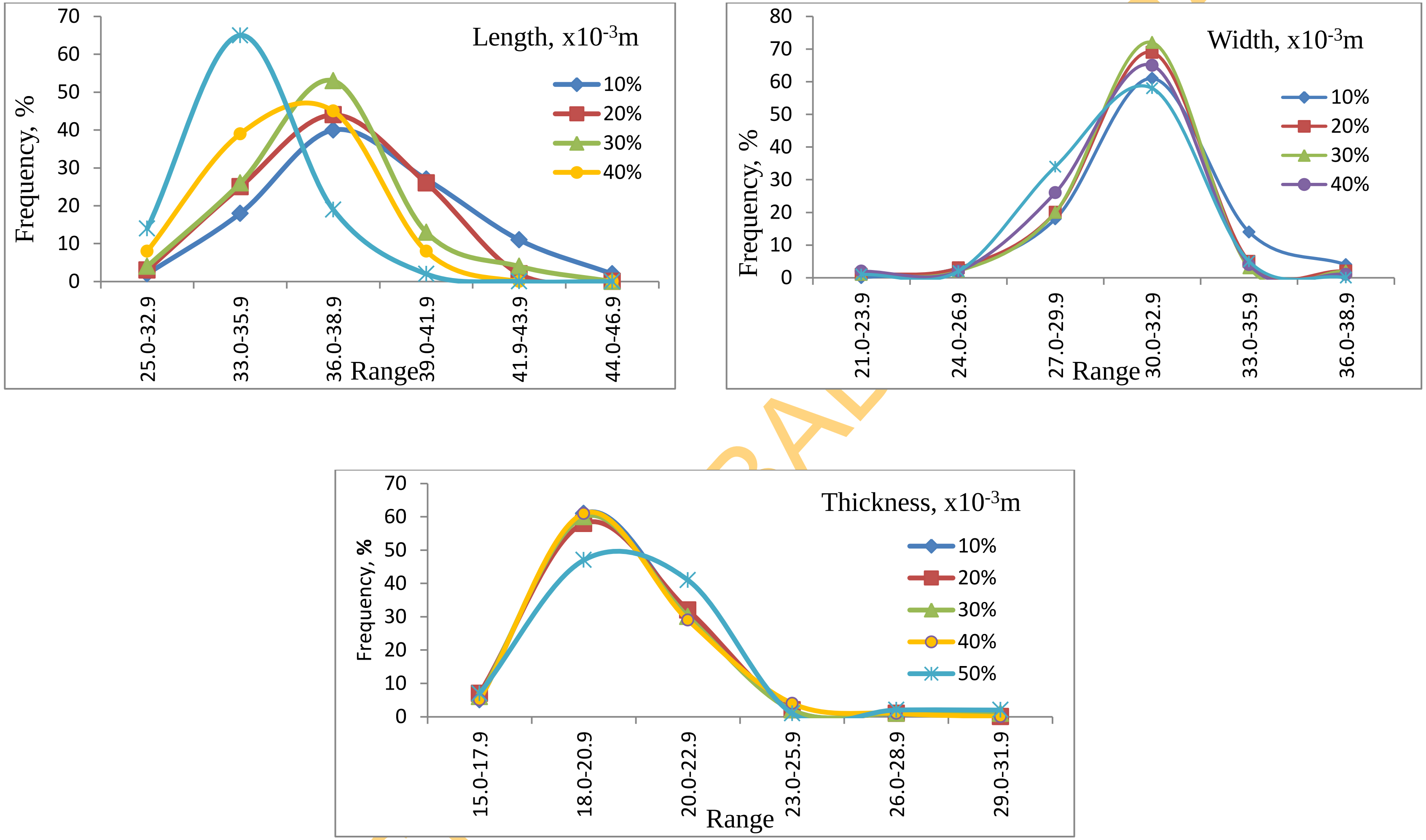


Fig. 4.1: Normal Distribution for *Irvingia gabonensis* seed dimensions at different moisture contents

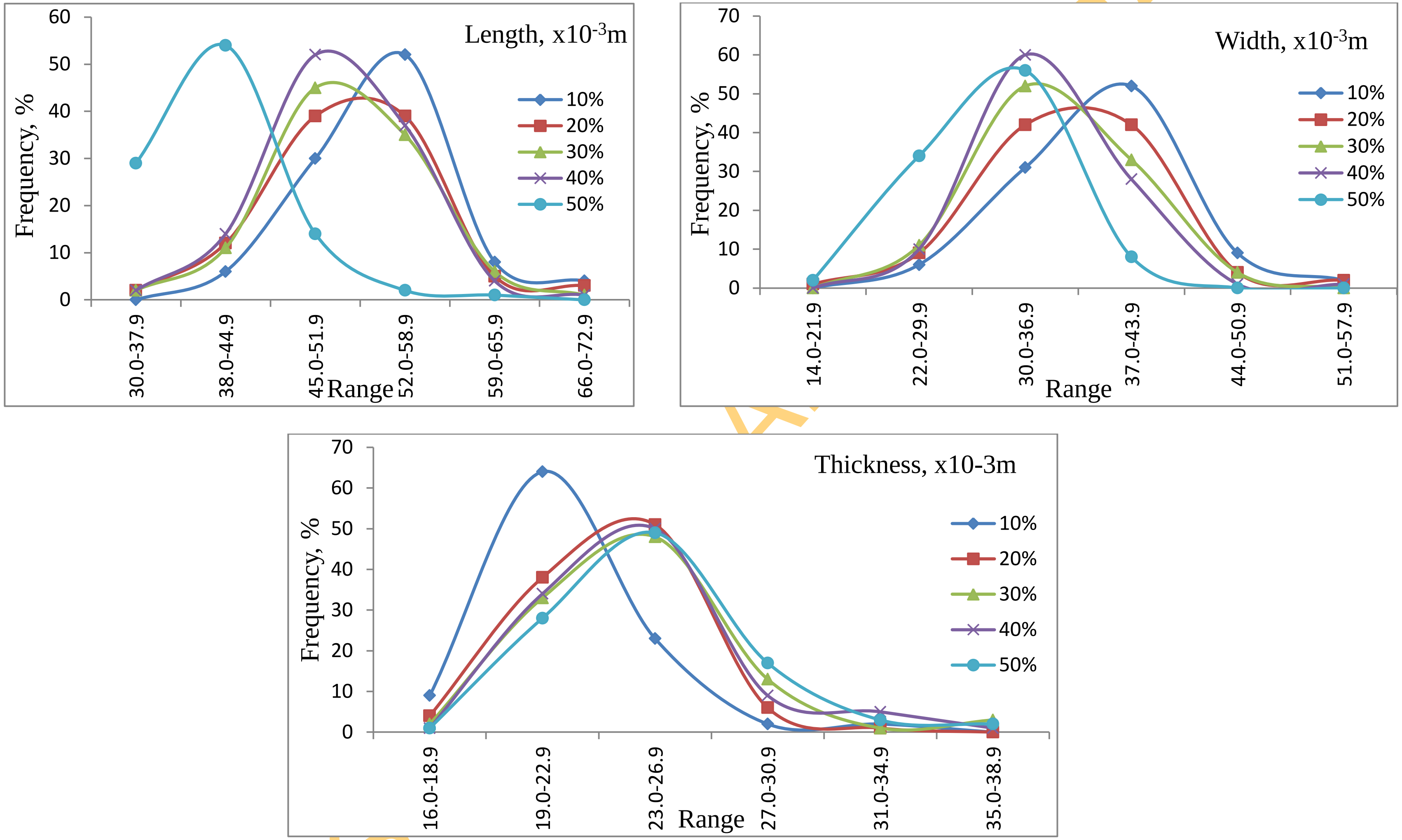


Fig. 4.2: Normal Distribution for *Irvingia wombolu* seed dimensions at different moisture contents

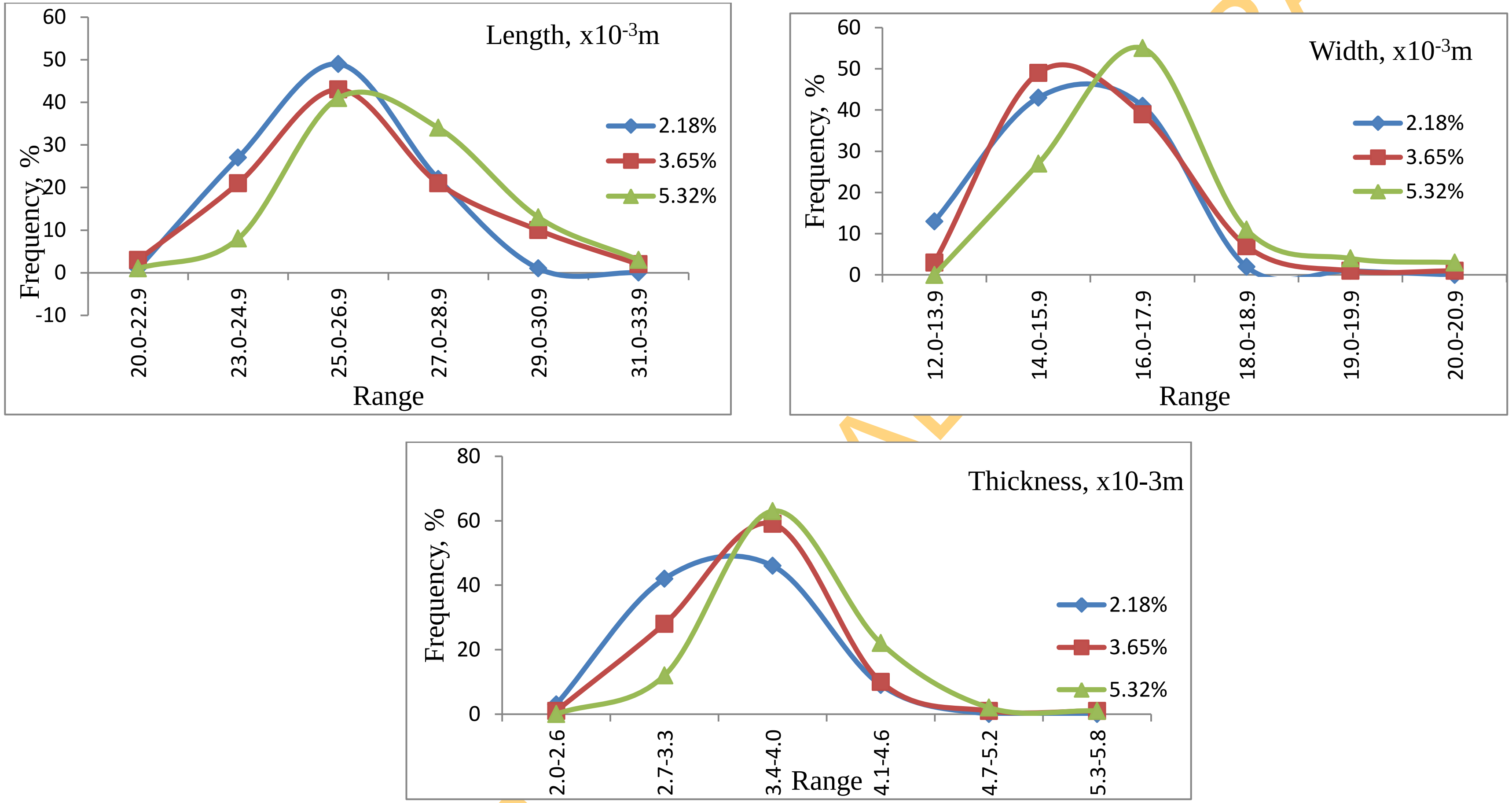


Fig. 4.3: Normal Distribution for Irvingia gabonensis kernel dimensions at different moisture contents

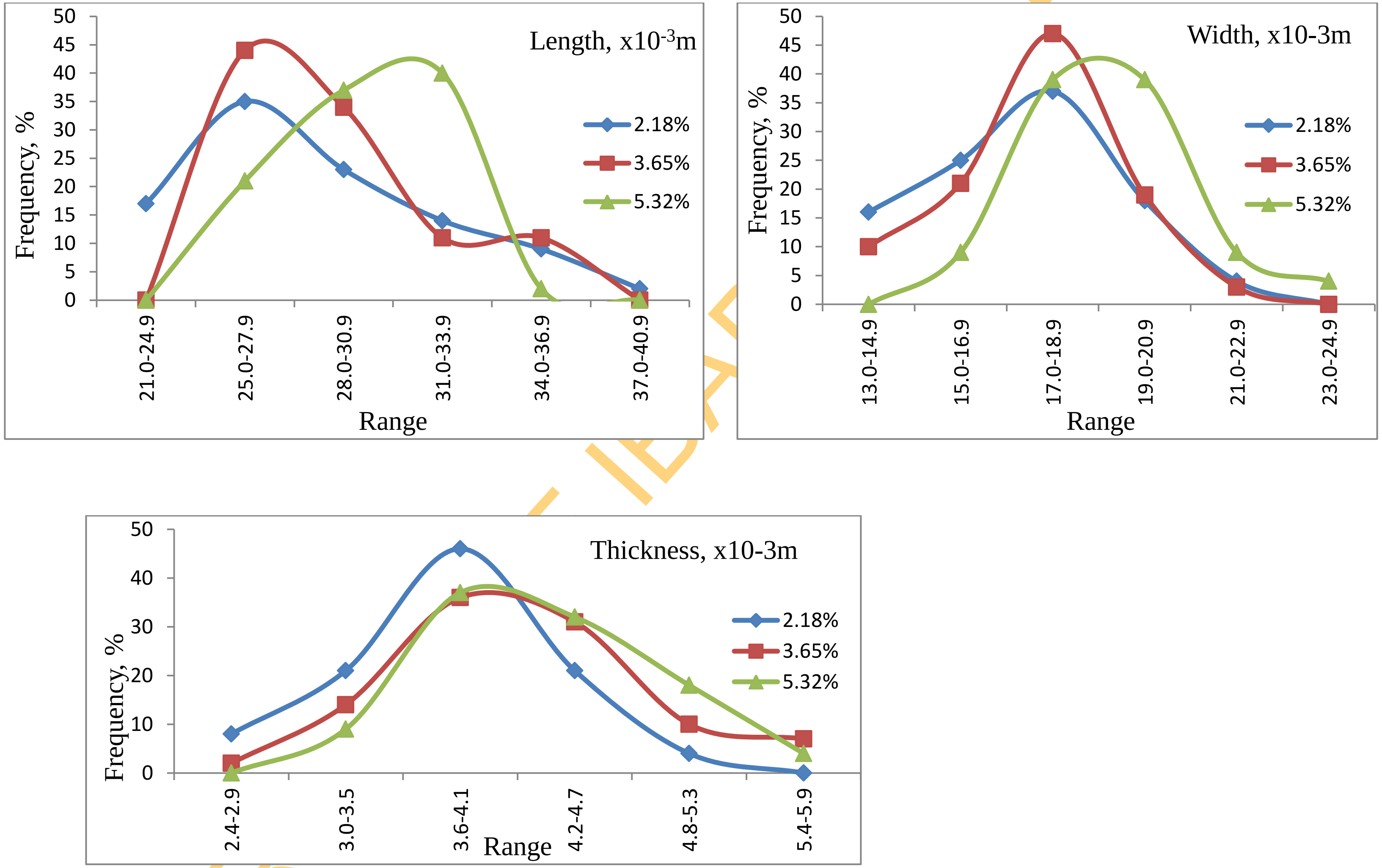


Fig. 4.4: Normal Distribution for *Irvingia wombolu* kernel dimensions at different moisture

4.2 Geometric Diameter and Sphericity

4.2.1 Geometric mean diameter

The geometric mean diameter and sphericity were calculated from the values of the length, width and thickness. The geometric mean diameter of the seed decreased as the moisture content increased for the two species of the bush mango (Fig 4.5). For *Irvingia gabonensis* seed, the geometric mean diameter decreased from 28.69 to 27.59 mm. However for *Irvingia wombolu* seed the geometric mean diameter decreased from 35.48 to 31.57 mm. The decrease in geometric mean diameter of the seed is due to the fact that two of the axial dimensions decreased with increase in moisture content.

The geometric mean diameter of bush mango kernel increased with increase in moisture content as shown in Fig 4.6. The geometric mean diameter of bush mango kernel increased from 11.18 to 12.05 mm for *Irvingia gabonensis* and from 12.33 to 13.52 mm for *Irvingia wombolu*. This is in agreement with findings of Ilori *et al*. (2011) for mexican sunflower seeds, Tavakoli *et al*. (2009) for barley grains and Yurtlu et al. (2010) for bay laurel seed.

The geometric mean diameter of the seed was significantly ($p<0.05$) affected by the moisture content, species and the interaction between the moisture content and species of the bush mango seed as shown in Table 4.5. The geometric mean diameter of the *Irvingia gabonesis* seed was not significantly different at the five moisture levels while that of *Irvingia wombolu* was significantly different. The geometric mean diameter of *Irvingia wombolu* seed was higher than that of *Irvingia gabonesis* seed at the five moisture levels and it decreased as the moisture content increased as shown in Figure 4.5. Also from Appendix A the geometric mean diameter of *Irvingia wombolu* seed was significantly ($p<0.05$) higher than that of *Irvingia gabonesis* seed.

Analysis of variance (Table 4.5) showed that the effect of species and moisture content on the geometric mean diameter of the kernel was highly significant ($p<0.05$) at the three levels. The interaction between the moisture content and species of bush mango did not significantly affect the geometric mean diameter of kernel. The geometric mean diameter of the kernel was significantly different for the two species of bush mango.

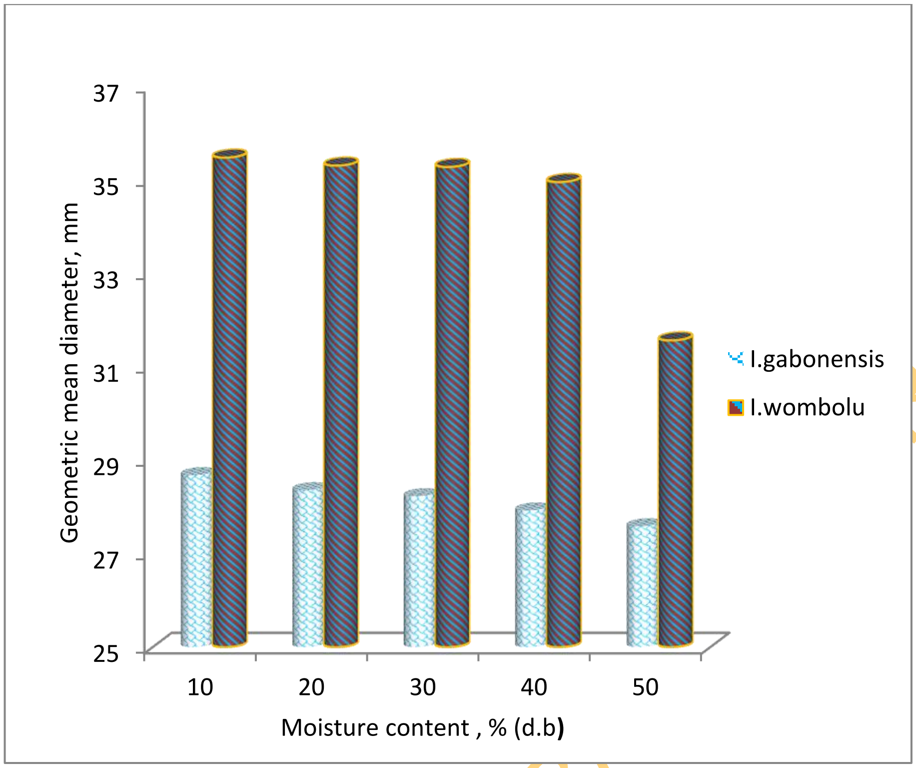


Fig 4.5: Variation in the geometric mean diameter of two species of bush mango seed.

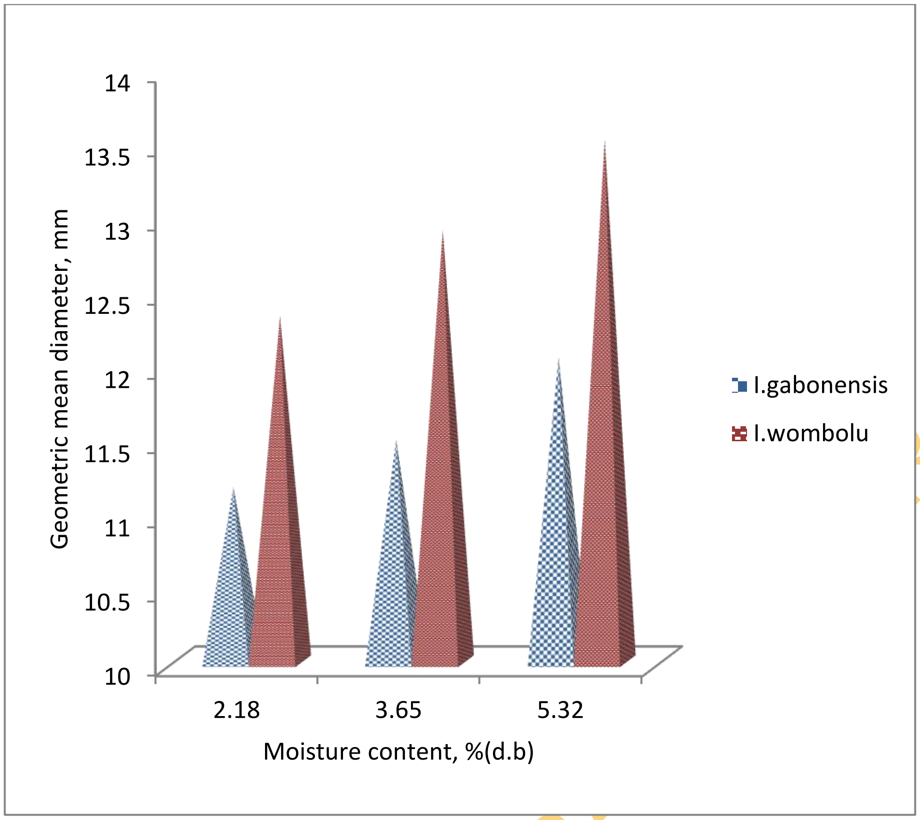


Fig 4.6: Variation in the geometric mean diameter of bush mango kernel**.**

Table 4.5: Analysis of variance for geometric mean diameter of bush mango seed and kernel

(a) Seed

Source of Variation	SS	df	MS	F	P-value	Fcrit
Treatment		9				
Species	10084.89	1	10084.89	2167.585**	1.4E-251	3.850869
Moisture content	814.5177	4	203.6294	43.76686**	7.46E-34	2.380921
Interaction (sp x m.c)	355.3388	4	88.83471	19.09359**	3.85E-15	2.380921
Error	4606.068	990	4.652594			
Total	15860.82	999				

(a) Kernel

Source of Variation	SS	df	MS	F	P-value	F crit
Treatment		5				
Species	259.3145	1	259.3145	369.2941**	2.29E-64	3.857161
Moisture content	106.4276	2	53.21381	75.78269**	4.86E-30	3.010892
Interaction (sp x m.c)	2.68161	2	1.340805	1.909463^{NS}	0.149068	3.010892
Error	417.1006	594	0.702189			
Total	785.5243	599				

** Significant

^{NS} Non Significant

The geometric mean diameter of *Irvingia wombolu* kernel was higher than that of *Irvingia gabonensis* kernel at the three levels of moisture content as evident from Fig 4.6. The geometric mean diameter of *Irvingia wombolu* kernel was significantly ($p<0.05$) higher than that *Irvingia gabonensis* at 2.18%, 3.65% and 5.32% as shown in Appendix B. This implies that the species of bush mango has to be considered when choosing screen size for processing equipment for the bush mango seed and kernel.

The geometric mean diameter is useful in estimation of projected area of particle moving in turbulent or near turbulent region of airstreams, especially with respect to ease of separating extraneous materials from the seeds and kernel during cleaning by pneumatic means. The regression equations for the geometric mean diameter of the bush mango seed and kernel are presented in Table 4.6.

4.2.2 Sphericity

The sphericity of bush mango seed increased with increase in moisture content of the bush mango seed for the two species (Fig 4.7). The sphericity values for *Irvingia gabonensis increased* from 74.74 to 79.65% and that of *Irvingia wombolu* increased from 66.72 to 77.97%. The fairly high sphericity values of the seed showed features favourable to rolling of the seed and therefore have practical application in handling operations such as conveying and grading.

Sphericity of the bush mango kernel also increased with increase in moisture content for the two species (Figure 4.7). The sphericity values for *Irvingia gabonensis* increased from 43.25 to 44.46% and *Irvingia wombolu* increased from 43.70 to 44.63%. An increase in sphericity may indicate that the rate of increase of width and thickness is higher compared to the length, giving the seed the assumed spherical shape. The low sphericity value of the kernel indicates that the kernel is favourable to sliding.

A similar trend of sphericity has been reported by Oyelade *et al*. (2006) for african star apple, Kashaninejad *et al.* (2006) for pistchio kernel, Aviara *et al.* (2014) for Brachystegia Eurycoma seed and Ahmadi *et al*. (2009) for fennel seeds. Other researchers have found that sphericity could be affected by moisture in different ways.

Table 4.6: Regression equations for geometric diameter and sphericity of bush mango seed and kernel

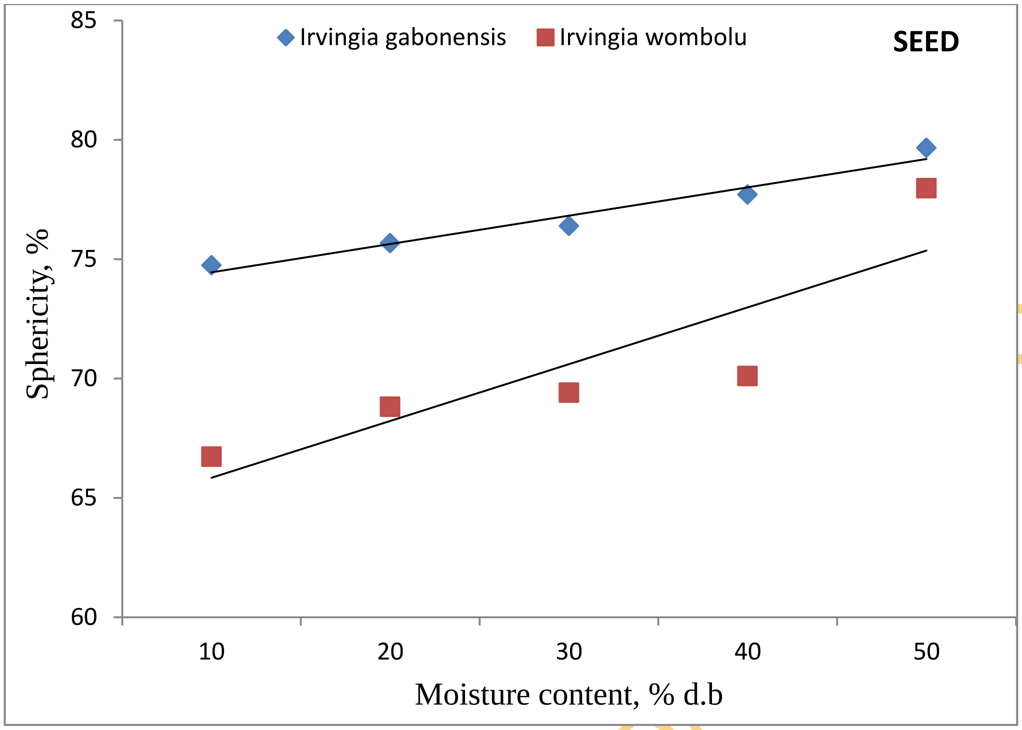
(a) Seed

Property	*Irvingia gabonensis*		*Irvingia wombolu*	
	Equations	R^2	Equations	R^2
Geometric mean diameter (mm)	28.988 - 0.280M	0.9726	36.967 - 0.817M	0.6071
Sphericity (%)	73.268 + 1.186M	0.9602	63.463 + 2.379M	0.7621
1000seed weight	7.505 + 0.763M	0.9116	12.852 + 1.840M	0.9505

(b) Kernel

Property	*Irvingia gabonensis*		*Irvingia wombolu*	
	Equations	R^2	Equations	R^2
Geometric mean diameter (mm)	42.708 + 0.6069M	0.9620	43.327 + 0.4673M	0.8825
Sphericity (%)	10.736 + 0.4339M	0.9984	11.724 + 0.5974M	0.9997
1000kernel weight	0.5139 + 0.4631M	0.8329	1.0911 + 1.1486M	0.7843

M = moisture content, % d.b.



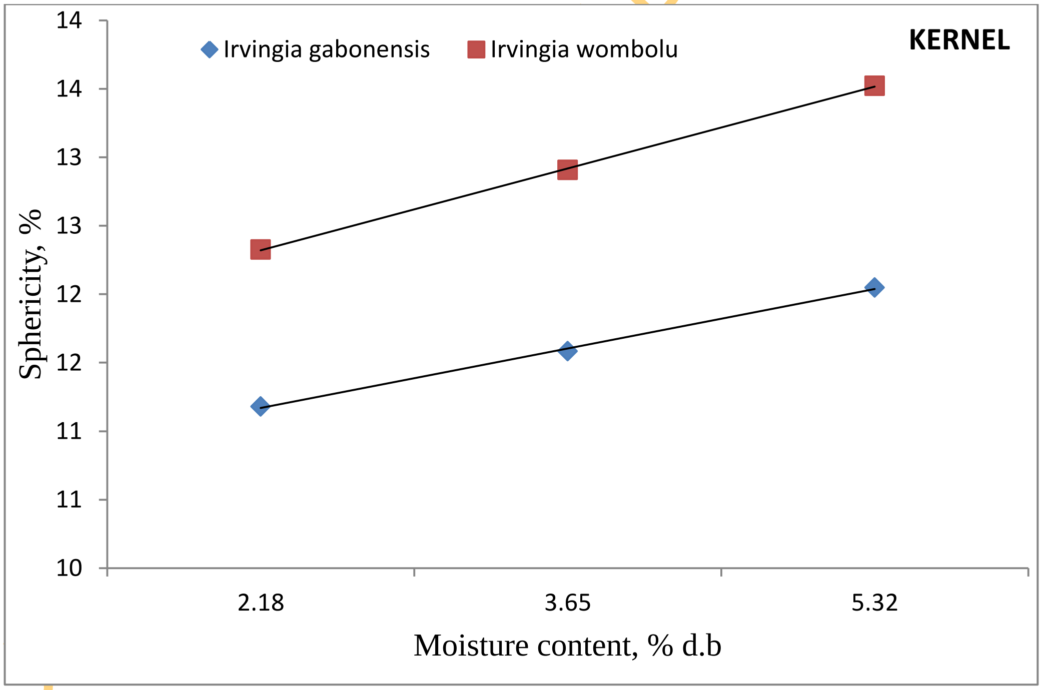


Fig. 4.7: Effect of moisture content on sphericity of bush mango seed and kernel

A decrease in the sphericity with increase in moisture content was observed for soyabeans (Shirkole *et al.*, 2011), grass pea (Zewdu and Solomon 2008) and red bean (Kiani *et al.*, 2008). Decrease in sphericity after certain moisture has been exceeded has been reported for red lentil grains (Isik, 2007) and sunflower seed (Isil and Izil 2007).

The sphericity of bush mango seed was significantly affected (P<0.05) by species, moisture content and the interaction between the moisture content and species of the bush mango as evident from Table 4.7. The sphericity of the bush mango seed was significantly different (P>0.05) for the two species at the five levels of moisture content. The sphericity of *Irvingia gabonensis* seed was significantly (p<0.05) higher than that of *Irvingia wombolu* at all the moisture levels as shown in Appendix A.

Sphericity of the kernel was significantly different (P<0.05) between 2.18 and 5.32% (d.b) for the two species. The moisture content had significant effect on the variation in sphericity of the bush mango kernel while species and interaction between moisture content and species did not significantly affect it (Table 4.7). The sphericity of *Irvingia wombolu* kernel was higher than the sphericity of *Irvingia gabonensis* kernel at the three levels of moisture content as evident from Fig 4.7. Also, the sphericity of *Irvingia wombolu* kernel was significantly (p<0.05) higher than *Irvingia gabonensis* at the three levels of moisture content as presented in Appendix B. Thus in the processing of the bush mango seed and kernel the same screen size cannot be used for the two species at any moisture level.

4.3 1000 Seed Weight

The weight of the bush mango seed increased with increase in moisture content from 10% to 50% (d.b) for the two species as shown in Figure 4.8. *Irvingia gabonensis* from 8.567 to 11.756 kg and *Irvingia wombolu* from 15.294 to 22.279 kg. The weight of the seed was significantly different (p>0.05) between 10% and 50% (d.b) for the two species of the bush mango.

The weight of *Irvingia gabonensis* kernel also increased from 0.86 to 1.78 kg while that of *Irvingia wombolu* increased from 1.28 to 1.58kg (Figure 4.8).

Table 4.7: Analysis of variance for sphericity of bush mango seed and kernel

(a) Seed

Source of Variation	SS	df	MS	F	P-value	F crit
Treatment		9				
Species	9684.602	1	9684.602	383.11**	2.27E-72	3.850869
Moisture content	7543.084	4	1885.771	74.5986**	2.68E-55	2.380921
Interaction (sp x m.c)	1337.278	4	334.3196	13.22524**	1.68E-10	2.380921
Error	25026.12	990	25.27891			
Total	43591.08	999				

(b) Kernel

Source of Variation	SS	df	MS	F	P-value	F crit
Treatment		5				
Species	17.32036	1	17.32036	1.504982^{NS}	0.220392	3.857161
Moisture content	123.865	2	61.93249	5.381371*	0.004829	3.010892
Interaction (sp x m.c)	2.195642	2	1.097821	0.095391^{NS}	0.909032	3.010892
Error	6836.157	594	11.50868			
Total	6979.538	599				

** Highly Significant

* Significant

^{NS} Non Significant

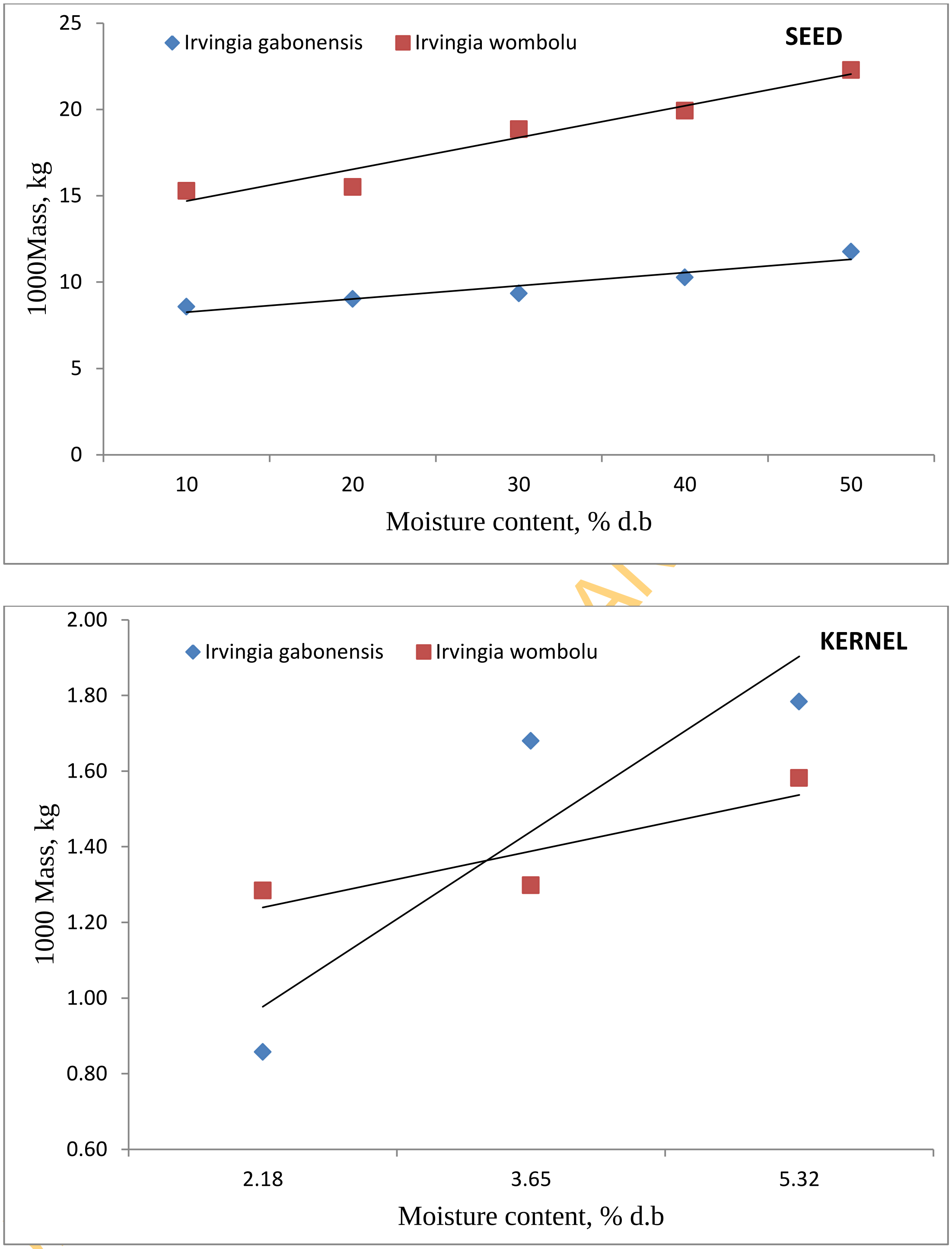


Fig. 4.8: Variation of 1000seed weight and 1000 kernel weight with moisture content

Similar trend have been reported for faba bean by Altuntas and Yildiz (2007) and black cumin by Gharib-Zahedi et al. (2010).

The seed and kernel weight is useful in determine effective diameter which can be used in the estimation of seed and kernel volume.The weights of agricultural products are exploited in design of cleaning equipment using aerodynamic forces; also practical application of mass is in the design of cleaning equipment for separation, conveying and elevating unit operations. The effect of moisture content, species and interaction between the species and moisture content on weight of seed was significant ($p<0.05$) as shown in Table 4.8. The weight of the two species of bush mango seed were significantly different ($p<0.05$) at the five levels of moisture content with *Irvingia wombolu* having the higher values as observed in Appendix A.

The weight of the kernel at the various level of moisture content was significantly different ($p<0.05$) from each other for *Irvingia gabonensis* and *Irvingia wombolu*. There was observed significant effect of moisture content, species and their interaction on the variation in the weight of the bush mango kernel for the two species (Table 4.8). The weight of *Irvingia gabonensis* kernel was significantly higher than *Irvingia wombolu* at 2.18%, 3.65% and 5.32% (Appendix B). The variation in 1000seed and 1000kernel weight can be expressed with the regression equations in Table 4.6 for the two species.

The correlation between the mass, sphericity and geometric mean diameter of the two species of bush mango seed and kernel were as shown in Table 4.9. The table showed that there was 66.7% positive correlation between these properties and moisture content for the seed while all the parameters were positively correlated for the kernel. The parametric model relating these properties are shown in Table 4.10 and Appendices A and B.

Table 4.8: Analysis of variance for 1000 seed weight of bush mango seed and kernel

(a) Seed

Source of Variation	SS	df	MS	F	P-value	F crit
Treatment		9				
Species	18407.02	1	18407.02	1243.025**	4.7E-177	3.850869
Moisture content	3517.256	4	879.314	59.38002**	5.7E-45	2.380921
Interaction (sp x m.c)	679.6602	4	169.9151	11.47435**	4.15E-09	2.380921
Error	14660.16	990	14.80825			
Total	37264.1	999				

(b) Kernel

Source of Variation	SS	Df	MS	F	P-value	F crit
Treatment		5				
Species	0.406537	1	0.406537	6.090031*	0.013875	3.857161
Moisture content	39.09727	2	19.54864	292.8441**	3.16E-89	3.010892
Interaction (sp x m.c)	18.04143	2	9.020716	135.1329**	4.27E-49	3.010892
Error	39.65213	594	0.066754			
Total	97.19737	599				

** Highly significant
* Significant

Table 4.9: Correlation Analysis for Mass, Sphericity and Geometric Mean for seed and kernel

(a) Seed

	Species							
	Irvingia gabonensis				*Irvingia wombolu*			
Variables	MC	MASS	SPH	GMD	MC	MASS	SPH	GMD
MC	1.0000	0.5579	0.4111	-0.2564	1.0000	0.4482	0.4721	-0.3772
		<.0001	<.0001	<.0001		<.0001	<.0001	<.0001
MASS	0.5579	1.0000	0.1543	0.3649	0.4482	1.0000	0.1643	0.1027
	<.0001		<.0001	<.0001	<.0001		0.0002	0.0210
SPH	0.4111	0.1543	1.0000	-0.0403	0.4721	0.1643	1.0000	-0.1756
	<.0001	0.0005		0.3667	<.0001	0.0002		<.0001
GMD	-0.2564	0.3649	-0.0403	1.0000	-0.3772	0.1027		1.0000
	<.0001	<.0001	0.3667		<.0001	0.0210	<.0001	

(a) Kernel

	Species							
	Irvingia gabonensis				*Irvingia wombolu*			
Variables	MC	MASS	SPH	GMD	MC	MASS	SPH	GMD
MC	1.0000	0.8008	0.1774	0.4615	1.0000	0.3772	0.0962	0.4548
		<.0001	0.0019	<.0001		<.0001	0.0947	<.0001
MASS	0.8008	1.0000	0.1863	0.3472	0.3793	1.0000	0.2119	0.5168
	<.0001		0.0011	<.0001	<.0001		0.0002	0.0210
SPH	0.1774	0.1863	1.0000	0.3382	0.0962	0.2119	1.0000	0.2173
	0.0019	0.0011		<.0001	<.0001	0.0002		0.0001
GMD	0.4615	0.3472	0.3382	1.0000	0.4548	0.5168	0.2173	1.0000
	<.0001	<.0001	<.0001		<.0001	0.0210	0.0001	

MC = Moisture Content

SPH = Sphericity

GMD = Geometric Mean Diameter

Table 4.10: Parametric equations for mass, sphericity and geometric mean diameter of bush mango seed and kernel

(a) Seed

Species	Equations	R^2
Irvingia gabonensis	$MC = 0.0419 + 0.0051M + 9.8443*10^{-4}SPH - 0.0049GMD$	0.7308
Irvingia wombolu	$MC = 0.0211 + 0.0011M + 6.7112*10^{-4}SPH - 0.0017GMD$	0.6857

(a) Kernel

Species	Equations	R^2
Irvingia gabonensis	$MC = -0.0277 + 0.0202M + 1.5205*10^{-4}SPH - 0.0037GMD$	0.7773
Irvingia wombolu	$MC = -0.0254 + 0.0079M + 7.7779*10^{-5}SPH - 0.0043GMD$	0.6281

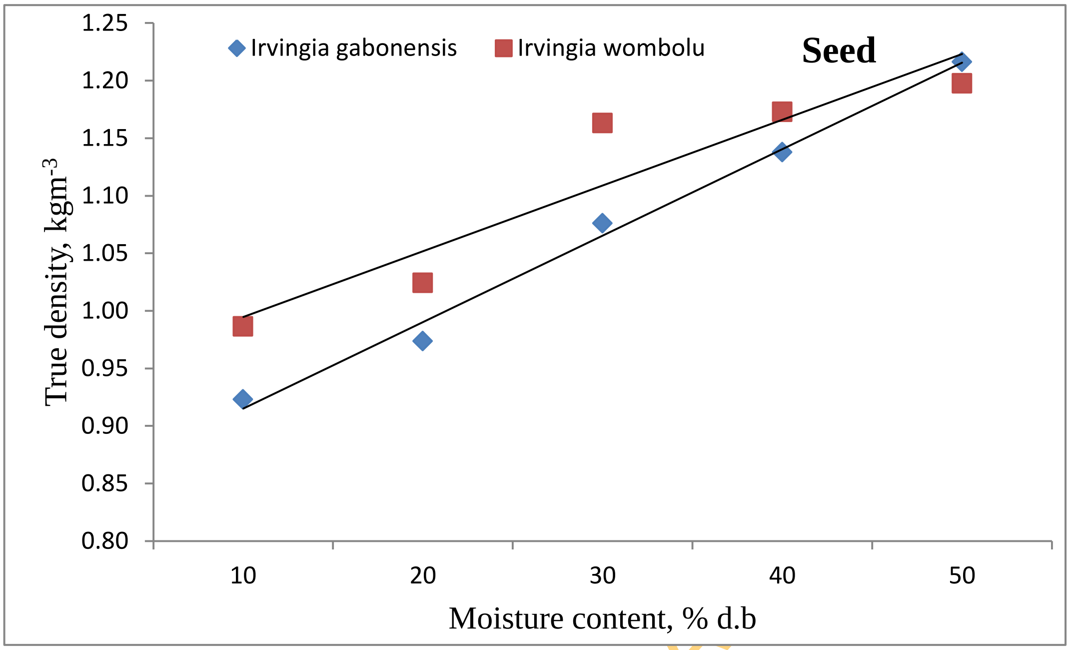
MC = Moisture Content
M = Mass
SPH = Sphericity
GMD = Geometric Mean Diameter

4.4 True Density

True density of the seed increased with increase in moisture content for the two species of the bush mango as presented in Figure 4.9 with the regression equation in Table 4.11. The true density of the seed increased from 923 to 1216 kgm^{-3} for *Irvingia gabonensis* and 986 to 1173k gm^{-3} for *Irvingia wombolu*. The true density for the kernel also increased with increase in moisture for the species as evident from Figure 4.9. It increased from 698 to 815 kgm^{-3} for *Irvingia gabonensis*, 968 to 1079 kgm^{-3} for *Irvingia wombolu*. The regression equations for the kernel's true density are as shown in Table 4.11. This increase in true density indicates that there was a higher grain mass increase in comparison to its volume increase as the moisture content increases.

A similar increasing trend in true density was observed by Wang *et al*. (2007) for flaxseed; Coskun *et al*. (2005) for sweet corn seed; Bart-Plange *et al*. (2012) for cashew nut and kernel; Tunde-Akintunde and Akintunde (2007) for beniseed and Gharibzahedi *et al*. (2010) for black cumin. It is however contrary to the result of Zewdu and Solomon (2007) and Dursun *et al*. (2006) who found the true density to decrease with increase in moisture content for tef seed and sugar beet respectively. The true density of the seed and kernel showed that they will both sink in water and therefore water cannot be used in their separation.

The true density of the seed was not significantly different ($p>0.05$) between 10 and 50% (d.b) moisture for the species of the bush mango. The ANOVA Table 4.12 showed that the moisture content and species had significant effect on the true density of the seed while the interaction of the species and moisture content was not significant. The true density of the kernel was not significantly different ($p>0.05$) for the two species at the three levels of moisture content. The ANOVA Table 4.12 indicates that moisture content did not have significant effect on the true density of the bush mango kernel while species was significant.



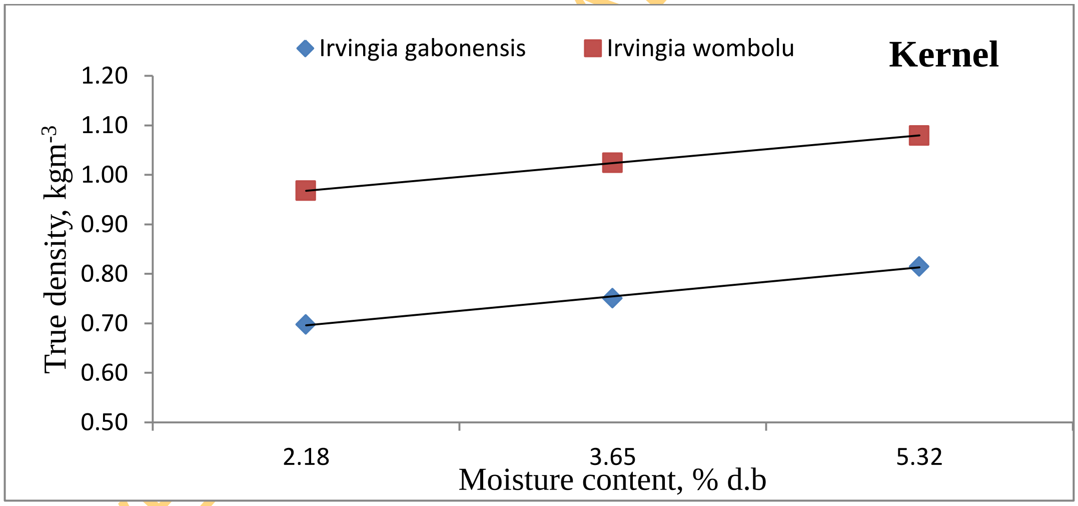


Figure 4.9: Variation in true density of bush mango seed and kernel

Table 4.11: Regression equations for densities and porosity of bush mango seed and kernel

(b) Seed

Properties	Irvingia gabonensis		Irvingia wombolu	
	Equations	R^2	Equations	R^2
True density (kgm^{-3})	0.8401 + 0.0751M	0.9919	0.9375 + 0.0571M	0.8795
Bulk density (kgm^{-3})	0.3918 + 0.0519M	0.9911	0.2716 + 0.0668M	0.9196
Porosity (%)	52.524 - 1.2455M	0.9753	69.242 - 3.8185M	0.8062

(c) Kernel

Properties	Irvingia gabonensis		Irvingia wombolu	
	Equations	R^2	Equations	R^2
True density (kgm^{-3})	0.6375 + 0.0585M	0.9973	0.9124 + 0.0557M	0.9999
Bulk density (kgm^{-3})	0.0426 + 0.3847M	0.9951	0.3872 + 0.0375M	0.9997
Porosity (%)	3.293 + 0.1838M	0.9996	3.680 + 0.2181M	0.8613

Species (spanning header above both tables)

M = moisture content, % d.b

Table 4.12: Analysis of variance for true density of bush mango seed and kernel

(a) Seed

Source of Variation	SS	df	MS	F	P-value	F crit
Species	0.094544	1	0.094544	7.810169**	0.005728	3.890867
Moisture content	1.816101	4	0.454025	37.50661**	4.17E-23	2.419187
Interaction (Sp x m.c)	0.062805	4	0.015701	1.297067^{NS}	0.272691	2.419187
Error	2.29999	190	0.012105			
Total	4.27344	199				

(b) Kernel

Source of Variation	SS	df	MS	F	P-value	F crit
Species	1.087904	1	1.087904	29.54782**	1.34E-06	4.019541
Moisture content	0.130386	2	0.065193	1.770657^{NS}	0.179961	3.168246
Interaction (sp x m.c)	0.0002	2	0.0001	0.002716^{NS}	0.997288	3.168246
Error	1.988194	54	0.036818			
Total	3.206684	59				

**Highly Significant

^{NS} Non Significant

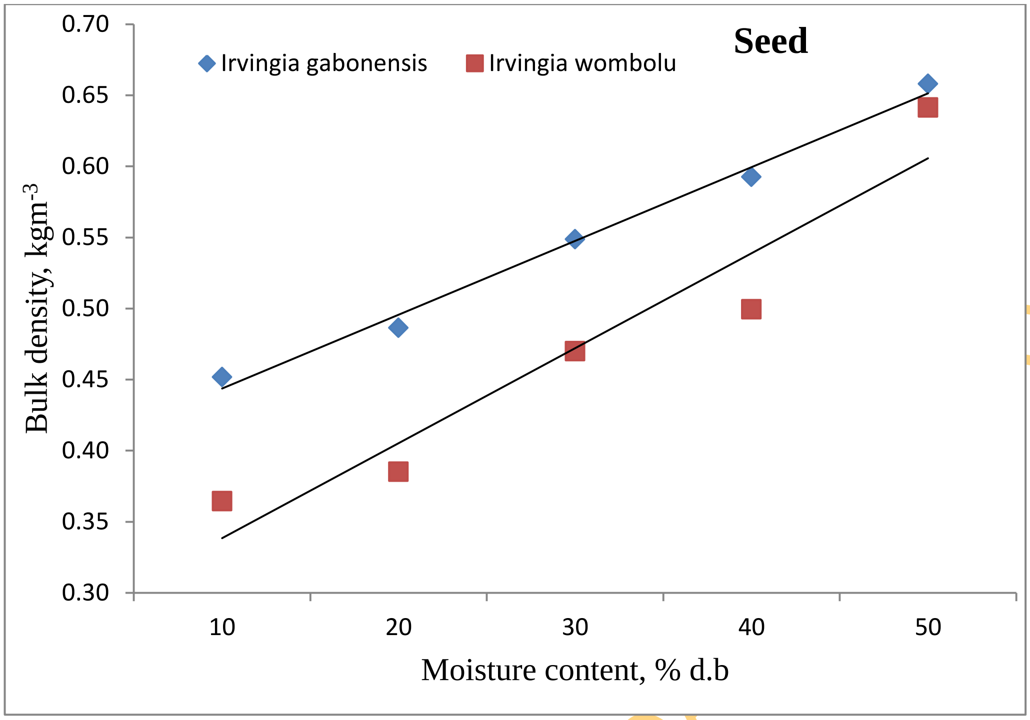
The true density of *Irvingia wombolu* seed and kernel was more than that of *Irvingia gabonensis* (Fig 4.9). The true density of the *Irvingia wombolu* seed was significantly ($p<0.05$) higher than *Irvingia gabonensis* between 10 and 30% d.b (Appendix A) while there was no significant difference between the two species true density between 40 and 50%. The true density of *Irvingia wombolu* kernel was significant ($p<0.05$) higher than that of *Irvingia gabonensis* at moisture of 2.18 and 3.65% but there was no significant difference at 5.32% as shown in Appendix B.

4.5 Bulk Density

The bulk density of the seed and kernel increased with increase in moisture content as presented in Figure 4.10. For the seed, *Irvingia gabonensis* from 452 to 658 kgm^{-3}and *Irvingia wombolu* from 364 to 641 kgm^{-3} in the moisture range of 10 to 50% (d.b). For the kernel, *Irvingia gabonensis* from 429 to 514 kgm^{-3} and *Irvingia wombolu* from 424 to 499 kgm^{-3}. The regression equations for the bulk density of the seed and kernel are presented in Table 4.9. Similar result was reported for guna fruit by Aviara *et al*. (2005). However others have reported a decrease in bulk density with increase in moisture content for neem seed by Ayind (2003); common bean by Ozturk *et al*. (2009); cashew nut and kernel by Bart-Plange *et al*. (2012) and tef seed by Zewdu and Solomon (2007). The variation in response of agricultural crops to change in moisture could be attributed to the fact that some seed gain more weight than the volume on the application of moisture.

The bulk densities of the seed and kernel were lower than their true densities because the air spaces in the grain bulk increase the volume while the weight is the same. The same effect was observed in beniseed, lentil seed and squash seed (Tunde-Akintunde and Akintunde, 2007; Amin *et al*., 2004; Paksoy and Ayind 2004). Bulk density can indicate the degree of kernel filling during growth and therefore an indicator of quality and predicated in breakage susceptibility and hardness studies, milling and baking qualities (Ozturk *et al*., 2009).

The bulk density of the seed was not significantly different ($p<0.05$) at all the moisture levels for the species of bush mango. Moisture content, species and interaction between species and moisture had significant effect on the bulk density of the seed (Table 4.13).



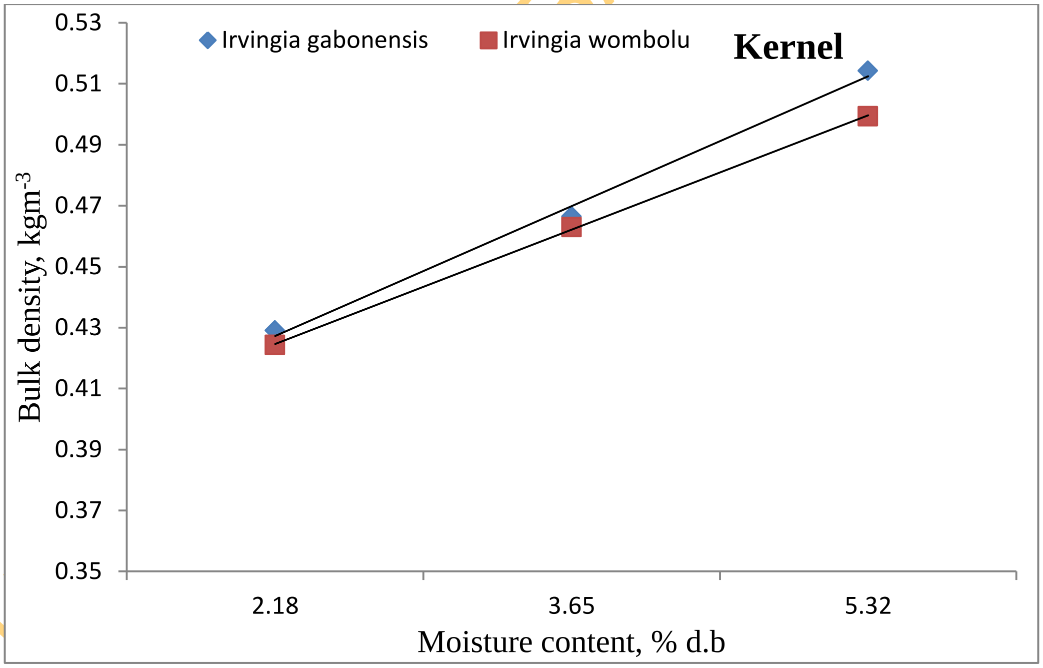


Figure 4.10: Variation in Bulk density of bush mango seed and kernel

Table 4.13: Analysis of variance for bulk density of bush mango seed and kernel

(a) Seed

Source of Variation	SS	df	MS	F	P-value	F crit
Species	0.284655	1	0.284655	1681.796**	2.52E-96	3.890867
Moisture content	1.468582	4	0.367145	2169.162**	2.6E-157	2.419187
Interaction (Sp x mc)	0.045729	4	0.011432	67.54445**	1.81E-35	2.419187
Error	0.032159	190	0.000169			
Total	1.831125	199				

(b) Kernel

Source of Variation	SS	df	MS	F	P-value	F crit
Species	0.000889	1	0.000889	21.93549**	1.94E-05	4.019541
Moisture content	0.064185	2	0.032093	791.6907**	9.83E-41	3.168246
Interaction (sp x m.c)	0.000396	2	0.000198	4.887728*	0.011194	3.168246
Error	0.002189	54	4.05E-05			
Total	0.06766	59				

**Highly Significant

* Significant

The kernel also followed similar trend as the seed that is the bulk density was significantly affected by the moisture, species and interaction between the two variables as shown in Table 4.13. The bulk density of *Irvingia gabonensis* seed and kernel was more than that of *Irvingia wombolu* as evident from Fig 4.10. The bulk density of *Irvingia gabonensis* seed is significantly higher than that of *Irvingia wombolu* at the five levels of moisture (Appendix A) while that of *Irvingia gabonensis* kernel is significantly higher than that of *Irvingia wombolu* at 5.32% only (Appendix B).

4.6 Porosity

The porosity of seed and kernel decreased with increase in moisture content for all the two species as shown in Figure 4.11. The porosity of the seed decrease 50.28 to 44.54% for *Irvingia gabonensis* and 62.81 to 46.38% for *Irvingia wombolu*. The kernel's porosity decreased from 37.92 to 27.25% for *Irvingia gabonensis*, and 55.75 to 52.47% for *Irvingia wombolu*.

The porosity decrease because an increase in moisture content results in a more significant increase / swelling of the linear dimension, thus reducing the airspaces and giving a more compact arrangement of seeds, invariably reducing the porosity of the seed bulk. The trend equations for the porosity of the seed and kernel are as shown in Table 4.9. Similar result was reported for pomegranate seed (Kingsley *et al.*, 2006), green wheat (Al-Mahasaneh and Rababah, 2007), caper fruit (Sessiz *et al.*, 2007), water melon seed (Koocheki *et al.*, 2007), okra seed (Sahoo and Srivastava, 2002), and sorghum (Mahapatra *et al.*, 2002).

However, some other researchers reported that porosity increase with increase in moisture for quinoa seed (Vilche *et al.*, 2003), flaxseed (Wang *et al.*, 2007), niger seed (Solomon and Zewdu, 2009), fennel seeds (Ahmadi *et al.*, 2009), amaranth seed (Abalone *et al.*, 2004) and black cumin (Gharibzahedi *et al.*, 2010). This indicates that the porosity of seed of different crops could respond differently to changes in the moisture content, which could be attributed to their morphological characteristics. Aeration will be more pronounced in seed with high porosity value.

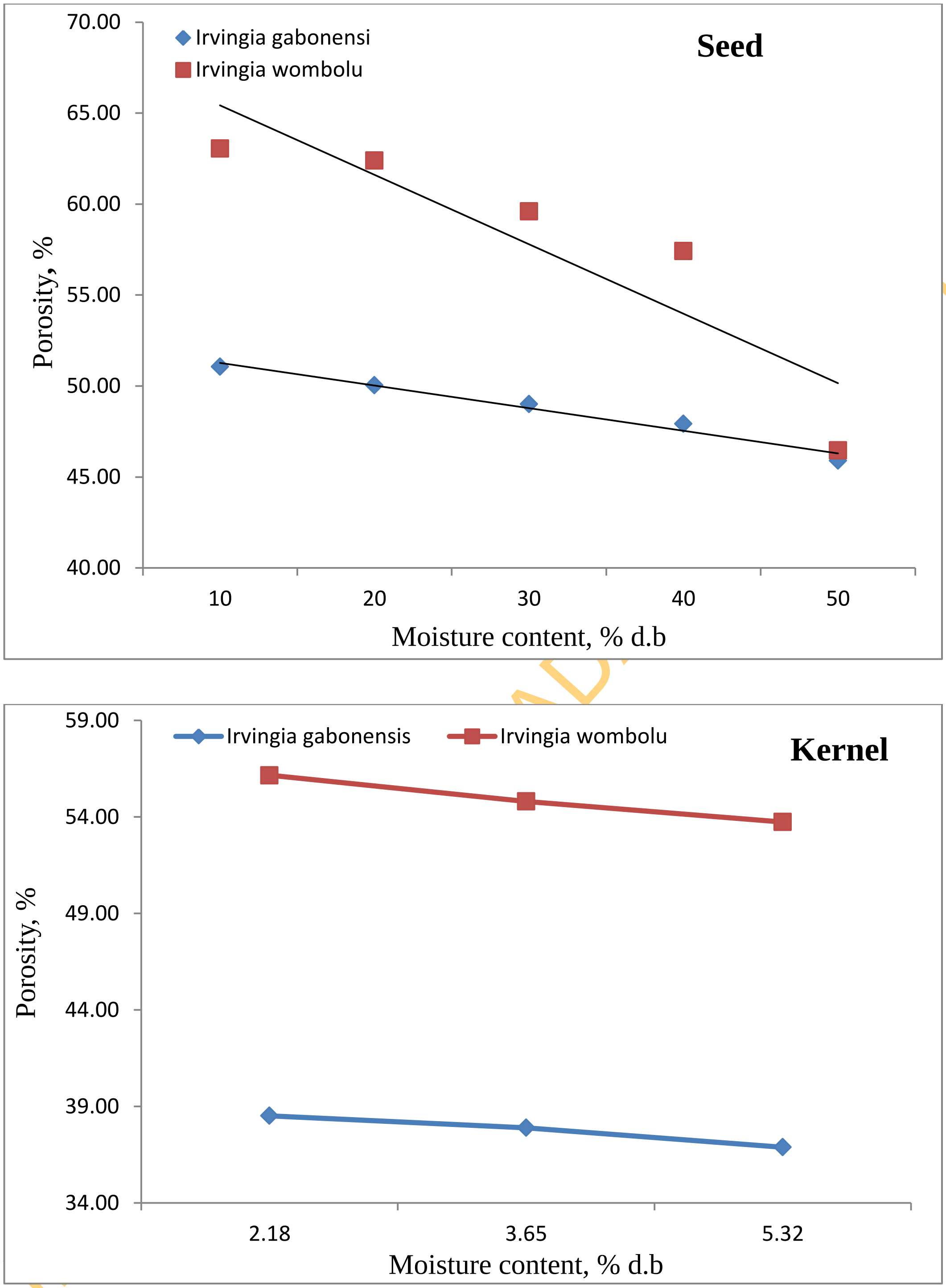


Figure 4.11: Variation in porosity of bush mango seed and kernel

The porosity of the *Irvingia gabonensis* seed was not significantly ($p>0.05$) different at the five moisture levels while it was significantly ($p<0.05$) different for *Irvingia wombolu.* On the other hand the porosity was not significantly ($p>0.05$) different for the two species of bush mango kernel. The ANOVA Table 4.14 showed that the moisture content, species and interaction had significant effect on porosity of the seed. Porosity of the kernel was however only significantly affected by species of the bush mango (Table 4.14). *Irvingia wombolu* seed and kernel had the highest values for the porosity at all levels of moisture contents as observed in Fig 4.11. The difference between the porosity of the seed for the two species was significant ($p<0.05$) except at 50% moisture level (Appendix A). The difference was however significant at the three moisture levels for the kernel (Appendix B).

The parametric model for the relationship between the densities and porosity of the bush mango seed and kernel are shown in Table 4.15 and Appendices A and B. The correlation between true density, bulk density, porosity and moisture content showed that for Irvingia gabonensis seed and kernel, it has 66.7% direct correlation. On the other hand, Irvingia wombolu seed has 33.3% while the kernel has 50% direct correlation as observed in Table 4.16.

Table 4.14: Analysis of variance for porosity of bush mango seed and kernel

(a) Seed

Source of Variation	SS	df	MS	F	P-value	F crit
Species	4442.954	1	4442.954	214.015**	5.91E-33	3.890867
Moisture content	3202.476	4	800.619	38.56544**	1.31E-23	2.419187
Interaction (sp x m.c)	777.332	4	194.333	9.36093**	6.31E-07	2.419187
Error	3944.402	190	20.76001			
Total	12367.16	199				

(b) Kernel

Source of Variation	SS	df	MS	F	P-value	F crit
Species	6421.555	1	6421.555	35.01437**	2.31E-07	4.019541
Moisture content	507.7249	2	253.8624	1.384218^{NS}	0.259265	3.168246
Interaction (sp x m.c)	157.2292	2	78.61461	0.428656^{NS}	0.653581	3.168246
Error	9903.476	54	183.3977			
Total	16989.99	59				

** Highly significant

^{NS} Not Significant

Table 4.15: Parametric equations for true density, bulk density and porosity of mango seed and kernel

(b) Seed

Species	Equations	R^2
Irvingia gabonensis	MC = –0.0849 + 0.0062TD + 0.2034BD + 0.0002P	0.9789
Irvingia wombolu	MC = 0.0686 + 0.0881TD – 0.0495BD – 0.0020P	0.9127

(c) Kernel

Species	Equations	R^2
Irvingia gabonensis	MC = –0.1445 – 0.0151TD + 0.3973BD – 0.0002P	0.9591
Irvingia wombolu	MC = 0.0236 + 0.1007TD + 0.0014BD – 0.0017P	0.9186

MC = Moisture Content
TD = True Density
BD = Bulk Density
P = Porosity

Table 4.16: Correlation Analysis for true density,bulk density and porosity of bush mango seed and kernel

Seed

	Species							
	Irvingia gabonensis				*Irvingia wombolu*			
Variables	MC	TD	BD	P	MC	TD	BD	P
MC	1.0000	0.6350	0.9892	-0.3408	1.0000	0.7160	0.9475	-0.8001
		<.0001	<.0001	0.0004		<.0001	<.0001	<.0001
TD	0.6350	1.0000	06281	0.4529	0.7160	1.0000	0.6660	-0.2649
	<.0001		<.0001	<.0001	<.0001		<.0001	0.0063
BD	0.9892	06281	1.0000	-0.3681	0.9475	0.6660	1.0000	-0.8937
	<.0001	<.0001		0.0001	<.0001	<.0001		<.0001
P	-0.3408	0.4529	-0.3681	1.0000	-0.8001	-0.2649	-0.8937	1.0000
	0.0004	<.0001	0.0001		<.0001	0.0063	<.0001	

(b) Kernel

	Species							
	Irvingia gabonensis				*Irvingia wombolu*			
Variables	MC	TD	BD	P	MC	TD	BD	P
MC	1.0000	0.2272	0.9781	-0.2390	1.0000	-0.7862	0.8726	-0.2240
		0.2036	<.0001	0.1804		<.0001	<.0001	0.2101
TD	0.2272	1.0000	0.2438	0.8245	-0.7862	1.0000	-0.9266	0.3974
	0.2036		0.1716	<.0001	<.0001		<.0001	0.0220
BD	0.9781	0.2438	1.0000	-0.2581	0.8726	-0.9266	1.0000	-0.0810
	<.0001	0.1716		0.1470	<.0001	<.0001		0.6542
P	-0.2390	0.8245	-0.2581	1.0000	-0.2240	0.3974	-0.0810	1.0000
	0.1804	<.0001	0.1470		0.2101	0.0220	0.6542	

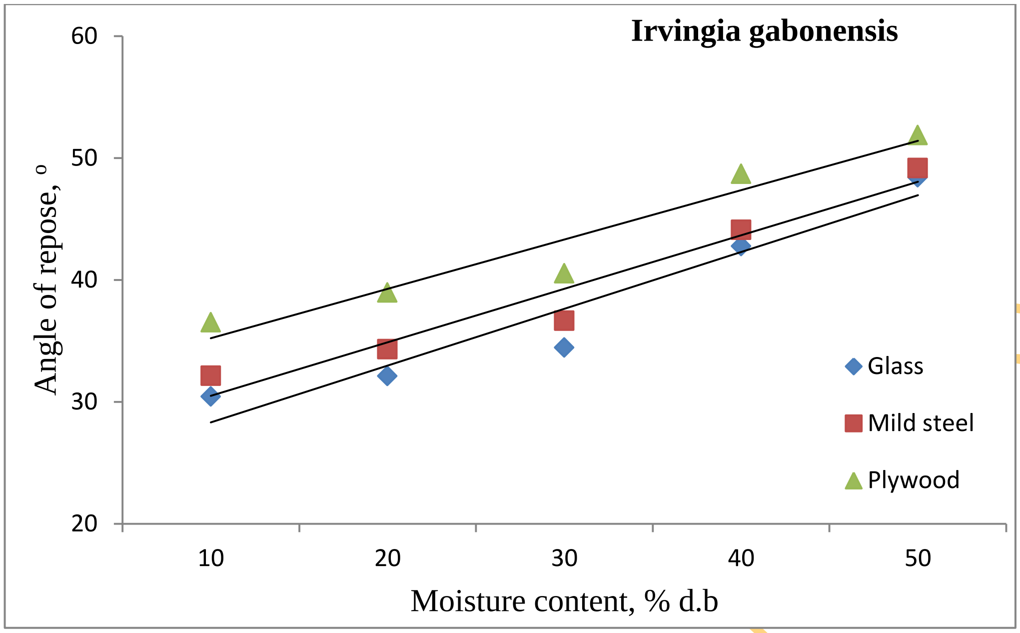
MC = Moisture Content
TD = True Density
BD = Bulk Density
P = Porosity

4.7 Angle of Repose

The angle of repose of the seed and kernel increased with increase in moisture content on all the three surfaces for the two species of bush mango (Figures 4.12 and 4.13). It increased from 36.51^o to 51.87^o for *Irvingia gabonensis* seed while it increased from 37.58^o to 52.87^o for *Irvingia wombolu* seed on plywood. Angle of repose of the kernel on plywood varied from 21.75^o to 26.09^o for *Irvingia wombolu* and 23.26^o to 26.13^o for *Irvingia gabonensis*. The variation of the angle of repose on glass for *Irvingia gabonensis* seed is from 30.44^o to 48.42^o and 33.13^o to 43.54^o for *Irvingia wombolu* seed while its variation for the kernel is 20.92^o to 25.09^o for *Irvingia gabonensis* and 21.36^o to 25.19^o for *Irvingia wombolu*. For mild steel, the angle of repose for *Irvingia gabonensis* seed is from 32.13^o to 49.17^o and 36.98^o to 48.80^o *Irvingia wombolu* while the angle of repose for the kernel is from 24.81^o to 27.25^o for *Irvingia gabonensis* and 22.79^o to 28.25^o for *Irvingia wombolu.* The regression equations for the angle of repose on the three structural materials are given in Table 4.17 for the seed and kernel.

Angle of repose of a material is a measure of resistance offered to the particles of a material by the same material due to its surface roughness and cohesiveness. The increase in angle of repose with increase in moisture can be explained as being due to the surface layer of moisture that surrounds each particle and that surface tension effect becomes predominant in holding aggregates of solids together. At higher moisture content seeds tend to stick together resulting in better stability and less flow ability, which increase the value of angle of repose (Irtwange and Igbeka, 2002).

The increase in values of angle of repose with increasing moisture content was also reported for lentil seed (Amin *et al*., 2004), beniseed (Tunde-Akintunde and Akintunde, 2007), tef seed (Zewedu and Solomon, 2007), bean seed (Gharibzahedi *et al*., 2010), hemp seed (Sacilik *et al*., 2003) and barley grain (Tavakoli *et al*., 2009). The angle of repose of the bush mango seed is greater than the value reported for lentil seed (Amin *et al*., 2004) and edible squash (Paksoy and Aydin, 2004). The difference could be attributed to differences in surface roughness of seed or grain.



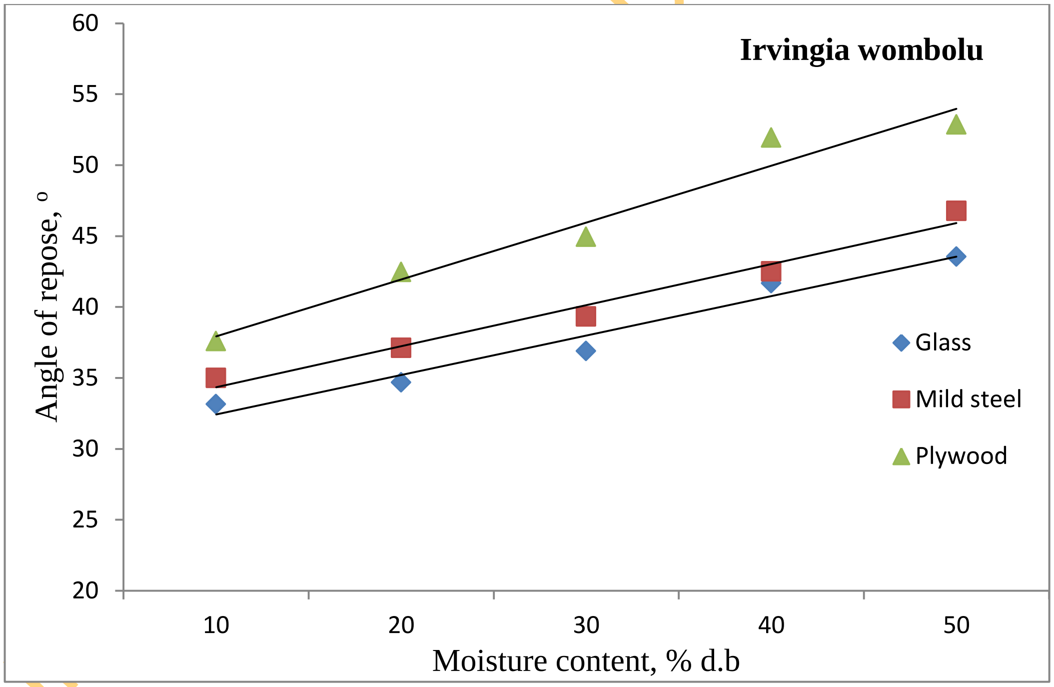
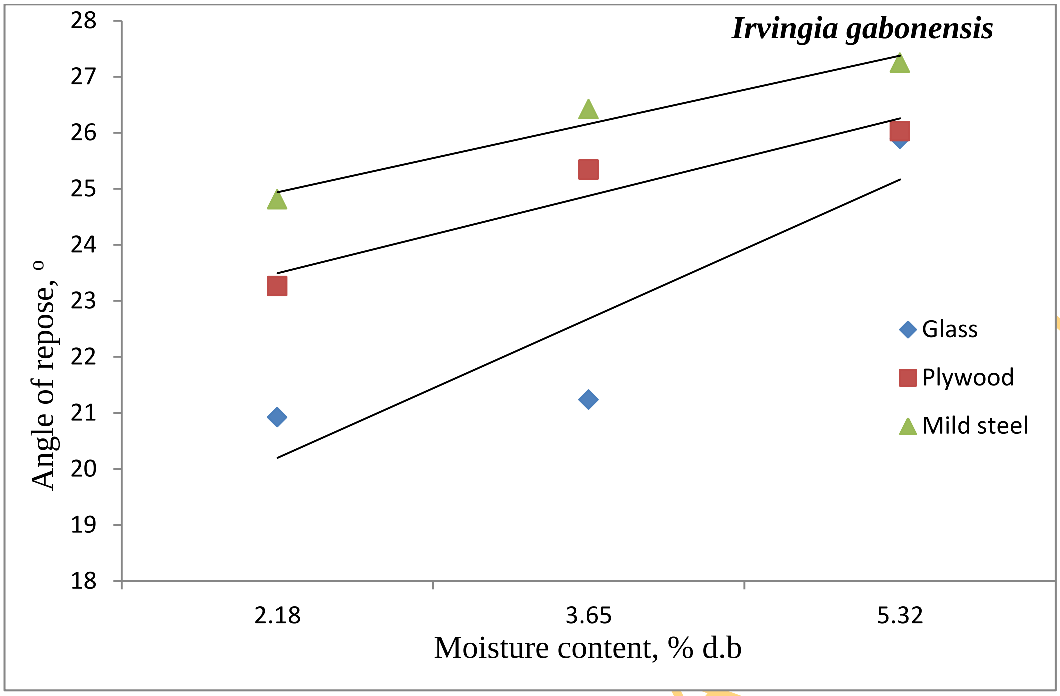


Figure 4.12: Effect of moisture on angle of repose of seed on three structural surfaces



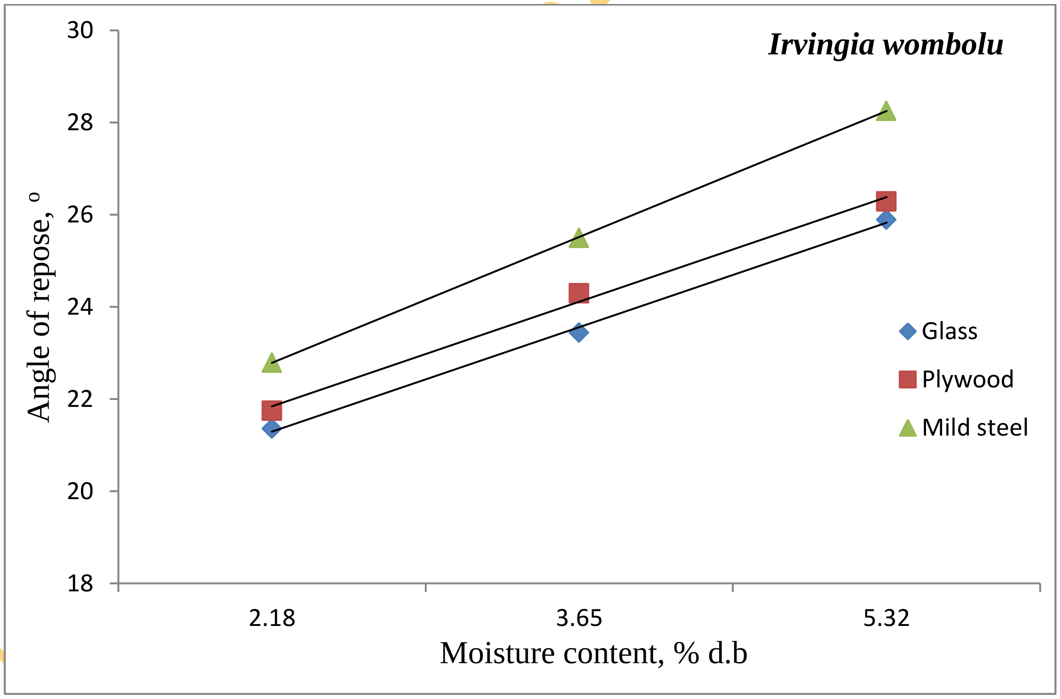


Figure 4.13: Effect of moisture on angle of repose of kernel on three structural surfaces

Table 4.17: Regression equations for angle of repose of bush mango seed and kernel

(a) Seed

	Species			
Structural surface	Irvingia gabonensis		Irvingia wombolu	
	Equations	R^2	Equations	R^2
Plywood	31.183 + 4.0448M	0.9349	33.940 + 4.0046M	0.9612
Mild steel	26.113 + 4.3870M	0.9445	31.446 + 2.8951M	0.9759
Glass	23.648 + 4.6626M	0.9241	29.639 + 2.7808M	0.9650

(b) Kernel

	Species			
Structural surface	Irvingia gabonensis		Irvingia wombolu	
	Equations	R^2	Equations	R^2
Plywood	22.111 + 1.3821M	0.9219	19.569 + 2.2703M	0.9949
Mild steel	23.719 + 1.2197M	0.9672	20.051 + 2.7317M	1.0000
Glass	17.714 + 2.4839M	0.7970	19.029 + 2.2665M	0.9979

M = moisture content, % d.b

Species of bush mango had significant effect on the angle of repose of seed on mild steel and plywood, while it does not have any significant effect on glass. The interaction between moisture and species was also significant on glass and mild steel. The angle of repose of the seed was however significantly ($p<0.05$) affected by moisture on the three structural material (Table 4.18). The species of bush mango had significant effect on the angle of repose of the kernel on glass and was not significant on plywood and mild steel. The angle of repose of the kernel was significantly affected by moisture content on the three structural surfaces while interaction between moisture and species was also significant on glass and mild steel (Table 4.19).

Irvingia wombolu seed had higher values for the angle of repose and was not significantly different at 40% moisture level on all the three structural surfaces (Appendix C). On the other hand *Irvingia gabonensis* kernel had higher values at 2.18 and 3.65% and was not significantly different at 5.32% moisture on the three surfaces as observed in Appendix D. This means that specie's angle of repose for both the seed and kernel had to be considered in the design of processing and handling equipment on the three structural surfaces. Although any of the species angle of repose can be used when the seed moisture is 40% (d.b) and kernel at 5.32% (d.b) on any of the three surfaces.

High angle of repose means rough surface imposing high resistance as they move against each other. Low angle of repose makes the seeds to spread out wider on a plane surface compared to high angle of repose. Low angle of repose is often advisable during belt conveying while high angle of repose is more desirable when unloading onto a horizontal surface (Koocheki *et al*., 2007).

Hence, low moisture is advisable for belt conveying, while high moisture is suitable for unloading. Angle of repose is not a measure of flow ability of solids but useful in determination of the contour of pile when free flowing bulk solids are discharged through a vertical or horizontal opening. Angle of repose has practical application in design of mechanization and agricultural products handling systems so as to minimized mechanical damage to crop during on-the-farm and off-the-farm handling, processing and storage.

Table 4.18: Analysis of variance for angle of repose of bush mango seed on three structural surfaces**.**

(a) Glass

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Species	1.497827	1	1.497827	0.327702^{NS}	0.570219	4.084746
Moisture content	1466.185	4	366.5463	80.19469**	1.48E-18	2.605975
Interaction (sp x mc)	110.6827	4	27.67067	6.053917*	0.000661	2.605975
Error	182.8282	40	4.570705			
Total	1761.194	49				

** Highly Significant, *Significant, ^{NS} Not Significant

(b) Mild steel

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Species	271.0786	1	271.0786	52.33481**	8.87E-09	4.084746
Moisture content	1393.868	4	348.4671	67.27553**	3.19E-17	2.605975
Interaction (Sp x mc)	105.7305	4	26.43263	5.10312*	0.002034	2.605975
Error	207.188	40	5.1797			
Total	1977.865	49				

** Highly Significant, *Significant, ^{NS} Not Significant

(c) Plywood

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Species	86.85521	1	86.85521	6.551605*	0.014364	4.084746
Moisture content	1685.851	4	421.4629	31.79151**	6.14E-12	2.605975
Interaction (Sp x mc)	23.32409	4	5.831024	0.439842^{NS}	0.779036	2.605975
Error	530.2836	40	13.25709			
Total	2326.314	49				

** Highly Significant, *Significant, ^{NS} Not Significant

Table 4.19: Analysis of variance for angle of repose of bush mango kernel on three structural surfaces.

(a) Glass

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Species	11.62779	1	11.62779	6.689661**	0.012426	4.019541
Moisture content	244.0936	2	122.0468	70.21557**	9.51E-16	3.168246
Interaction (Sp x m.c)	13.68426	2	6.842132	3.936393*	0.025359	3.168246
Error	93.86135	54	1.738173			
Total	363.267	59				

** Highly Significant, *Significant

(b) Mild steel

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Species	6.229808	1	6.229808	2.820439^{NS}	0.098849	4.019541
Moisture content	156.5857	2	78.29284	35.44574**	1.47E-10	3.168246
Interaction (Sp x m.c)	23.42463	2	11.71231	5.302549**	0.007896	3.168246
Error	119.2756	54	2.208808			
Total	305.5158	59				

** Highly Significant, ^{NS} Not Significant

(c) Plywood

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Species	8.793482	1	8.793482	3.794504^{NS}	0.056627	4.019541
Moisture content	136.5875	2	68.29376	29.46966**	2.23E-09	3.168246
Interaction (Sp x m.c)	8.46576	2	4.23288	1.826544^{NS}	0.170774	3.168246
Error	125.141	54	2.317426			
Total	278.9878	59				

** Highly Significant, ^{NS} Not Significant

A parametic model describing the relationship between the three strustural surfaces used for the angle of repose of bush mango seed and kernel are given in Table 4.20.The correlation of angle of repose on the three structural materials with moisture content was positive for both the seed and kernel of bush mango as observed in Table 4.21.

4.8 Coefficient of static friction

The coefficient of static friction for the two species of bush mango seeds and kernels with respect to glass (μ_{gl}), plywood (μ_{pl}), galvanized iron sheet (μ_{gs}), stainless steel (μ_{ss}) and mild steel (μ_{ms}) surfaces at different moisture levels are presented in Table 4.22.

4.8.1 Glass

The coefficient of friction for glass (μ_{gl}) increased with increasing moisture content from 10 to 50% for the seed and 2.18 to 5.32% for the kernel. The coefficient of static friction on glass surface observed for *Irvingia gabonensis* seed increased from 0.31 to 0.42 and 0.30 to 0.51 for *Irvingia wombolu* seed as evident from Table 4.22. The kernel coefficient of static friction increased from 0.45 to 0.53 and 0.43 to 0.52 for *Irvingia wombolu* and *Irvingia gabonensis* respectively Table 4.22.

The coefficients of frictions for Irvingia wombolu seeds are higher than those of *Irvingia gabonensis* while the reverse is the case for the kernels as shown in Table 4.22. These values of coefficient of friction were greater than pistachio nuts (Razavi and Taghizadeh, 2007) and pine nuts (Ozguven and Kubilay, 2004).

The coefficient of static friction of the seed and kernel on glass were significantly affected by species of bush mango and moisture content. The interaction between the moisture content and the species were however statistically non-significant (Table 4.23). The regression equations showing the variation with moisture content of the coefficient of friction for the seed and kernel are given in Table 4.24.

Table 4.20: Parametric equations for angle of repose of mango seed and kernel on three Structural materials

(c) Seed

Species	Equations	R^2
Irvingia gabonensis	$MC = -0.0493 + 0.0064G + 0.0013M + 0.0011P$	0.8953
Irvingia wombolu	$MC = -0.0923 + 0.0011G - 0.0011M - 0.0008P$	0.9073

(d) Kernel

Species	Equations	R^2
Irvingia gabonensis	$MC = -0.1574 + 0.0028GS + 0.0029MS + 0.0023PL$	0.8508
Irvingia wombolu	$MC = 0.0938 + 0.0023GS + 0.0017MS + 0.0014PL$	0.8079

MC = Moisture Content
MS = Mild Steel
GS = Glass
PL = Plywood

Table 4.21: Correlation Analysis for angle of repose bush mango seed and kernel

Seed

	Species							
	Irvingia gabonensis				*Irvingia wombolu*			
Variables	MC	GS	MS	PL	MC	GS	MS	PL
MC	1.0000	0.9336	0.9465	0.8499	1.0000	0.8954	0.8582	0.8873
		<.0001	<.0001	<.0001		<.0001	<.0001	<.0001
GS	0.9336	1.0000	0.9560	0.8600	0.8954	1.0000	0.7394	0.8504
	<.0001		<.0001	<.0001	<.0001		<.0001	<.0001
MS	0.9465	0.9560	1.0000	0.8782	0.8583	0.7394	1.0000	0.7142
	<.0001	<.0001		<.0001	<.0001	<.0001		<.0001
PL	0.8499	0.8600	0.8782	1.0000	0.8873	0.8505	0.7142	1.0000
	<.0001	<.0001	<.0001		<.0001	<.0001	<.0001	

(a) Kernel

	Species							
	Irvingia gabonensis				*Irvingia wombolu*			
Variables	MC	GS	MS	PL	MC	GS	MS	PL
MC	1.0000	0.8466	0.6937	0.6906	1.0000	0.7905	0.8095	0.7532
		<.0001	<.0001	<.0001		<.0001	<.0001	<.0001
GS	0.8466	1.0000	0.5151	0.8245	0.7905	1.0000	0.6209	0.5440
	<.0001		0.0022	0.0010	<.0001		0.0001	0.0011
MS	0.6937	0.2438	1.0000	-0.2581	0.8095	0.6209	1.0000	0.7077
	<.0001	0.0022		0.0374	<.0001	0.0001		<.0001
PL	0.6906	0.5451	0.3638	1.0000	0.7532	0.5440	0.7077	1.0000
	<.0001	0.0010	0.0374		<.0001	0.0011	<.0001	

MC = Moisture Content

GS = Glass

MS = Mild Steel

PL = Plywood

Table 4.22: Variation of coefficient of static friction of bush mango seed and kernel on five structural surfaces

(a) Seed

Species	Moisture Content	Structural Surfaces Glass	Plywood	Stainless Steel	Galvanized Steel	Mild Steel
Irvingia wombolu	10%	0.304	0.613	0.452	0.425	0.596
	20%	0.386	0.658	0.505	0.440	0.623
	30%	0.436	0.795	0.512	0.525	0.650
	40%	0.482	0.847	0.546	0.639	0.739
	50%	0.512	1.090	0.673	0.809	0.924
Irvingia gabonensis	10%	0.308	0.691	0.393	0.482	0.539
	20%	0.320	0.887	0.411	0.503	0.568
	30%	0.390	0.892	0.477	0.509	0.611
	40%	0.416	0.953	0.540	0.617	0.688
	50%	0.421	0.977	0.575	0.665	0.719

(b) Kernel

Species	Moisture Content	Structural Surfaces Glass	Plywood	Stainless steel	Galvanized Steel	Mild Steel
Irvingia wombolu	2.18%	0.427	0.549	0.383	0.487	0.501
	3.65%	0.442	0.552	0.415	0.510	0.566
	5.32%	0.517	0.592	0.442	0.544	0.618
Irvingia gabonensis	2.18%	0.451	0.544	0.434	0.484	0.519
	3.65%	0.494	0.585	0.474	0.514	0.542
	5.32%	0.526	0.633	0.506	0.555	0.569

Table 4.23: Analysis of variance of coefficient of friction on glass surface for bush mango seed and kernel.

(a) Seed

Source of Variation	SS	df	MS	F	P-value	F crit
Species	0.03541	1	0.03541	15.10747**	0.000373	4.084746
Moisture content	0.179973	4	0.044993	19.19583**	6.99E-09	2.605975
Interaction (Sp x m.c)	0.012764	4	0.003191	1.361358^{NS}	0.264498	2.605975
Error	0.093756	40	0.002344			
Total	0.321903	49				

** Significant ^{NS} Non Significant

(b) Kernel

Source of Variation	SS	df	MS	F	P-value	F crit
Species	0.012108	1	0.012108	4.250467**	0.044067	4.019541
Moisture content	0.069729	2	0.034865	12.23868**	4.14E-05	3.168246
Interaction (Sp x m.c)	0.004983	2	0.002492	0.874637^{NS}	0.422837	3.168246
Error	0.153832	54	0.002849			
Total	0.240653	59				

** Significant ^{NS} Non Significant

Table 4.24: Regression equations for coefficient of friction of bush mango seed and kernel

(a) Seed

	Species			
Structural surface	*Irvingia gabonensis*		*Irvingia wombolu*	
	Equations	R^2	Equations	R^2
Plywood	0.0638M + 0.6882	0.8032	0.1142M + 0.4580	0.9234
Mild steel	0.0481M +0.4808	0.9744	0.0772M + 0.4750	0.8421
Glass	0.0322M + 0.2742	0.9051	0.0512M + 0.2705	0.9681
Galvanized steel	0.0482M + 0.4105	0.8828	0.0967M + 0.2774	0.9190
Stainless steel	0.0495M + 0.3307	0.9737	0.0482M + 0.3929	0.8480

(b) Kernel

	Species			
Structural surface	*Irvingia gabonensis*		*Irvingia wombolu*	
	Equations	R^2	Equations	R^2
Plywood	0.0360M + 0.5351	0.9997	0.0481M + 0.4524	0.8827
Mild steel	0.0444M + 0.4987	0.9973	0.0215M + 0.5213	0.8047
Glass	0.0373M + 0.4156	0.9906	0.0451M + 0.3718	0.8716
Galvanized steel	0.0355M + 0.4466	0.9936	0.0287M + 0.4563	0.9870
Stainless steel	0.0359M + 0.3995	0.9954	0.0294M + 0.3544	0.9976

M = moisture content, % d.b

4.8.2 Plywood

The coefficient of static friction on plywood is 0.69 to 0.98 for *Irvingia gabonensis* seed while it is 0.61 to 1.09 for *Irvingia wombolu* as the moisture content is increased. On the other hand *Irvingia wombolu* kernel has its value varying from 0.51 to 0.64 and 0.51 to 0.61 for *Irvingia gabonensis* kernel as shown in Table 4.22. The static coefficient of friction of bush mango seeds on plywood surface were greater than the values reported for cowpea seed (Kabas *et al*., 2007), lentil (Amin *et al*., 2004), African star apple (Oyelade *et al*., 2005), almond nut (Ayind, 2003), pomegranate seed (Kingsley *et al*., 2006) and green wheat (Al-Mahaseneh and Rababah, 2007).

The coefficient of static friction of the seed on plywood was significantly affected by species of bush mango, moisture content and the interaction between the moisture content and species. The kernel's coefficient of friction was significantly affected by the moisture content while species and the interaction between the moisture content and species were statistically non-significant (Table 4.25). The regression equations showing the variation with moisture content of the coefficient of friction for the seed and kernel are given in Table 4.24.

4.8.3 Galvanized Steel

The results obtained for the coefficient of static friction on galvanized steel surface are shown in Table 4.22 revealed that *Irvingia gabonensis* seed varied from 0.48 to 0.67 and *Irvingia wombolu* from 0.42 to 0.81. The kernels coefficient of friction is 0.49 to 0.56 and 0.49 to 0.54 for *Irvingia gabonensis* and *Irvingia wombolu* respectively. Table 4.22 shows the variation of the coefficient of friction on galvanized steel for the bush mango seed and kernel. The coefficient of static friction of bush mango seed and kernel on galvanized steel were greater than what was reported for guna seed (Aviara and Hague, 2001), barbunia bean (Cetin, 2007), faba beans (Altuntas and Yildiz, 2007), hackberry (Demir *et al*., 2002) and gumbo fruit (Akar and Ayind, 2005).

Table 4.25: Analysis of variance for coefficient of bush mango seed and kernel on plywood surface

(a) Seed

Source of Variation	SS	df	MS	F	P-value	F crit
Species	0.078338	1	0.078338	41.66649**	1.08E-07	4.084746
Moisture content	0.808763	4	0.202191	107.5417**	7.62E-21	2.605975
Interaction (Sp x m.c)	0.15094	4	0.037735	20.07059**	3.93E-09	2.605975
Error	0.075205	40	0.00188			
Total	1.113245	49				

** Significant ^{NS} Non Significant

(b) Kernel

Source of Variation	SS	df	MS	F	P-value	F crit
Species	0.008085	1	0.008085	2.094715^{NS}	0.15359	4.019541
Moisture content	0.045052	2	0.022526	5.836218**	0.005073	3.168246
Interaction (Sp x m.c)	0.005929	2	0.002964	0.76806^{NS}	0.468913	3.168246
Error	0.208425	54	0.00386			
Total	0.267491	59				

** Significant ^{NS} Non Significant

The moisture content and the interaction between the moisture and species had significant effect on the coefficient of friction on galvanized steel for the seed while only the moisture was significant in the case of the kernel (Table 4.26). The regression equations for the variation are given in Tables 4.24 for the seed and kernel.

4.8.4 Stainless Steel

The variation of coefficient of friction with moisture content on stainless steel was found to increase linearly with increase in moisture content for both the seed and kernel. The seed increased from 0.39 to 0.58 and 0.45 to 0.67 for *Irvingia gabonensis* and *Irvingia wombolu* seeds respectively as observed in Table 4.22. The kernels coefficient of friction on the other hand increased from 0.43 to 0.51 and 0.39 to 0.44 for *Irvingia gabonensis* and *Irvingia wombolu* kernels (Table 4.22).

The coefficient of friction of the seed and kernel were significantly affected by moisture content and species of the bush mango (Table 4.27). The regression equation with R^2 values for the seeds and kernels are shown in Table 4.24.

4.8.5 Mild Steel

The coefficient of static friction on mild steel varied from 0.54 to 0.72 for *Irvingia gabonensis* seed and 0.60 to 0.92 for *Irvingia wombolu* as moisture content is increased from 10 to 50% moisture content. On the other hand *Irvingia wombolu* kernel has its value varying from 0.54 to 0.63 and 0.55 to 0.59 for *Irvingia gabonensis* kernel.

The moisture content, species of bush mango and interaction between moisture and species had significant effect on the coefficient of friction of the seed while the moisture and species significantly affect the kernel’s coefficient of friction (Table 4.28). The variation of coefficient of friction with moisture of seed and kernel on plywood are displayed in Table 4.22. The R^2 value and the regression equations are shown in Table 4.24 for the seed and kernel.

Table 4.26: Analysis of variance for coefficient of bush mango seed and kernel on galvanized steel surface

(a) Seed

Source of Variation	SS	df	MS	F	P-value	F crit
Species	0.001977	1	0.001977	0.72501^{NS}	0.399574	4.084746
Moisture content	0.571074	4	0.142769	52.35639**	2.25E-15	2.605975
Interaction (Sp x m.c)	0.069563	4	0.017391	6.377564**	0.000456	2.605975
Error	0.109074	40	0.002727			
Total	0.751689	49				

** Significant ^{NS} Non Significant

(b) Kernel

Source of Variation	SS	df	MS	F	P-value	F crit
Species	0.000219	1	0.000219	0.103673^{NS}	0.748709	4.019541
Moisture content	0.041546	2	0.020773	9.831495**	0.000229	3.168246
Interaction (Sp x m.c)	0.000457	2	0.000229	0.108185^{NS}	0.897655	3.168246
Error	0.114096	54	0.002113			
Total	0.156318	59				

** Significant ^{NS} Non Significant

Table 4.27: Analysis of variance for coefficient of bush mango seed and kernel on stainless steel surface.

(a) Seed

Source of Variation	SS	df	MS	F	P-value	F crit
Species	0.042241	1	0.042241	19.39633**	7.73E-05	4.084746
Moisture content	0.247047	4	0.061762	28.36013**	3.32E-11	2.605975
Interaction (sp x m.c)	0.015577	4	0.003894	1.788141^{NS}	0.150248	2.605975
Error	0.087111	40	0.002178			
Total	0.391974	49				

** Significant ^{NS} Non Significant

(b) Kernel

Source of Variation	SS	df	MS	F	P-value	F crit
Species	0.050804	1	0.050804	40.89064**	3.95E-08	4.019541
Moisture content	0.04281	2	0.021405	17.22833**	1.63E-06	3.168246
Interaction (sp x m.c)	0.000438	2	0.000219	0.176461^{NS}	0.838713	3.168246
Error	0.067091	54	0.001242			
Total	0.161143	59				

** Significant ^{NS} Non Significant

Table 4.28: Analysis of variance for coefficient of bush mango seed and kernel on mild steel surface.

(a) Seed

Source of Variation	SS	df	MS	F	P-value	F crit
Species	0.082989	1	0.082989	32.62354**	1.2E-06	4.084746
Moisture content	0.424105	4	0.106026	41.67957**	9.28E-14	2.605975
Interaction (Sp x m.c)	0.048392	4	0.012098	4.755746**	0.00311	2.605975
Error	0.101754	40	0.002544			
Total	0.65724	49				

** Significant ^{NS} Non Significant

(b) Kernel

Source of Variation	SS	df	MS	F	P-value	F crit
Species	0.051198	1	0.051198	16.31436**	0.000171	4.019541
Moisture content	0.07351	2	0.036755	11.71205**	5.96E-05	3.168246
Interaction (Sp x m.c)	0.00477	2	0.002385	0.759986^{NS}	0.472609	3.168246
Error	0.169463	54	0.003138			
Total	0.298941	59				

** Significant ^{NS} Non Significant

4.8.6 Overview of coefficient of static friction

The coefficient of static friction of the seed is higher than that of the kernel against all the structural surfaces. This shows that the kernel encounters less resistance to sliding than the seed on these surfaces. The coefficient of static friction of the seed and kernel increased linearly with increase in moisture content on all the surfaces used for the study. The increase in coefficient of static friction with moisture content may be explained by increased in cohesive force of wet seeds and kernels with the structural surface, since the surface becomes sticker as moisture content increases. Similar variation were reported for millet (Baryeh, 2002), almond nut (Aydin, 2003), barbunia bean (Cetin, 2007), pistachio nut and kernel (Razavi *et al.*, 2007) and caper fruit (Sessiz *et al*., 2007).

Plywood has the highest coefficient of static friction for the seed and kernel at all the moisture levels. This might be due to the surface roughness which is largest in plywood. However glass had the least for the seed while stainless steel had the least for the kernel. The stainless steel had the least value for the kernel due to the oily nature of the kernel which made it easier for it to move on it. The coefficient of static friction is a parameter required in the determination of lateral pressures on walls of storage structures, it can be deduced that increase in coefficient of static friction will bring about increase in lateral pressure on the walls of the bush mango seed and kernel storage structures as moisture content increases. Therefore, maximum values of coefficient of static friction should be used in the design of the storage structure.

The analysis of variance table shows that the static coefficient of friction of the bush mango seed is significantly affected by moisture content and material surface. The species of bush mango and interaction between moisture and species does not have significant ($p>0.05$) effect on the coefficient of static friction of the seed (Table 4.29). The effect of material surface on coefficient of static friction of seed showed that for *Irvingia gabonensis*, glass and galvanized steel, plywood and galvanized steel were not significantly different ($p>0.05$) at 30% moisture level.

Table 4.29: Analysis of variance for material effect on coefficient of friction of bush mango seed

Source of Variation	SS	df	MS	F	P-value	F crit
Species	0.017382	1	0.017382	0.623607^{NS}	0.430489	3.880497
Material	5.639333	4	1.409833	315.6062**	5.08E-91	2.411768
Moisture content	2.066979	4	0.516745	18.53878**	2.72E-13	2.409257
Interaction (Sp x m.c)	0.213233	4	0.053308	1.912494^{NS}	0.109014	2.409257
Within	6.689692	236	0.027874			
Total	8.987287	249				

** Significant ^{NS} Non Significant

At 40% moisture, glass and plywood, plywood and galvanised steel, galvanized steel and mild steel are not statistically different. In the case of *Irvingia wombolu* seed, the effect of material surface on coefficient of static friction of kernel was not significant on glass and plywood, plywood and galvanized steel, galvanized steel and mild steel at 40 and 50% moisture levels.

The material surface effect on coefficient of friction of the kernel was not significant different at 3.65 and 5.32% for glass and galvanized steel, plywood and mild steel, plywood and galvanized steel and galvanized steel and mild steel for the two species of bush mango

The coefficient of static friction of bush mango seed was significantly ($p<0.05$) affected by species on all the structural surfaces except on galvanized steel while the kernel was significantly ($p>0.05$) affected by species on all the structural surfaces except galvanized and mild steel.

The higher the coefficient of friction is, the lower the mobility coefficient is hence requiring larger hopper opening. The coefficient of friction is important in the design of conveyors because friction is necessary to hold material to the conveying surface without slipping or sliding backwards.

In view of the above finding, it is recommended that galvanized steel be used in the construction of processing and handling equipment. This is due to the fact that it is the material that is not statistically affected by species of bush mango and also the coefficient of friction on it was significantly not different from most of the other materials.

4.9 Mechanical properties of bush mango seed

4.9.1 Rupture force of bush mango seed

Rupture in biological material happens in bio yield point where initial rupture starts taking place (Emadi *et al*., 2009). The rupture force of the seed decreased with increase in moisture content from 10 to 40% but with further increments in moisture to 50%, it increased for the two species in the three directions of loading of the seed as presented in

Figure 4.14. The reason for this trend is that when the seed absorbed water, the shell became soft and weak and this was responsible for the initial reduction in rupture force.

However, further absorption of water by the seed made the kernel inside to swell up and fill the clearance between the kernel and the shell thereby become structurally turgid and this resulted in an increase in rupture force again. Similar results were obtained for African nutmeg (Burubai *et al*., 2008); shea nut (Olaniyan and Oje, 2002).

The rupture force was significantly ($p<0.05$) affected by moisture content of the seed for the two species in the three direction of loading (Table 4.30). The species of bush mango had significant effect on the rupture force of the seed for the two species at the five levels of moisture content in the three directions of loading as observed in Table 4.30. The direction of loading and moisture content of the seed significantly affect the rupture force at the five levels of moisture for the two species (Table 4.30). The rupture force was highest in the longitudinal direction followed by axial and then transverse (Figure 4.14). This could be because the area of contact between the seed and the compression plates of the Instron testing machine was largest in the transverse loading direction. The same trend was observed for guna seed (Aviara *et al*., 2005) and shea nut (Olaniyan and Oje, 2002). The rupture force of *Irvingia wombolu* was significantly higher than that of *Irvingia gabonesis* in all the direction of loading at the five levels of moisture content (Appendix E). The rupture force for the species in the three direction of loading can be estimated from the quadratic equations in Tables 4.31 and 4.32.

4.9.2 Deformation of bush mango seed

Deformation of the seed increased progressively as moisture content was increased from 10 to 50% (d.b) for the two species of the bush mango seed in the three direction of loading as observed in Figure 4.15. This trend is attributed to the fact that at higher moistures, seeds become softened and tend to flatten easily under load and thus subject to greater bruises. Some other researchers that obtained similar results included Burubai *et al*. (2008) for African nutmeg.

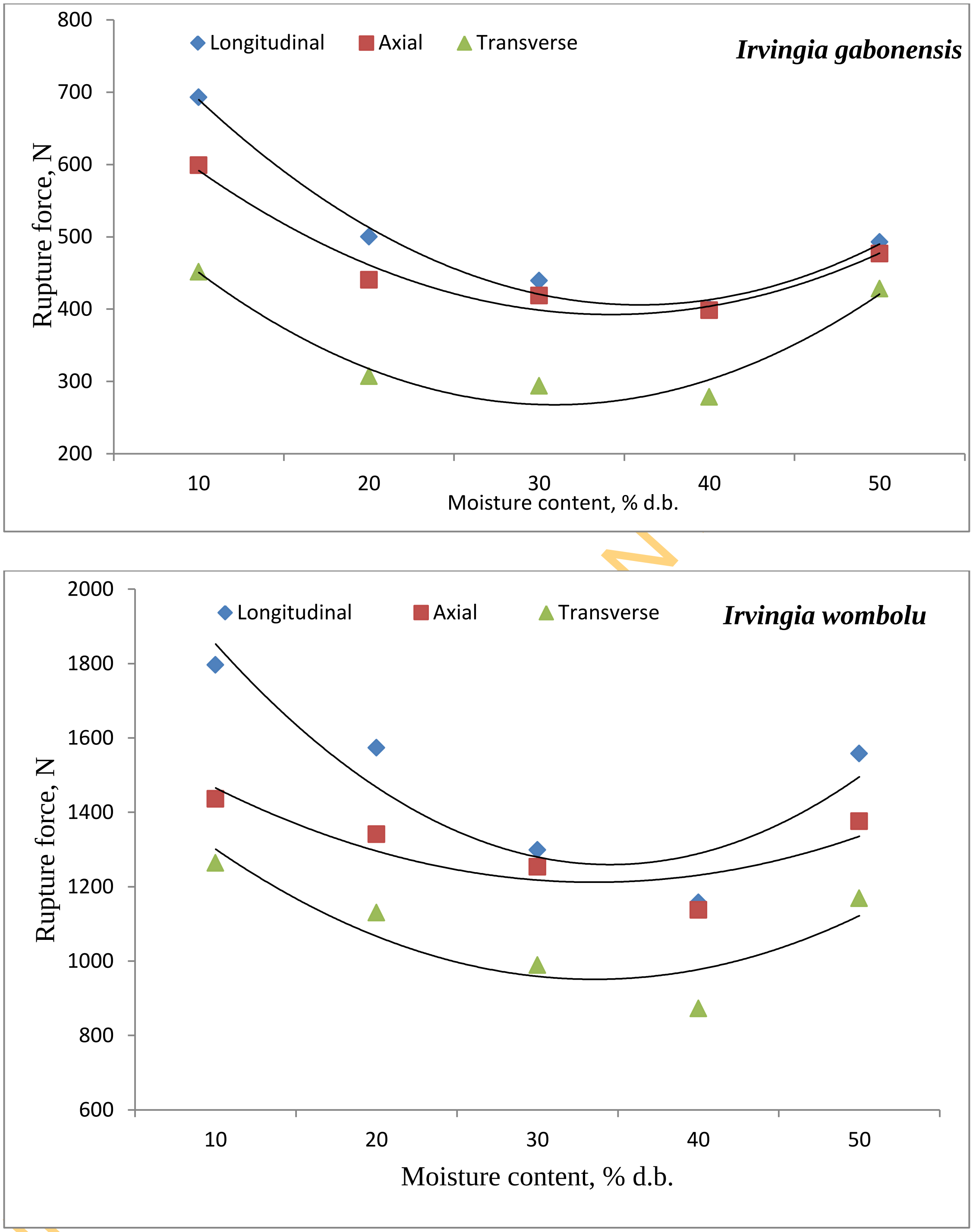


Fig 4.14: Variation in rupture force of bush mango seed with in three loading directions

Table 4.30: Analysis of variance for effect of moisture species and loading directions on rupture force of seed

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Moisture content	1955896	4	488974.1	24.01251**	3.87E-15	2.436317
Species	27032041	1	27032041	1327.488**	2.62E-73	3.908741
Loading	1893073	2	946536.7	47.64663**	1.32E-16	3.058928
Interaction (sp x m.c)	303023.8	4	75755.94	3.720218**	0.006562	2.436317
Error	2850863	138	20363.31			
Total	32141824	149				

** Significant ^{NS} Non Significant

Table 4.31: Regression equations for mechanical properties of *Irvingia gabonensis* seed

Properties	Loading direction	Equations	R^2
Rupture force (N)	Longitudinal	$42.282M^2 - 303.6M + 950.97$	0.9868
	Axial	$33.968M^2 - 232.4M + 790.12$	0.9639
	Transverse	$41.881M^2 - 258.8M + 667.59$	0.9475
Deformation (mm)	Longitudinal	$0.289M + 0.913$	0.9605
	Axial	$0.350M + 1.052$	0.9669
	Transverse	$0.400M + 1.704$	0.9832
Failure stress (Nmm^{-2})	Longitudinal	$-1.1289M^2 – 51.31M + 652.2$	0.9297
	Axial	$10.247M^2 - 102.97M + 699.02$	0.9748
	Transverse	$38.312M^2 - 386.06M + 1697.40$	0.9414
Modulus of stiffness (Nmm^{-1})	Longitudinal	$50.341M^2 - 398.34M + 961.80$	0.9630
	Axial	$26.385M^2 - 218.03M + 606.37$	0.9994
	Transverse	$16.866M^2 - 124.13M + 314.31$	0.9633
Modulus of elasticity (Nmm^{-2})	Longitudinal	$4148.5M + 3863.10$	0.9672
	Axial	$2481.6M + 5346.80$	0.9587
	Transverse	$2966.5M + 2209.50$	0.9261

M = moisture content, % d.b

Table 4.32: Regression equations for mechanical properties of *Irvingia wombolu* seed

Properties	Loading direction	Equations	R^2
Rupture force	Longitudinal	$98.605M^2 - 680.86x + 2434.7$	0.8578
	Axial	$45.651M^2 - 306.35x + 1725.9$	0.7312
	Transverse	$63.119M^2 - 423.41x + 1661.0$	0.7955
Deformation (mm)	Longitudinal	$0.366M + 1.530$	0.9671
	Axial	$0.395M +2.265$	0.9506
	Transverse	$0.362M + 2.860$	0.9220
Failure stress (Nmm^{-2})	Longitudinal	$-11.055M^2 – 75.743M + 1695.1$	0.9967
	Axial	$2.7643M^2 – 72.216M + 1701.5$	0.9981
	Transverse	$-135.84M^2 – 539.88M + 2560.8$	0.8806
Modulus of stiffness (Nmm^{-1})	Longitudinal	$48.929M^2 – 419.95M + 1319.9$	0.9577
	Axial	$22.569M^2 – 194.31M + 729.39$	0.9595
	Transverse	$13.121M^2 – 116.69M + 488.03$	0.9590
Modulus of elasticity (Nmm^{-2})	Longitudinal	$2830.4M + 14097$	0.9832
	Axial	$31972M + 10174$	0.9030
	Transverse	$2946.4M + 97668$	0.9014

M = moisture content, % d.b

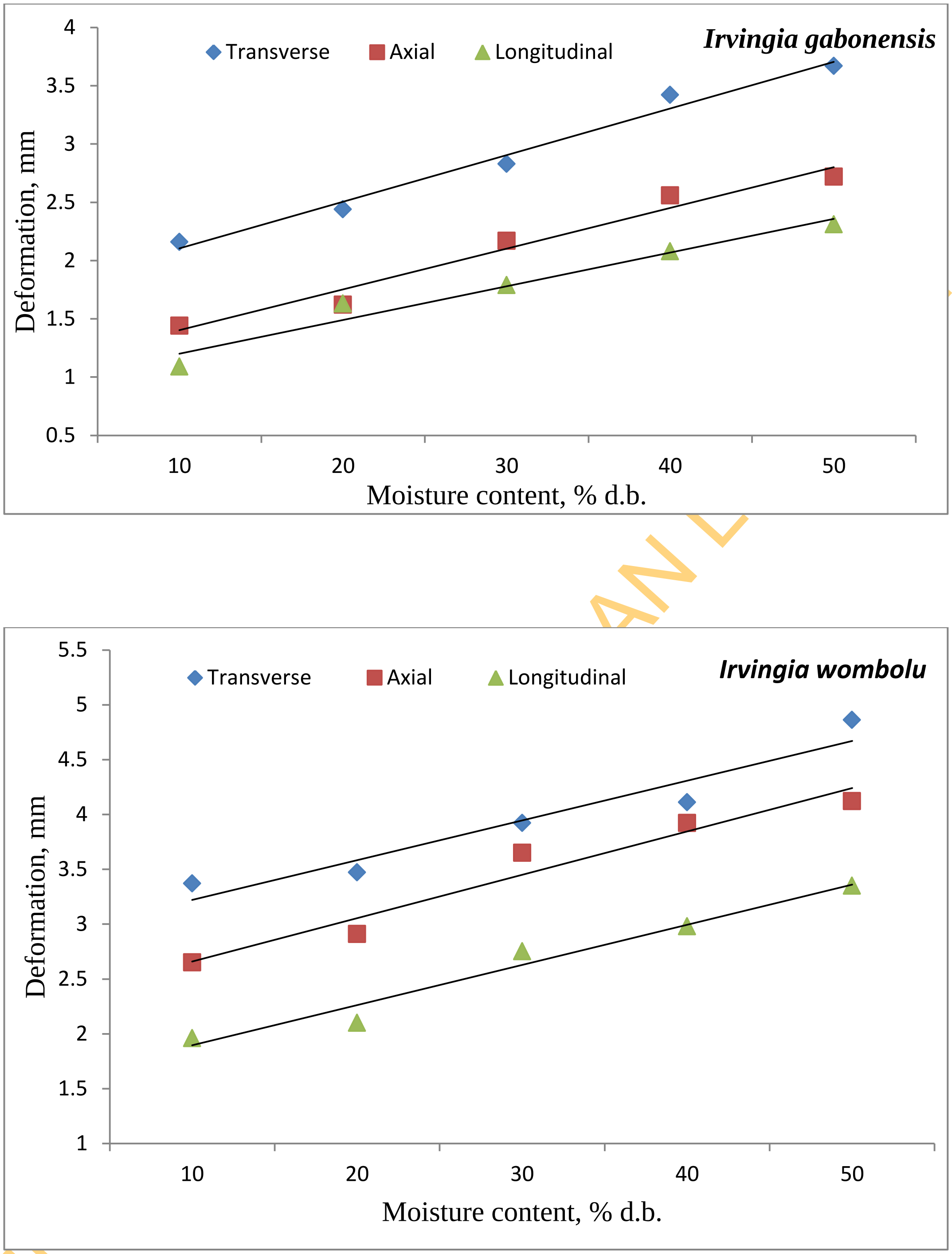


Fig 4.15: Variation in deformation of bush mango seed in three loading directions

The deformation of the seed was significantly affected by moisture content for the two species in the three directions of loading. Species of the bush mango had significant ($p<0.05$) effect on the deformation of the seed at the five levels of moisture content in the three loading directions as presented in Table 4.33.

The deformation of *Irvingia wombolu* was higher than those of *Irvingia gabonensis* and was significantly different at all the moisture levels in the three directions of loadings (Appendix E).

The loading directions of the seed significantly affect the deformation of seed for the species at the five levels of moisture content for as presented in Table 4.33. The transverse direction of loading had the highest deformation followed by the axial and lastly the longitudinal direction. The reason for this is that, when the seed were compressed in the transverse direction, they absorbed more energy before reaching the rupture point compared to the other two direction of loading and consequently experienced greatest deformation. The deformation of seed in the three directions can be estimated from the equations in Tables 4.31 and 4.32.

4.9.3: Failure stress

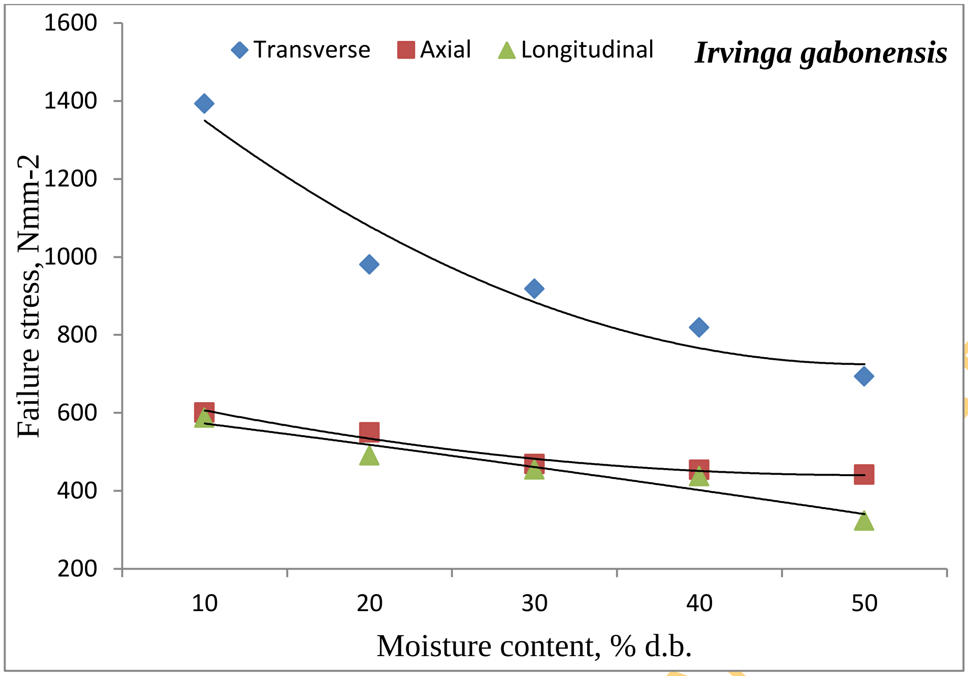
The failure stress otherwise called the yield stress at which the seed coat fails under of the applied load. The results obtained reveals that the failure stress of the seed decreased with increase in moisture content for the two species in the three directions of loading as shown in Figure 4.16. Based on these results, it is clear to note that more stress is used to initiate seed coat rupture of bush mango in the longitudinal direction of loading. Similar results were reported by Burubai *et al*. (2008) for African nutmeg and Mamman and Umar, (2005) for balanites aegyptiaca nuts.

The failure stress was significantly different at the five levels of moisture content for the two species in the three directions of loading. The failure stress was significantly affected by moisture for the two species in the three directions of loading. The change in the failure stress was parabolic in nature for the two species in the transverse direction of loading (Figure 4.16). The species of bush mango had significant effect on the failure stress of the seed in the three direction of loading at the various moisture content (Table 4.34).

Table 4.33: Analysis of variance for effect of moisture, species and loading directions on deformation of seed

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Moisture content	59.04191	4	14.76048	89.59355**	1.29E-37	2.436317
Species	41.56454	1	41.56454	252.2896**	3.97E-33	3.908741
Orientation	34.98232	2	17.49116	53.84766**	3.46E-18	3.058928
Interaction (Sp x m.c)	1.746556	4	0.436639	2.650323**	0.035795	2.436317
Within	46.77506	138	0.324827			
Total	125.4179	149				

** Significant ^{NS} Non Significant



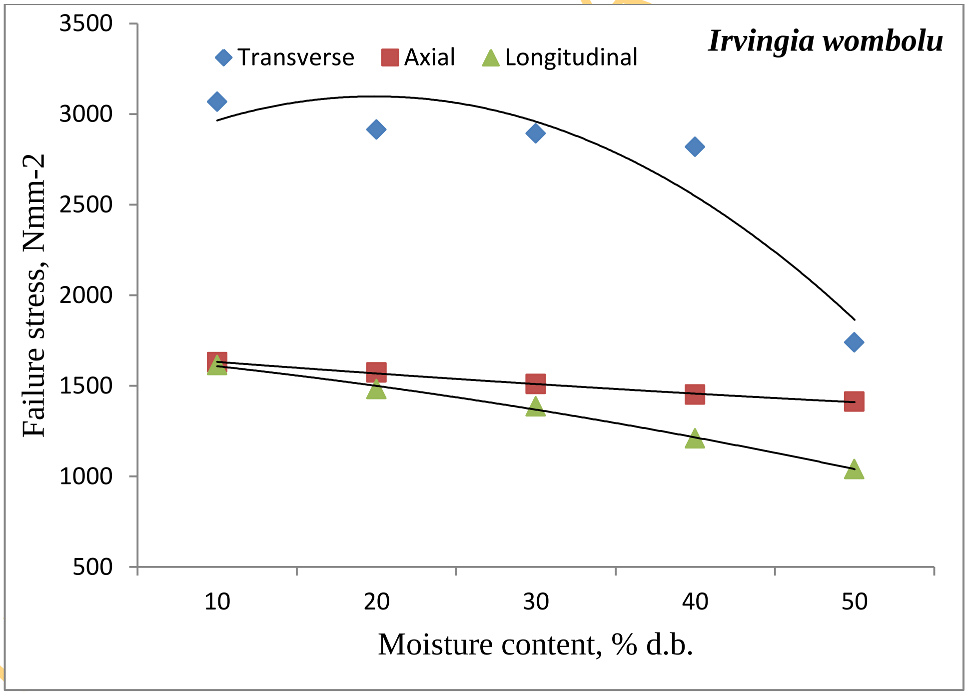


Fig 4.16: Variation in Failure stress of bush mango seed in three loading directions

Table 4.34: Analysis of variance for effect of moisture, species and loading direction on failure stress of seed

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Moisture content	18801296	4	4700324	38.88937**	7.28E-22	2.436317
Species	54769667	1	54769667	453.1513**	9.84E-46	3.908741
Orientation	25302592	2	12651296	194.777**	1.11E-41	3.058928
Interaction (Sp x m.c)	4074225	4	1018556	8.427294**	4.03E-06	2.436317
Error	16920957	138	120864			
Total	94566145	149				

** Significant ^{NS} Non Significant

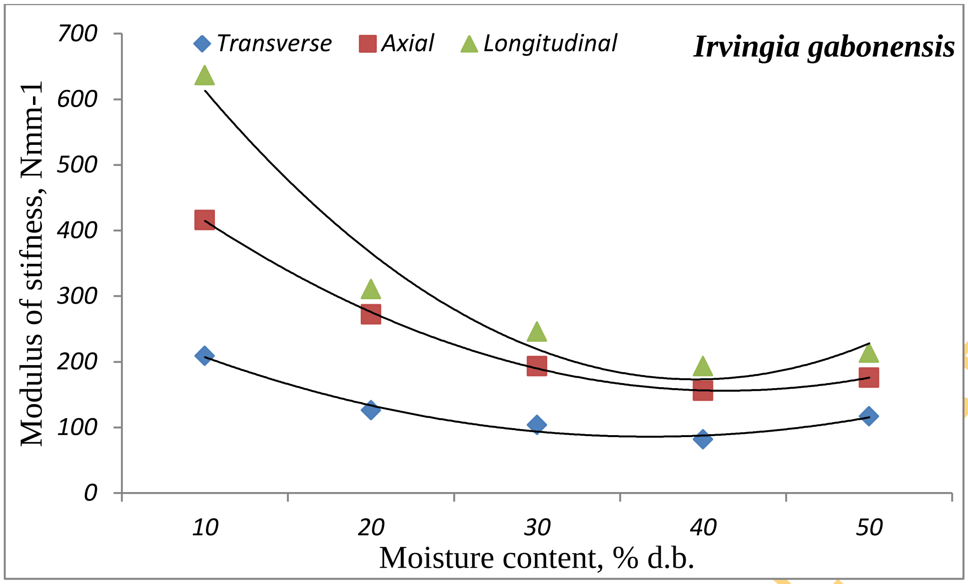
The failure stress was significantly affected by the direction of loading of bush mango seed (Table 4.34). The failure stress of *Irvingia wombolu* seed were significantly higher than those of Irvingia *gabonensis* seed in the three directions of loading (Appendix E). The failure stress was highest in the longitudinal direction,followed by the axial and transverse direction respectively (Figure 4.16).

Based on this result, it is clear to note that more stress is used to initiate seed coat rupture of the bush mango seed in the longitudinal direction. These results were consistent with the findings of Mamman and Umar (2005) for balanites aegyptiaca nuts. The failure stress decreased linearly in the longitudinal and axial directions while it decreased in parabolic form in the transverse direction for the two species. The estimate equations are given in Tables 4.31 and 4.32.

4.9.4: Stiffness Modulus /firmness

The modulus of stiffness of the seed decreased to a minimum value when the moisture content was increased from 10 to 40% (d.b) and later increased as moisture increased to 50% (d.b) as observed Figure 4.17. The reason for this trend is that as the seed absorbed moisture, it became structurally weak and firmness under this condition was reduced. With further increase in moisture, the kernel swelled up and filled up the shell and hence, firmness rose again. Olaniyan and Oje, (2002) made similar observation for Shea nut.

The modulus of stiffness was significantly different at all the levels of moisture content in the three directions of loading. Moisture content of the bush mango seed significantly ($p<0.05$) affect the modulus of stiffness of the seed for the two species in the three direction of loading (Table 4.35). The change in the modulus of stiffness was significantly parabolic in the three direction of loading. Modulus of stiffness of the bush mango seed was significantly affected by species of bush mango in the three direction of loading for the two species. The modulus of stiffness of the seed was not significant affected by the direction of loading of the seed and the interaction between species and moisture content at the five levels of moisture content (Table 4.35).



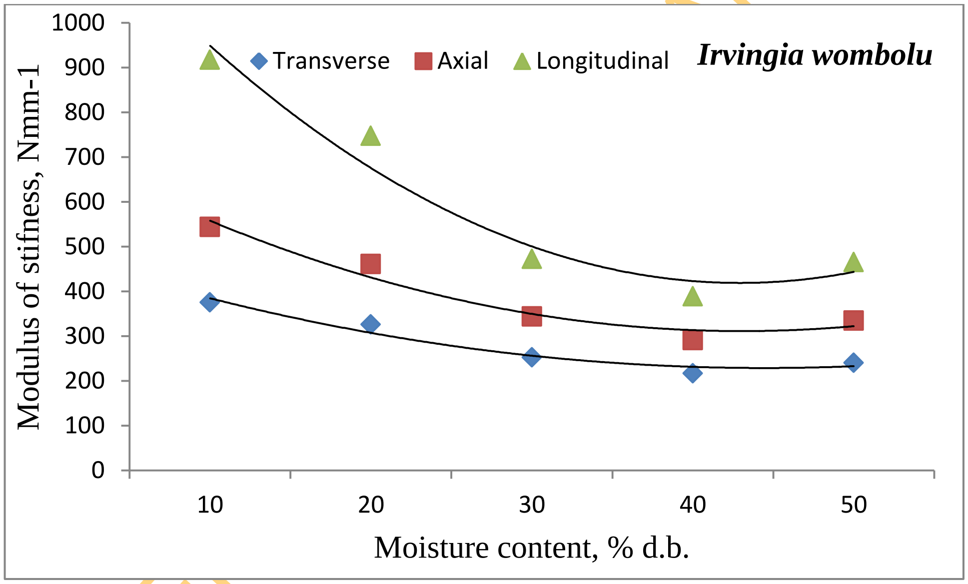


Fig 4.17: Variation in stiffness of bush mango seed in three loading directions

Table 4.35: Analysis of variance for effect of moisture, species and loading directions on stiffness

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Moisture content	431651.6	4	107912.9	13.11973**	4.22E-09	2.436317
Species	1379714	1	1379714	167.7414**	1.03E-25	3.908741
Orientation	43935.75	2	21967.87	2.030205^{NS}	0.13505	3.058928
Interaction (Sp x m.c)	52607.02	4	13151.75	1.598951^{NS}	0.177947	2.436317
Error	1151534	140	8225.24			
Total	3015506	149				

** Significant ^{NS} Non Significant

The modulus of stiffness of *Irvingia wombolu* were significantly ($p<0.05$) higher than those of *Irvingia gabonensis* in the three direction of loading at the five levels of moisture content (Appendix E). The modulus of stiffness was highest in the longitudinal loading direction as shown in Figure 4.17. The high value in this direction could be attributed to the fact that, when the seed was compressed in the longitudinal direction, the area in contact with the compression plate was smallest compared to the other loading direction.

Thus, the seed experienced just slight deformation before rupture and, hence, the ratio of force to deformation at rupture point (firmness) was highest in the longitudinal loading direction. Equation predicting the firmness can be found in Tables 4.31 and 4.32.

4.9.5 Young modulus of bush mango seed

This is a measure of rigidity of the specimen or in other words a measure of how easily the seed coat of bush mango can be deformed. Young modulus of elasticity of seed increased with increase in moisture content for the two species of bush mango in the three directions of loading as presented in Figure 4.18. The increments were also linear for the two species in the three direction of loading (Figure 4.18). Similar linear relationship between Young's modulus and moisture content was reported for kiwifruit (Seyed and Maryam, 2007) and cashew nut (Bart-Plange *et al*., 2012). However contrary was reported for African nutmeg (Burubai *et al*., 2008).

The Young modulus of the seed was significantly different at the five levels of moisture for the two species. The moisture content of the seed significantly affects the Young modulus of elasticity in the three direction of loading as observed in Table 4.36. The effect of species of bush mango was significance on the Young modulus of elasticity of the seed. On the other hand, Young modulus of elasticity of was not significantly affected in the three directions of loading. The longitudinal direction of loading had the highest, followed by the axial and transverse respectively with *Irvingia wombolu* higher than *Irvingia gabonensis* (Appendix E). The Young modulus of elasticity can be predicted from equations in Tables 4.31 and 4.32.

The parametric models for the mechanical properties determined for the two species are shown in Table 4.37 and Appendix E.

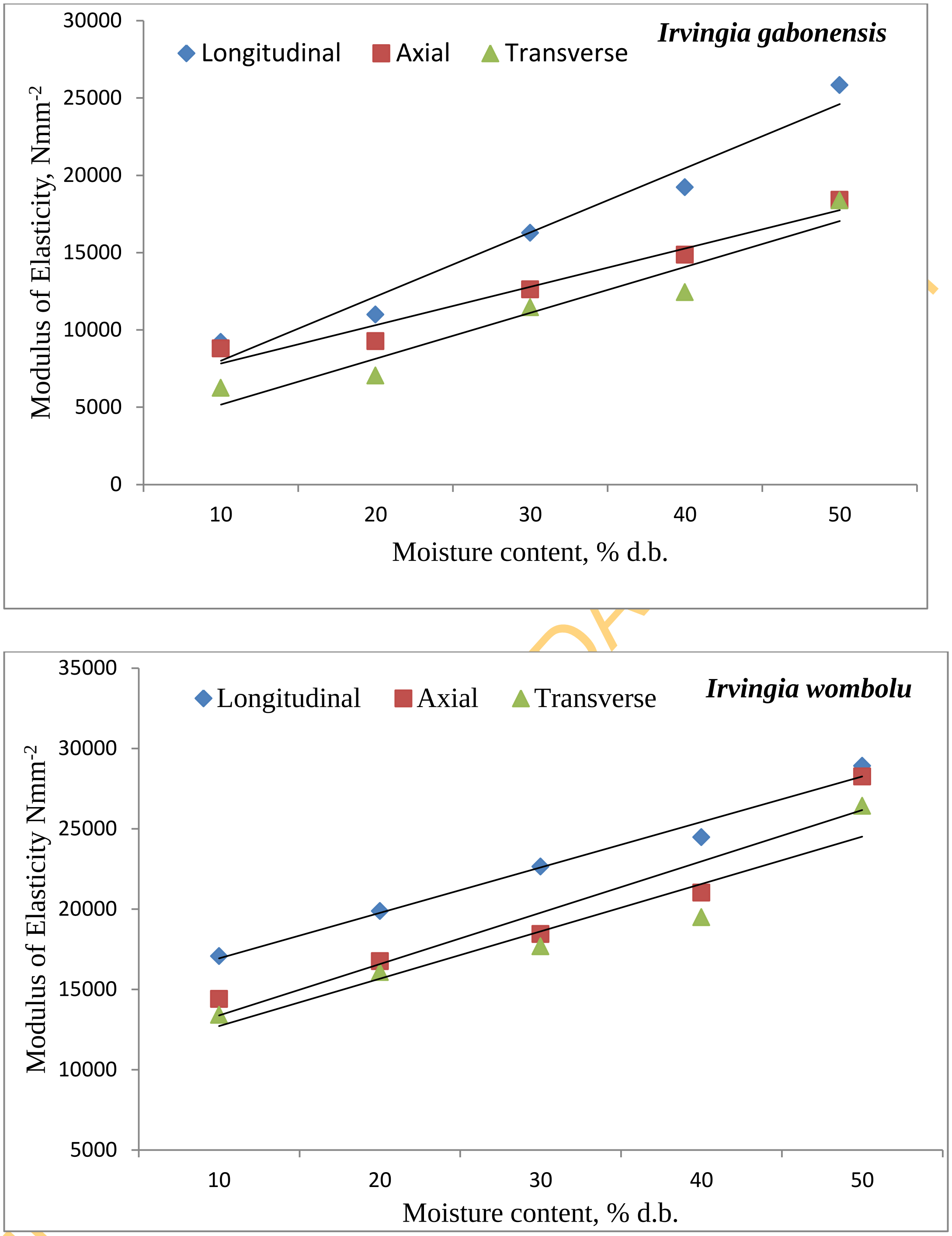


Fig 4.18: Variation in Young's modulus of bush mango seed in three loading directions

Table 4.36: Analysis of variance for effect of moisture, species and loading direction on Young's modulus of seed

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Moisture content	9.51E+08	4	2.38E+08	12.61946**	8.53E-09	2.436317
Species	1.79E+09	1	1.79E+09	95.20246**	1.77E-17	3.908741
Orientation	74718297	2	37359149	1.509896^{NS}	0.22441	3.058928
Interaction (Sp x m.c)	2.63E+08	4	65841219	3.493716**	0.009418	2.436317
Error	2.64E+09	140	18845613			
Total	5.65E+09	149				

** Significant ^{NS} Non Significant

Table 4.37: Parametric equations for mechanical properties of bush mango seed

(a) Transverse

Species	Equations	R^2
Irvingia gabonensis	$MC = 0.0195 - 0.5*10^{-4}RF + 0.0150DF - 0.3599*10^{-4}FS + 0.3305*10^{-4}MOS + 0.6949*10^{-7}MOE$	0.9815
Irvingia wombolu	$MC = 0.0351 + 0.9644*10^{-6}RF + 0.0047DF - 0.1737*10^{-4}FS - 0.3078*10^{-4}MOS + 0.9218*10^{-6}MOE$	0.9675

(b) Longitudinal

Species	Equations	R^2
Irvingia gabonensis	$MC = 0.0697 - 0.801*10^{-5}RF + 0.0013DF - 0.1226*10^{-4}FS - 0.4908*10^{-4}MOS + 0.8380*10^{-6}MOE$	0.9675
Irvingia wombolu	$MC = 0.0697 - 0.801*10^{-5}RF + 0.0013DF - 0.1226*10^{-4}FS - 0.4908*10^{-4}MOS + 0.8380*10^{-6}MOE$	0.9675

(c) Axial

Species	Equations	R^2
Irvingia gabonensis	$MC = 0.00509 + 0.9437*10^{-5}RF - 0.00329DF - 0.2760*10^{-5}FS - 0.1208*10^{-3}MOS + 0.2280*10^{-5}MOE$	0.9675
Irvingia wombolu	$MC = -0.0242 - 0.7200*10^{-5}RF + 0.0107DF - 0.1960*10^{-5}FS - 0.4908*10^{-4}MOS + 0.8380*10^{-6}MOE$	0.9675

RF = Rupture Force
DF = Deformation
FS = Failure Stress
MOS = Modulus of Stiffness
MOE = Modulus of Elasticity

4.10 Thermal properties of bush mango kernel

4.10.1 Thermal Conductivity of bush mango kernel

The thermal conductivity of the kernel increased as the moisture content was increase from 2.18 to 5.32% (d.b) for the two species as presented in Table 4.38. Similar trend was reported for thermal conductivity of cumin seed (Singh and Goswami, 2000), cowpea (Bart-Plange *et al*., 2009), shea-nut (Aviara *et al*., 2008), banana (Mariani *et al*., 2008) and cassava (Nwabanne, 2009). The thermal conductivity of bush mango kernel varied from 0.097 to 0.228 $Wm^{-1}K^{-1}$ depending upon the moisture content for the two species. The thermal conductivity of bush mango kernel was comparable with that of berberis fruit (0.132 to 0.4898 $Wm^{-1}K^{-1}$) at moisture content from 19.3 to 74.3% (w.b) (Mortaza *et al*., 2008), borage seed (0.11 to 0.28 $Wm^{-1}K^{-1}$) from moisture content 1.2 to 30.3% (w.b) (Yang *et al*., 2002) and cashew kernel (0.210 to 0.230 $Wm^{-1}K^{-1}$) at moisture from 5.0 to 9.0% (w.b.) (Bart-Plange *et al*., 2012). However, Kurozawa *et al*. (2008) found thermal conductivity of cashew apple to increase from 0.57 to 0.61 $Wm^{-1}K^{-1}$ which was lower than that of bush mango kernel.

The values of thermal conductivity are the amount of heat flow through unit thickness of material over a unit area per unit time for unit temperature difference. Specific heat dictates the quantity of heat to be absorbed by a material, while thermal conductivity sets the rate of this addition. Biological materials are not homogenous and vary in cellular structure, composition and air content, therefore their thermal conduction is expected to be greater than non-biological materials as observed in bush mango. Thermal conductivity varies with chemical composition, physical structure, state of the substance and temperature. However, the thermal conductivity generated in this work can be applied in processes that involve heat transfer such as cooking, curing dehydration and storage. It is also effective and efficient in heat treatment of pest control or ease of germination.

Table 4.38: Variation in the thermal Properties of bush mango kernel

Species	Moisture content	Thermal conductivity ($Wm^{-1}K^{-1}$)	Specific heat Capacity ($JkgK^{-1}$)	Thermal diffusivity ($\times10^{-4}$ m^2s^{-1})
Irvingia gabonensis	2.18%	0.118^c	795.966^b	2.938^c
	3.65%	0.152^b	886.290^{ab}	3.679^b
	5.32%	0.173^a	979.414^a	4.135^a
Irvingia wombolu	2.18%	0.173^c	982.774^b	3.540^b
	3.65%	0.202^b	1091.964^b	4.018^{ab}
	5.32%	0.228^a	1266.564^a	4.246^a

^{a,b,c}*Mean values with the same superscripts are not significantly different at 0.05 level*

Irvingia wombolu had the highest values for the thermal conductivity at the three levels of moisture contents. The thermal conductivity was significantly different between 2.18 and 3.65% *Irvingia wombolu*. It was also significantly different between 3.65 and 5.32% for the two species. Moisture content of the kernel had significance effect on the thermal conductivity of the kernel (Table 4.39).

The analysis of variance (ANOVA) showed that the effect of species of bush mango on the thermal conductivity of the kernel was highly significant at ($p<0.05$) at the three moisture levels (Table 4.39). The interaction between species and moisture content was not significant on the thermal conductivity of the kernel.

The thermal conductivity of *Irvingia gabonensis* was higher than those of *Irvingia wombolu* at the three levels of moisture contents as observe in Appendix F. The thermal conductivity of the kernel can be predicted using equations in Table 4.40.

4.10.2 Specific heat capacity of bush mango kernel

The specific heat of bush mango kernel in the moisture range of 2.18 to 5.32% (d.b) varied from 795.97 to 1266.56 $Jkg^{-1}K^{-1}$ for the two species of the kernel (Table 4.37). These values are less than those of shea-nut kernel as reported by Aviara and Haque (2001) and for gros banana by Bart-Plange *et al*. (2012). The specific heat of bush mango kernel increased with increasing moisture content. The trend in specific heat correlates well with other research works. Yang *et al*. (2002) reported increase in specific heat for cumin seed with increase in moisture content. Other researchers also reported similar results: Singh and Goswami (2000) for cumin seed; Tansakul and Lumyong (2008) for straw mushroom; Aviara and Haque (2001) for shea-nut kernel; Nwabanne (2009) for fermented ground cassava and Aviara *et al*. (2008) for guna seed.

Specific heat is the amount of heat required to raise the temperature of a unit mass of grain by 1 ^{o}C. It is important in aeration, drying and milling of grain. It has to do with variation in temperature with the amount of heat stored within the substance, therefore essential in cooling.

Table 4.39: Analysis of variance for effect moisture on thermal conductivity of kernel

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Moisture content	0.015334	2	0.007667	61.45644**	3.61E-10	3.402826
Species	0.021424	1	0.021424	171.7239**	1.98E-12	4.259677
Interaction (Sp x m.c)	4.93E-05	2	2.46E-05	0.197423^{NS}	0.822163	3.402826
Error	0.002994	24	0.000125			
Total	0.039802	29				

** Significant ^{NS} Non significant

Table 4.40: Regression equations for thermal properties of bush mango kernel

	Species			
	Irvingia gabonensis		Irvingia wombolu	
Properties	Equations	R^2	Equations	R^2
Thermal conductivity	0.0277M + 0.0921	0.9811	0.0274M + 0.1462	0.9930
Specific heat	91.724M + 703.78	0.9950	141.89M + 829.98	0.9826
Thermal diffussivity	0.5980M + 2.3877	0.9815	0.3526M + 3.2295	0.9598

M = moisture content, % d.b

The specific heat was significantly different ($p<0.05$) for the species at the three levels of moisture content. The ANOVA for the effect of moisture content on the specific heat revealed that it was highly significant (Table 4.41). The specific heat of bush mango kernel was significantly ($p<0.05$) influenced by the species of the bush mango. The specific heat of *Irvingia wombolu* was significantly higher than *Irvingia gabonensis* at 2.18, 3.65 and 5.32% (Appendix E).

The interaction between the moisture content and species of bush mango did not have significant effect on the specific heat of the kernel. The regression equations in Table 4.40 showed the increment in specific heat with increase in moisture is linear.

4.10.3 Thermal diffusivity of bush mango kernel

The thermal diffusivity of the kernel increased as the moisture content was increased from 2.18 to 5.32% (d.b) for the two species as presented in Table 4.38. *Irvingia wombolu* had the highest values for the thermal diffussivity at the three levels of moisture contents. The thermal diffusivity of bush mango kernel varied from 2.335 to 4.337 x $10^{-4}m^2s^{-1}$ depending upon the moisture content for the two species. The thermal diffussivity of the kernel increased linearly with moisture content as presented in Table 4.38. Aviara and Haque (2001), Hombani and Al-Askar (2000) and Tansakul and Lumyong (2008), reported a linear relationship between thermal diffusivity and moisture content for shea-nut, straw mushroom and dates. On the contrary, Singh and Goswami (2000), reported nonlinear relationship between thermal diffusivity and moisture content of cumin seed.

Thermal diffusivity is the rate at which heat diffuses out of a material. It is a quantity which measures the rate of temperature change and indicates the speed at which equilibrium will be reached. Thermal diffusivity varies with chemical composition, physical structure, state of the substance and temperature. In order to predict heat transfer in food grain and determine the fluctuation in external and internal temperature of stored grain, thermal diffusivity becomes essential. Therefore, this work shows that *Irvingia wombolu* will dry faster than *Irvingia gabonensis.*

Table 4.41: Analysis of variance for effect moisture on specific heat of kernel

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Moisture content	274827.8	2	137413.9	18.89379**	1.18E-05	3.402826
Species	384916.4	1	384916.4	52.92427**	1.63E-07	4.259677
Interaction (Sp x m.c)	14218.98	2	7109.492	0.977523^{NS}	0.390727	3.402826
Error	174551.2	24	7272.965			
Total	848514.3	29				

** Significant ^{NS} Non significant

The thermal diffusivity was significantly different between 2.18 and 3.65% and 3.65 and 5.32% for *Irvingia gabonensis* while it was not significantly different at the three moisture levels for *Irvingia wombolu*. The analysis of variance (ANOVA) showed that the effect of species of bush mango and moisture content on the thermal diffusivity of the kernel were highly significant at ($p<0.05$) as observed in Table 4.42. The interaction between the species and moisture content was however non-significant. The thermal diffusivity of *Irvingia wombolu* was higher than that of *Irvingia gabonensis* at the three levels of moisture contents (Appendix E).

The regression equations predicting the thermal diffusivity of bush mango kernel are presented in Table 4.40. The parametric model of the thermal properties of bush mango kernel is given in Table 4.43 for the two species with detail in Appendix F. The correlation of the two species of bush mango kernel's thermal properties with moisture content showed they have 50% positive correlation as observed in Table 4.44.

Table 4.42: Analysis of variance for effect moisture on thermal diffussivity of kernel

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Moisture content	4.64E-08	2	2.32E-08	20.42621**	6.6E-06	3.402826
Species	9.24E-09	1	9.24E-09	8.142057**	0.008767	4.259677
Interaction (Sp x m.c)	3.02E-09	2	1.51E-09	1.328345^{NS}	0.283701	3.402826
Error	2.72E-08	24	1.14E-09			
Total	8.59E-08	29				

**significant ^{NS} Non significant

Table 4.43: Parametric equations for thermal properties of mango kernel

Species	Equations	R^2
Irvingia gabonensis	$MC = 0.2062 + 0.556TC - 0.1266*10^{-3}SH - 355.4707TD$	0.9653
Irvingia wombolu	$MC = 0.2119 + 1.1316TC - 0.1818*10^{-3}SH - 503.6757TD$	0.9683

MC = Moisture Content
TC = Thermal Conductivity
SH = Specific Heat
TD = Thermal Diffussivity

Table 4.44: Correlation Analysis for thermal properties bush mango kernel

	Species							
	Irvingia gabonensis				*Irvingia wombolu*			
Variables	MC	TC	SH	TD	MC	TC	SH	TD
MC	1.0000	-0.9461	-0.8351	-0.6586	1.0000	-0.9084	-0.7758	-0.9208
		<.0001	<.0001	0.0030		<.0001	0.0003	<.0001
TC	-0.9461	1.0000	0.7337	0.7959	-0.9084	1.0000	0.8711	0.9241
	<.0001		0.0005	<.0001	<.0001		<.0001	<.0001
SH	-0.8351	0.7337	1.0000	0.1853	-0.7758	0.8711	1.0000	0.6405
	<.0001	0.0005		0.4616	0.0003	<.0001		0.0056
TD	-0.6586	0.7959	0.1853	1.0000	-0.9208	0.9241	0.6405	1.0000
	0.0030	<.0001	0.4616		<.0001	<.0001	0.0056	

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The reason for this thesis is to create data on the required parameters needed for the design of engineering processing, handling and storage equipment for the two species of bush mango commonly utilized in Nigeria. In order to do this, the physical, friction, mechanical and thermal properties of the two species of bush mango seed and kernel with respect to moisture content were taken into consideration.

5.1.1 Physical Properties

The linear dimensions are very important in the selection of sieve or screen size in the design of separating, dehulling and decorticating equipment and in the sizing of the hopper.

The geometric mean diameter of bush mango seed decreased as the moisture content is increased while that of the kernel increased. The geometric mean diameters of the seed and kernel were significantly affected by moisture content and species of the bush mango. The sphericity of the bush mango seed was significantly affected by moisture content and species of the bush mango. The bush mango kernel sphericity was not significantly affected by species and interaction between moisture and species but was significantly by moisture content. The weight of bush mango seed and kernel were significantly affected by the species, moisture content and interaction between moisture content and species of the bush mango. The linear dimensions of *Irvingia wombolu* were significantly greater than those of *Irvingia gabonensis*.

The true density of the seed and kernel increased with increase in moisture content. Species of the bush mango significantly affected the true density of the seed and kernel. The true density of the seed was significantly affected by moisture content while that of the kernel was not significantly affected. The bulk density of the bush mango seed and kernel were significantly affected by moisture content, species and interaction between species of the bush mango and moisture content. The true density of *Irvingia wombolu* seed and kernel were significantly more than those *Irvingia gabonensis*.

Moisture content and species of the bush mango had significant effect on the porosity of seed. The porosity of the kernel was significantly affected by the species of bush mango while it was not significantly affected by moisture content.

5.1.2 Friction Properties

The angle of repose was determined on three structural surfaces for the seed and kernel. The angle of repose of bush mango seed and kernel increased with increase in moisture content for the two species on the three structural surfaces. Species of the bush mango significantly affected the angle of repose of the seed on mild steel and plywood while it was significant only on glass surface for the kernel. However, moisture content significantly influenced the angle of repose of the seed and kernel on all the three structural surfaces. *Irvingia gabonensis* angle of repose was significantly higher than that of *Irvingia wombolu* for the kernel while *Irvingia wombolu* was higher in the case of the seed.

The coefficient of static friction was measured on five structural surfaces for the seed and kernel. The coefficient of static friction of the bush mango seed and kernel on the five structural surfaces increased with increase in moisture. The coefficient of static friction was highest on plywood for both the seed and kernel at the studied moisture content. However glass had the least for the seed while stainless steel had the least for the kernel. The coefficient of static friction was significantly affected by species and moisture content on all the structural surfaces except galvanized steel surface for the seed. The kernel's coefficient of static friction was however significantly affected on glass, stainless and mild steels.

5.1.3 Mechanical properties

The rupture force, failure stress and stiffness decreased with increase in moisture content in the three directions o f loading. The deformation and modulus of elasticity on the other hand increased with increase in moisture content.The rupture force, failure stress, modulus of stiffness and Young modulus of elasticity were highest in the longitudinal direction while deformation was highest in the transverse direction for the species. The mechanical properties of the bush mango seed were significantly affected by moisture content and species of the bush mango in the three loading direction. The rupture force, failure stress and deformation were significantly affected by direction of loading while stiffness and modulus of elasticity were not affected. The mechanical properties of *Irvingia wombolu* seed were significantly higher than those of *Irvingia gabonensis*.

5.1.4 Thermal Properties

The three thermal properties measured that is specific heat, thermal conductivity and diffusivity all increased with increase in moisture content for the two species. The moisture content and species of the bush mango significantly affected the thermal properties. The thermal conductivity, specific heat and thermal diffusivity of the *Irvingia wombolu* kernel were significantly higher than that of *Irvingia gabonensis*. The thermal properties of the bush mango kernel were significantly different at the three levels of moisture content for each of the species.

5.2 Contribution to Knowledge

In order to reduce drudgery associated with the cracking of bush mango seed and also encourage large scale production of its kernel, knowledge of its mechanical properties in relation to moisture content and loading directions must be sort out. At higher moisture content, there was tendency of the kernel to swell up and fill clearance between it and the shell; therefore the whole seed behave like a structurally turgid material. Therefore failure parameters should be the basis for the choice of cracking principles for bush mango seed. As observed from earlier discussions, energy required to obtain this cracking can be greatly reduced if the seeds were cracked at lower moisture content. Also least energy was required in cracking the seed when they were cracked in the transverse loading direction. Therefore, these parameters should be taken into consideration when forming a cracking principle for bush mango seed.

There may be practical difficulties in any machine design which involves combining these factors and energy required for cracking. What is important is for the cracking to be obtained at minimum energy and with minimum effort used to position the seeds during loading. A machine based on the results of this study can be seen as a means of mechanizing the existing manual (use of stone) method where cracking is by impact or instantaneous compression.

5.3 Recomendations

The risks of danage cracking of the kernel during storage and processing is high. Therefore, the mechanical properties of the kernel should be determined. Also the thermal properties of the kernel should be determined in relation to temperture.

REFERENCES.

Abalone, R., Cassineva, A., Easton, A. and Lava, M. A. 2004. Some physical properties of amaranth seeds. *Biosystems Engineering* 89.1: 109-117.

Adamson, I., Okafor, C. and Abu-Bakare, A. 1986. Erythrocyte membrane ATPases in diabetes: effect of dikanut (Irvingia gabonensis). *Enzyme* 36.3: 212-215.

Agbetoye, A. S., Oladele, P., Kolawole, L. and Ogunlowo M. 2007. Strength and elasticity properties of cassava tuber. *International Journal of Food Engineering* 17.3: 13-18.

Agbor, L.O.N. 1994. Marketing trends and potential for *Irvingia gabonesis*, products in Nigeria. Proceedings of ICRAF-IITA Conf. *Irvingia gabonesis*, May 3-5, Ibadan, Nigeria,.

Ahmadi, H., Fathollahzadeh, H. and Mobil, H. 2009. Post harvest physical and mechanical properties of Apricot fruits, pits and kernels (C.V. Sonnati salmas) cultivated in Iran. *Pakistan Journal of Nutrition* 8: 264-268.

Akaaimo, D. I. and Raji A. O. 2006. Some physical and engineering properties of prosopis africana seed. *Biosystem Engineering* 95.2: 197-205.

Akar, R. and Ayind, C. 2005. Some physical properties of gumbo fruits varieties. *Journal of Food Engineering* 66: 387-393.

Akinci, I., Ozdemir, F., Topuz, A., Kabas, O. and Canakci, M. 2004. Some physical and nutritional properties of juniperus drupacca fruits. *Journal of Food Engineering* 65: 325-331.

Alagusundaram, K., Jayas, D. S., Muir, W. E. and White, N. D. 1991. Thermal conductivity of bulk barley, lentils and peas. Transaction of the ASAE 34.4: 1784-1788.

Ali, N. L. 2012. Some physical properties of caper. *Journal of Agricultural Technology* 8.4: 1199-1206.

Al-Mahaseneh, M. A. and Rababah, T. M. 2007. Effect of moisture content on some physical properties of green wheat. *Journal of Food Engineering* 79: 1467-1473.

Altuntas, E. and Yildiz, M. 2007. Effect of moisture content on some physical and mechanical properties of faba bean (*Viciafaba* L.) grains. *Journal of food Engineering Research* 78: 174-183.

Amin, M. N., Hossain, M. A. and Roy, K. C. 2004. Effect of moisture content on some physical properties of lentil seeds. *Journal of Food Engineering* 65: 83-87.

Anegbeh, P. O., Usoro C., Ukafor, V., Tchoundjeu, Z., Leakey, R. R. B and Schreckenberg, K. 2003. Domestication of *Irvingia gabonesis* phenotypic variation of fruits and kernels in a Nigeria Village. *Agroforest system* 58.3: 213-218.

ASAE Standards, 2002. Moisture measurement – ungrounded grain and seeds: American Society of Agricultural Engineers S352.2 St. Joseph Michigan, USA, Agricultural Engineers year book.

Asoegwu, S. N., Ohanyere, S., Kanu, O. and Iwueke, C.,2006. Physical properties of African oil bean seed (*Penta-clothra* macrophylla). *Agricultural Engineering International:* the *CIGR Ejournal* 8: 5-6.

Atangana, A. R., Ukafor, V., Anegbeh, P., Asaah, E., Tchoundjeu, Z., Fondoun, J. M., Ndoumbe, M and Leakey, R. R. B. 2002. Domestication of *1rvingia gabonensis*. The selection of multiple traits for potential cultivars from Cameroon and Nigeria. *Agroforestry system* 5.3: 221-229.

Atiku, A., Aviara, N. And Haque, M. 2004. Performance evaluation of a bambara groundnut sheller. *Agricultural Engineering International*: *CIGR Journal of Scientific Research and Development* 6: 2-4

Aviara, N. A. and Haque M. A. 2001. Moisture dependence of thermel properties of sheanut kernel. *Journal of Food Engineering* 47:109–113.

Aviara, N. A., Haque, M. A. and Ogunjimi L. A. 2008. Thermal properties of guna seed. *International Agrophysics* 22:291-297.

Aviara, N. A., Ibrahim, E. B. and Onuoha, L. N. 2014. Physical properties of *Brachystegia eurycoma* seeds as affected by moisture content. International Journal of Agricutural and Biological Engineering 7.1: 84-93.

Aviara, N. A., Oluwole, F. A. and Haque M. A. 2005b. Effect of moisture content on some physical properties of sheanut (Butyrosepernum). *International Agrophyics* 19: 193-198.

Aydin, C. 2003. Physical properties of almond nut and kernel. *Journal of Food Engineering* 60: 315-320.

Aydin, C. and Ozean, M. 2002. Some physico-mechanic properties of terebinth (*Pistacia terebinthus L*.) fruits. *Journal of Food Engineering* 53.1: 97- 101.

Ayuk, E. T., Duguna, B., Kengue, J., Mollet, M., Tiki-Manga, T. and Zenkeng, P. 1999. Uses, management and economic potential of *Irvingia gabonesis* in the humid lowlands of Cameroon. *Forest Ecology Management* 113.1: 1-9.

Bagvand, A. and Lorestani, N. A. 2013. Determination of physical properties and mechanical behavior of sunflower seeds. *International Journal of Agriculture and Crop Sciences* 5.11: 1255-1259.

Bart-Plange, A. and Baryeh, E. A. 2002. The physical properties of category B cocoa beans. *Journal of Food Engineering* 60: 219- 227.

Bart-Plange, A., Addo, A., Kumi, F. and Piegu, A. K. 2012. Some moisture dependent thermal properties of cashew kernel (Anarcadium occidentale L.). *Australian Journal of Agricultural Engineering* 3.2: 65-69.

Bart-Plange, A., Asare, V. and Addo, A. 2009. Thermal conductivity of maize and cowpea. Journal of Engineering and Technology 2.3: 6-11.

Bart-Plange, A., Dzisi, K. A. and Darko, J. O. 2005. Effects of moisture content on selected physical properties of two varieties of cowpea. Agricultural and Food Science Journal of Ghana 4: 329-340.

Baryeh, E. A. 2002. Physical properties of millet. *Journal of Agricultural Engineering Research* 51: 39-46.

Baryeh, E. A. And Mangape, B. K. 2002. Some physical properties of QP 38 variety pigeon pea. *Journal of Food Engineering* 56: 341 -347

Bello, M., Tolaba, M. P. and Suarez, C. 2004. Factors affecting water uptake of rice grain during soaking. *Lebesm. Wiss. Technology* 37: 811-816.

Burubai, M. A., Amula, E., Davies, R. M., Etepke, G.W. and Daworiye, S. P. 2008. Determination of poisson's ratio and modulus of African nutmeg (*Monodora myristicsa*). *International Agrophysics* 22: 99-102.

Burubai, W., Akor, A. J., Igoni, A. H. and Puyate, Y. T. 2007. Some physical properties of African nutmeg (*Monodora myristica*). *International Agrophysics* 21: 123-126.

Califano, A. N. and Calvelo, A. 1991. Thermal conductivity of potato between 50 and 100^{o}C. *Journal of Food Science* 56: 586–589.

Cetin, M. 2007. Physical properties of barbunia bean (*Phaseolus vulgaris* L. cv. 'Barbuniz') seed. *Journal of Food Engineering* 80: 353–358.

Chemperek, P. and Rydzak, I. 2006. Vacuum wetting of soyabean seeds and maize grains at different temperature and time conditions. *TEKA Kom. Mot. Energy Roln*. 6: 24-31.

Chukwu, O. and Sunmonu, M. O. 2010. Determination of selected engineering properties of cowpea (*Vigna unguicilata*) related to design of processing machines. *International Journal of Engineering and Technology* 2.6: 373-378.

Coskun, M. B., Yalçin, I. and Özarslan, C. 2005. Physical properties of sweet corn seed (*Zea mays saccharata* Sturt). *Journal of Food Engineering* 74.4: 523-528.

Davies, R. M. 2009. Engineering properties of three varieties of melon seeds as potentials for development of melon processing machines. *Advance Journal of Food Science and Technology* 2.1: 63-66.

Demir, F., Dogan, H., Ozean, M. and Haciseferogullari, H. 2002. Nutritional and physical properties of hackberry (Celtis australis L.). Journal of Food Engineering 54: 241-247.

Dudu, P. O., Okiwelu, S. N. and Lale, N. E. S. 1998a. Attractancy of diethyl ether extracts of *Arachis hypogaea* (Linnaeus) (Papilionaceae), *Citrullus lanatus* (Thunberg) (Cucurbitaceae) and *Irvingia gabonensis var excelsa* (Baillon) (*Irvingiaceae*) to *Oryzaephilus mercator* (Fauvel) (Coleoptera: Silvanidae). *Journal of Stored Products Research* 34.4: 237-241.

Dudu, P. O., Okiwelu, S. N. and Lale, N. E. S. 1998b. Oviposition of *Oryzaephilus mercator* (Fauvel) (Coleoptera: Silvanidae) on *Arachis hypogaea* (Linnaeus) (Papilionaceae), *Citrullus lanatus* (Thunberg) (Cucurbitaceae) and *Irvingia gabonensis var excelsa* (Baillon) (*Irvingiaceae*). *Journal of Stored Products Research* 34.1: 37-44.

Dursun, E. and Dursun, I. 2005. Some physical properties of caper seed. *Biosystem Engineering* 92.2: 237-245.

Dursun, I., Dursun, E. and Tugrul, K. 2006. Some physical properties of sugar beet seeds. *Journal of Stored products Research* 5:149-155.

Ejifor, M.A.N. 1994. Nutritional values of Ogbono (*Irvingia gabonensis var. Excelsa*). Proceeding ICRAF-IITA Conference *Irvingia gabonensis*, May 3-5, Ibadan, Nigeria

Eke, C.N.U., Asoegwu, S.N. and Nwandikom, G.I. 2007. Physical properties of jackbean (Canavalia ensiformis). *Agricultural Engineering International CIGR E Journal* 9: 1-11.

Emadi, B., Abbaspour-Fard, M. H. and Yarlagadda P. K. 2009. Mechanical properties of melon measured by compression, solar and cutting modes. *International Journal of Food Properties* 12: 780-790.

Esref, I. and Halil, U. 2007. Moisture dependence of physical properties of white speckled red kidney bean grains. *Journal of Food Engineering* 82: 209-216.

Etebu, E. 2012. Postharvest pathology and phytochemicals of *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) fruits and wastes. *Journal of Agricultural Science Research* 2.6: 285-294.

Faleye T., Atere O. A., Oladipo O. N. and Agaja M. O. 2013. Determination of some physical and mechanical properties of some cowpea varieties. *African Journal of Agricultural Research* 8.49: 6485-6487.

Festus, C. and Nwala, L. 2012. Extraction and processing of Ogbono cotyledon for long shelf- life. *Academic Research International* 2.1: 139-145.

Gharibzahedi, S. M. T., Etemad, V., Mirarab-Razi, J. and Fos'hat, M. 2010. Study on some engineering attributes of pine nut (Pinuspinea) to design of processing equipment. *Journal of Agricultural Engineering Research* 56.3: 99-106.

Ghasemi, V. M., Mobli, H., Jafari, A., Keyhani, A. R., Heidari, S.M., Rafiee, S. and Kheiralipour, K. 2008. Some physical properties of rough rice (*Oryza Sativa*) grain. *Journal of Cereal Science* 47: 496-501.

Gursoy and Guzel, E. 2010. Determination of physical properties of some grains. *Research Journal of Applied Sciences, Engineering and Technology* 2.5:492

Harris, D. J. 1996. A revision of the *Irvingiaceae* in Africa. Bullentin du Jardin Botanique National de Beligique 65.1: 143-196.

Hauhouot-ihara, M., Criner, G. H., Brusewitz and Solie, J. B. 2000. Selected physical characteristics and aerodynamics properties of cheat seed for separation from wheat. *Agricultural Engineering International: The CIGR Journal* 2: 17-21.

Hombani, A. I. and Al-Askar, S. R. 2000. Effective thermal properties of dates. *Research Bulletin, Agricultural Research* Center, King Saud University. 92: 5-20

Ilori, T. A., Oradugba, O. B. and Raji, A. O. 2011. Physical properties of mexican sunflower seed. *International Agrophysics* 25: 1-4.

Irtwange, S. V. and Igbeka, J.C. 2002. Some physical properties of two african yam bean (Sphenostyls stenocarpa) accessions and their interrelations with moisture content. *Applied Engineering in Agriculture* 18.5: 567-576.

Igbozulike, A. O. and Aremu, A. K. 2009. Moisture dependent physical properties of Garcinia kola seeds. Journal of Agricultural Tec hnology 5.2: 239-248.

Isik, E. 2007. Some physical and mechanical properties of round red lentil grains. *Applied Engineering in Agriculture* 23.4: 503-509.

Isil, E. and Unal, H. 2007. Moisture dependent physical properties of white speckled red kidney bean grains. *Journal of Food Engineering* 82.2: 209-216.

Izil, N., Unal, H. and Sincik, M. 2009. Physical and mechanical properties of rapeseed at different moisture content cont ents. International Agrophysics 23: 137-145.

Isil, E. and Izil, N. 2007. Physical properties of sunflower seed (*Helianhus annus* L.). *International Journal of Agricultural Research* 2.8: 677-686.

Joseph, J. K. 1995. Physico-chemical attributes of wild mango (*Irvingia gabonensis*) seeds. *Bioresource Technology* 53.2: 179-181

Joseph, K. and Aworh, O. C. 1992. Postharvest treatment of wild mango (Irvingia gabonensis) for improved shelf life. *Food Chemistry 44: 45-48.*

Kabas, O., Yilmaz, E., Ozmerzi, A. and Akinci, I. 2007. Some physical and nutritional properties of cowpea seed (Vignasinensis L.). *Journal of Food Engineering* 79: 1405-1409.

Karababa, E. 2006. Physical properties of popcorn kernels. *Journal of Food Engineering* 72: 100-110.

Karimi, M., Kheiralipour, K., Tabatabaeefar, A., Khoubakht, G. M., Naderi, M. and Heidarbeigi, K. 2009. The effect of moisture content on physical properties of wheat. *Pakistan Journal of Nutrition* 8.1: 90-95

Kashaninejal, M. and Kashiri, M. 2007. Hydration kinetics and changes in some physical properties of wheat kernels. *Iranian Food Science and Technology Research Journal* 5: 55-73.

Kashaninejad, M., Mortazavi, A., Safekori, A. and Tabil, L.G. 2006. Some physical properties of pistachio (*Pistacia vera L.*). *Journal of Food Engineering* 72: 30-38.

Khodabakhshian, R. and Emadi, B. 2011. Determination of the modulus of elasticity in Agricultural seeds on the basis of elasticity theory. *Middle-East Journal of Scientific Research* 7.3: 367-373.

Khodabakhshian, R., Emadi, B. and Abbaspourfard, M. H. 2010. Gravimetrical properties of sunflower seeds and kernels. *World Applied Science Journal* 8.1: 119-128.

Kiani, D., Kiani, M., Minaei, S., Maghsoudi, H. and Gbasemi, V. M. 2008. Moisture dependent physical properties of red bean (*Phaseolus vulgaris* L.) grains. International Agrophysics 22: 231-237.

Kibar, H., Ozturk, T. and Esen, B. 2010. The effect of moisture content on physical and mechanical properties of rice (*Oryza sativa L.*). *Journal of Agricultural Research* 8.3: 741-749.

Kilickan, A., Ucer, N. and Yalcin, I. 2010. Some physical properties of spinach (Spinaciaoleracae L.) seed. *African Journal of Biotechnology* 9.5: 648-655.

Kingsley, A. R. P., Manikantan, M. R. and Jain, R. K. 2006. Moisture dependent physical properties of dried pomegranate seeds. *Journal of Food Engineering* 75: 492-496.

Koocheki, A., Razavi, S. M. A., Milani, E., Moghadan, T. M., Abedini, M., Alamatiyan, S. and Izadikhah S. 2007. Physical properties of water melon seed as a function of moisture content and variety. *International Agrophysics* 21: 349-359.

Kurozawa, L. W., Park, K. J. and Azonbel, P. M. 2008. Thermal conductivity and thermal diffusivity of papaya (*Carica papaya*, L.) and Cashew apple (*Anacardium occidentale*, L.). *Brazil Journal of Technology*. 11: 78-85.

Ladipo, D. O. and Boland, D. J. 1994. Trade in *Irvingia* kernels. In Ladipo, D. O. and Boland, D. J. (eds.): Proceedings of the international workshop on *Irvingia* in West Africa. International centre for Research in Agroforestry (ICRAF) Nairobi, Kenya.

Leakey R.R.B. and Tchoundjeu Z. 2001. Diversification of Tree crops: Domestication of companion crops for poverty reduction and enviromental services. *Experimental Agriculture* 37: 279-296.

Leakey R.R.B., Fondoun J.M., Atangana A. and Tchoundjeu Z. 2000. Quantitative descriptors of variation in the fruits and seeds of *Irvingia's*. *Agroforest systems* 50: 47-58.

Leakey, R. R. B., Greenwel, P., Hall, M. N., Atangan, A. R., Usoro, C., Anegbeh, P. O., Fondoun, J. M. and Tchoundjeu, Z. 2005. Domestication of Irvingia gabonesis: Tree-to-tree variation in food-thickening properties and in fat and protein content of dika nut. *Food Chemistry* 90.4: 365-378.

Lesley, L. and Brown, N. 2004 Bush Mango (*Irvingia gabonensis* and *I. wombolu*). In: Key Non-Timber Forest Products of Central Africa: State of the Knowledge (Eds Clark LE, Sunderland TCH): 15-45. *SD Publication Series*. USAID, Arlington.

Lowe, A. J., Gillies, C. M., Wilson J. and Dawson I. K. 2000. Conservation genetics of bush mango from central/west African implications from random amplified polymorphic DNA analysis. *Molecular Ecology* 9: 831-841.

Mahapatra, A. K., Patrick, C. and Diau, P. 2002. Effect of moisture content on some physical properties of sorghum (Mahube variety) seeds. *Journal* of *Agricultural Engineering* 11.1: 1-10.

Mamman, E. and Umar, B. 2005. Effect of moisture content and loading orientation on the mechanical properties of balanities aegyptiaca nuts. *Journal of Scientific Research* 7.2: 20-25.

Mariani, V. C., Barbosa de Lima, A. G. and Coelho, L. S. 2008. Apparent thermal diffusivity of the banana during drying using inverse method. *Journal of Food Engineering* 85.4:569-579.

Mohsenin, N. N. 1980. Thermal properties of Foods and Agricultural Materials. New York: Gordon and Breach.

Mohsenin, N. N. 1986. Physical Properties of Plant and Animal Materials. Structure, Physical Characteristics and Mechanical Properties. 2nd updated and revised ed. New York: Gordon and Breach.

Mortaza, A., Mohammad H. K. And Seyed B.H. 2008. specific heat and thermal conductivity of berberis fruit (*Berberis vulgaris*). *American Journal of Agricultural and Biological Sciences.* 3.1 : 330-336.

Ndoye, O., Ruiz-Perez, M. and Eyebe, A. 1998. The markets of non-timber forest products in the humid forest zone of Cameroon. Rural Development Forestry Network Paper 22c, ODI, London, United Kingdom.

Ngondi, J., Oben, J. and Minka, S. 2005. The effect of *Irvingia gabonensis* seeds on body weight and blood lipids of obese subjects in Cameroon. *Lipids Health Diseases* 4:12.

Nkwatoh, A. F., Labode, P., Iyassa, S. M. and Nkwatoh, F. W. 2010. Evaluation of *Irvingia* (*I. gabonensis* and *I. Wombolu* Bail) Trade; a major Non-Timber Forest Product in the Ejagham Forest Reserve of South West Cameroon. *Ethiopian Journal of Environmental Studies and Management* 4.1: 69-77.

Nwabanne J. T. 2009. Drying characteristics and engineering properties of fermented ground cassava. *African Journal of Biotecnology* 8.5: 873-876

Nwakonobi, T. U. and Onwualu, A. P. 2009. Effect of moisture content and typee of structural surfaces on coefficient of friction of two Nigerian food grains: Sorghum (*Sorghum bicolor*) and Millet (*Pennisetum glaucum*). *Agricultural Engineering International: The CIGR Ejournal* 11: 1152.

Nzekwe, U., Ojieifo, I. M. and Emuh, F. N. 2005. Assesment of kernel economic yield of irvingia gabonensis (wild mango) in South Eastern Nigeria. *The Nigerian Journal of Research and Production* 7: 48-52.

Ogbonnaya, C. and Sunmonu, M. O. 2010. Determination of selected engineering properties of cowpea (*Vingna unguiculata*) related to design of processing machines. *International Journal of Engineering and Technology* 2.6: 373-378.

Ogunjimi, L. A. O., Aviara, N. A. and Aregbesola, O. A. 2002. Some engineering properties of locust bean seed. *Journal of Food Engineering I55.2: 95-99.*

Ogunsina, B. S., Koya, O. A. and Adeosun O.O. 2008. Deformation and frature of dika nut (*Irvingia gabonensis*) under uni-axial compressive loading. *International Agrophysics* 22: 249-253.

Okafor, J. C. and Fernandes, E. C. M. 1987. Compound farms of South-eastern Nigeria: A predominant agroforestry home garden system with crops and small livestock. *Agroforestry Systems* 5:154-168.

Okafor, J. C. 1975. Varietal delimitation in *Irvingia gabonensis* (Irvingiaceae). *Bulletin du Jardin Botanique National de Belgique* 45: 211-221.

Okafor, J. C. 1987. Development of Forest Trees crops for food supplies in Nigeria. *Ecology Management* 1: 235-247.

Olajide, A. S. and Bamgboye, I. 2014. Moisture dependent mechanical and thermal properties of locust bean (*Parkia biglobosa*). *Agricultural Engineering International CIGR Journal* 16.1: 99-106.

Olaniyan, A.M. and Oje, K. 2002. Some aspects of the mechanical properties of shea nut. *Biosystem Engineering* 81.4: 413-420

Omogbai, F. E. 1990. Lipid composition of tropical seeds used in Nigeria diet.*Journal of the Science of Food and Agriculture 50.*2: 253-255.

Omobuwajo, T. O., Sanni, L. A. and Balami, Y. A. 2000. Physical properties of sorrel seeds. *Journal of Food Engineering* 45: 37-41

Omoruyi, F. and Adamson, I. 1994. Effect of supplements of dikanut (*Irvingia gabonensis*) and cellulose on plasma lipids and composition of hepatic phospholipids in streptozotocin-induced diabetic rat. *Nutrition Research* 14.4: 537-544.

Orhevba, B. A., Idah, P. A., Adebayo, S. E. and Nwankwo, C. C. 2013. Determination of some engineering properties of dika nut (*Irvingia gabonensis*) at two moisture content levels as relevant to its processing. *International Journal of Engineering Research and Applications* 3.2: 182-188.

Owolarafe, O. K., Olabige, M. T., Faborode, M. O. 2007. Physical and mechanical properties of two varieties of fresh oil palm fruits. *Journal of Food Engineering* 78: 1228-1232.

Oyelade, O. J., Odugbenro, P. O., Abioyem, A. O. and Raji, N. L. 2005. Some physical properties of African star apple (*Chrysophyllum alibidium*) seeds. *Journal of Food Engineering* 67: 435-440.

Ozguven, F. and Kubilay, V. 2004. Some physical, mechanical and aerodynamic properties of pine (*Pinus pinea*) nuts. *Journal of Food Engineering* 68: 341-347.

Ozturk, I., Kara, M., Elkoca, E. and Ercisli, S. 2009. Physico-chemical grain properties of new common bean cv *Elkoca*-05. *Scienctific Research and Eassy* 4.2: 88-93.

Paksoy, M. and Aydin, C. 2004. Some physical properties of edible squash (*Cucurbita pepo* L.) Seeds. *Journal of Food Engineering* 65: 225-231.

Polat, C. Aydin, C. and Erol, B. 2007. Some Physical and mechanical properties of pistacho nut. *Bulgaria Journal of Agricultural Science* 35: 237-246.

Raji, A. O. and Favier J. F. 2004. Model for the deformation in agricultural and food particulate materials under bulk compressive loading using discrete element method: compression of oil seeds. *Journal of Food Enginering* 64.11: 373-380.

Razavi, S. M. A., Emadzadeh, B., Rafe, A. and Mohammed, A. A. 2007. The physical properties of pistachio nut and its kernel as function of moisture content and variety. *Journal of food engineering* 81: 209-217.

Razavi, S. M. A. and Taghizadeh, M. 2007. The specific heat of pistachio nuts as affected by moisture content, temperature and variety. *Journal of food engineering* 79: 158-167.

Razavi, M. E. 2006. Some physical properties of the watermelon seeds. *Journal of Agricultural Engineering* Research 13: 65-69.

Resio, A. N. C., Aguerre, R. J. and Suarez, C. 2005. Analysis of simultaneous water absorption and water-starch reaction during soaking of amaranth grain. *Journal of Food Engieering* 68: 265-270.

Ruiz, R. S., Vizcarra M. G. and Martinez, C. 2007. Hydration of grain kernels and its effect on drying. *Swiss Society of Food Science and Technology* 41.7: 1310-1316.

Sacilik, K., Ozturk, R. And Luskin, R. 2003. Same physical properties of hemp seed. *Biosystems Engineering*. 86 (2) 191-198.

Saeeid, F., Mohammed, N., and Behzed, K. 2009. Some physical properties of groundnut (*Arachis hypogaea*) kernel NC2 as a function of moisture content. *American-Eurasian Journal of Agricultural and Environment.*

Sahoo, P. K. and Srivastava, A. P. 2002. Physical properties of okra seed. *Biosystem Engineering* 83.4: 441-448.

Said, P. P. and Pradhan, R. C. 2013. Moisture dependent physical properties of *Lagenaria siceraria* seed. International Journal of Agricultural and Biological Engineering 6.4: 111-120.

Seifi, M. R. and Alimardani, R. 2010. The moisture content effect on some physical and mechanical properties of corn (Sc 704). *Journal of Agricultural Science* 2.4: 125-134.

Selvi, K.C., Pinar, Y. and Yesiloglu, E. 2006. Some physical properties of linseed. *Biosystem Engineering* 95.4: 607-612.

Sessiz, A., Esgici, R. and Kizil, S. 2007. Moisture-dependent physical properties of caper fruit. *Journal of Food Engineering* 79: 1426-1431.

Seyed. M. A. R.and Maryam, B. P. 2007 same physical and mechanical properties of kiwi fruit. *International Journal of food Engineering* 3.6: 56-57.

Shirkole, S. S., Kenghe, R. N. and Nimkar, P. M. 2011. Moisture dependent physical properties of soyabean. International Journal of Engineering Science and Technology 3.5: 3807-3814.

Shirmohammadi, M. and Yarlagadda, P. 2012. Experimental study on the mechanical properties of pumpkin tissue. Journal of Achievement in Material and Manufacturing Engineering 54.1: 16-24.

Simons, A.S. and Leakey, R. R. B. 2004. Tree domestication in tropical agroforestry. *Agroforest systems* 61: 167-181.

Singh, K. K. and Goswani, T. K. 2000. Thermal properties of cumin seed. *Journal of Food Engineering* 45: 181-187.

Solomon, W. K. and Zewdu, A. D. 2009. Moisture dependent physical properties of niger (*Guiconia abyssinica* Cass.) seed. *Industrial Crops and Production* 29:165-170

Stroshine, R. and Hamann, D. 1995. Some physical properties of agricultural materials and food products. Course manual, Purdue University, Indiana

Tabatabaeefar, A. 2003. Moisture-dependent physical properties of wheat. *International Agrophysics* 17: 207–211.

Taiz and Zeiger, 2002. Plant Physiology. Fourth Edition, Sinauer Associates.

Tansakul, A. and Lumyong, R. 2008. Thermal properties of straw Mushroom. J*ournal of Food Engineering* 87: 91-98.

Tavakoli, M., Tavakoli, H., Rajabipour, A., Ahmadi, H. and Gharib-Zahedi, S. M. T. 2009. Moisture-dependent of physical properties of barley grains. *International Journal of Agricultural and Biological Engineering* 2.4: 207-210.

Tchoundjeu, Z. and Atangana, A. R. 2007. *Irvingia gabonensis* (Aubry Lecomte ex O'Rorke) Baill. [Internet] Record from PROTA4U. Lemmens, R.H.M.J., Louppe, D. and Oteng-Amoako, A.A. (Editors). PROTA (Plant Resources of Tropical Africa / Ressources vegetales de l'Afrique tropcale), Wageningen, Nertherlands. http://www.prota4u.org/search.asp. Accessed 3 May 2014.

Teye, E. and Abano, E. E. 2012. Physical properties of two varieties of sweet potato grown in the coastal savannah zone of Ghana. *International Journal of Science and Nature* 3.1: 105-109.

Tunde-Akintunde. T. Y. and Akintunde B. O. 2007. Effect of moisture content and variety on selected properties of beninseed. *Agricultural Engineering International:* CIGR Ejournal 9: 1-13.

Varnamkhasti, M. G., Mobil, H., Jafari, A., Keyhani, A. R. Soltanabadi, M. H., Rafice, S. and Kheiralipour, K., 2008. Some physical properties of rough rice (Oryza sativa) grain. Journal of Cereal Science 47: 496-501.

Vilche, C., Gely, M. and Santall, E. 2003. Physical properties of quuinoa seeds. *Biosystem Engineering* 86.1: 57-63.

Wang, B., Li, D., Wang, L., Huang, Z., Zhang, L., Chen, X. and Mao, Z. 2007. Effect of moisture content on the physical properties of fibered flax seed. *International Agrophysics* 19: 193-198.

Wilhelm, L.R., Suter, D.A., and Brusewitz, G.H. 2004. Physical properties of food material. In *Food and Process Engineering Technology*, 23-25. ASAE, St Joseph, MI.

Yang, W., Sokhansanji, S., Tang, J. and Winter, P. 2002. Determination of thermal conductivity, specific heat and thermal diffusivity of borage seeds. *Biosystems Engineering* 82: 169-176.

Zewdu, A. and Solomon, W. 2008. Moisture dependent physical properties of grass pea (*Laathyrus sativus L.*) seeds. Agricultural Engineering International, CIGR e-Journal 10: FP06027.

Zewdu, A.D. and Solomon, W.K. 2007. Moisture dependent physical properties of tef seed. *Biosystem Engineering* 96.1: 57-63.

APPENDICES

Appendix A

Table A1: Axial Dimension of *Irvingia gabonensis* seed for moisture content 10% (d.b)

S/N	Axial Dimensions (mm) a	b	c	Geometric mean diameter Dp (mm) = $(abc)^{1/3}$	Sphericity ϕ = $\{(abc^{1/3})\}/a$	1000 seed weight kg
1	37.73	31.62	18.82	74.771	28.211	9.22
2	36.65	28.10	18.71	73.149	26.809	7.07
3	42.43	33.10	19.61	71.174	30.199	9.17
4	40.15	31.29	20.41	73.444	29.488	9.72
5	39.47	32.64	19.36	74.024	29.217	9.43
6	39.65	36.88	21.40	79.477	31.512	10.84
7	41.76	29.76	19.12	68.844	28.749	7.43
8	41.88	30.92	19.32	69.836	29.247	8.37
9	36.06	30.49	18.61	75.849	27.351	8.02
10	40.89	31.97	19.12	71.504	29.238	9.10
11	37.25	31.10	20.30	76.913	28.650	8.49
12	39.88	35.28	19.15	75.173	29.979	11.31
13	45.49	31.53	20.07	67.372	30.648	7.49
14	36.90	30.15	19.48	75.557	27.881	8.79
15	37.04	31.27	18.74	75.310	27.895	9.60
16	43.17	34.42	20.56	72.414	31.261	10.49
17	37.28	31.09	16.46	71.675	26.720	8.21
18	36.73	31.65	18.99	76.375	28.053	9.20
19	43.48	33.95	19.70	70.725	30.751	8.55
20	38.22	30.76	19.20	73.944	28.261	9.17
21	37.49	30.30	19.97	75.509	28.308	7.53
22	40.81	31.51	21.80	74.437	30.378	8.75
23	35.50	29.49	20.04	77.691	27.580	7.89
24	38.43	28.55	16.31	68.062	26.156	7.75
25	36.81	36.90	20.57	82.435	30.344	9.18
26	36.56	36.90	19.56	81.432	29.771	8.49
27	39.28	29.54	18.80	71.134	27.941	8.20
28	41.92	31.72	18.97	69.960	29.327	8.42
29	37.09	31.01	20.09	76.793	28.483	7.59
30	39.44	33.72	19.22	74.689	29.457	9.14
31	42.20	29.52	20.07	69.291	29.241	8.70
32	40.95	30.77	19.62	71.139	29.131	8.78
33	36.94	31.42	20.19	77.467	28.616	9.50
34	36.26	29.47	19.76	76.226	27.640	7.34
35	43.40	33.44	19.30	69.976	30.370	10.74
36	35.67	26.96	20.27	75.449	26.913	7.03
37	34.53	28.11	19.57	77.272	26.682	7.66
38	39.35	30.38	20.53	73.852	29.061	8.78
39	37.94	30.87	19.86	75.239	28.546	9.70
40	34.83	30.75	24.02	84.756	29.521	7.51
41	36.50	30.89	19.29	76.475	27.914	9.16
42	36.94	30.10	19.24	75.149	27.760	7.21
43	40.61	32.46	19.54	72.723	29.533	9.08
44	35.92	33.97	20.16	80.966	29.083	9.54
45	39.74	34.42	20.38	76.299	30.321	11.22
46	38.82	30.72	20.35	74.580	28.952	7.38
47	32.61	29.30	20.17	82.216	26.811	8.60
48	37.65	30.06	19.79	74.869	28.188	7.64
49	38.12	30.30	20.37	75.170	28.655	6.11
50	35.40	29.95	19.26	77.212	27.333	7.48
51	41.25	33.56	18.70	71.714	29.582	7.32

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	a	b	c	Dp (mm) = $(abc)^{1/3}$	ϕ = $\{(abc^{1/3})\}/a$	kg
52	43.72	32.09	20.63	70.227	30.703	10.00
53	32.36	32.84	19.80	85.313	27.607	10.20
54	38.73	36.85	19.95	78.843	30.536	10.60
55	39.86	30.91	22.78	76.242	30.390	8.20
56	36.90	31.78	19.16	76.471	28.218	9.60
57	37.22	30.86	19.49	75.721	28.183	8.50
58	39.04	30.04	18.96	72.029	28.120	6.60
59	38.92	31.91	20.26	75.291	29.303	10.20
60	37.72	31.40	19.77	75.846	28.609	10.10
61	37.80	30.92	20.38	76.118	28.773	8.90
62	38.99	31.71	19.68	74.320	28.977	9.30
63	42.88	33.22	19.34	70.434	30.202	10.10
64	38.33	32.34	20.10	76.200	29.207	9.70
65	35.37	26.71	19.04	74.078	26.201	4.00
66	36.91	30.04	26.71	83.823	30.939	9.30
67	41.94	32.88	18.64	70.368	29.512	11.00
68	35.99	32.17	18.75	77.511	27.896	8.40
69	46.53	32.06	19.90	66.545	30.963	10.20
70	39.01	30.08	20.54	74.047	28.886	8.50
71	33.29	30.16	22.50	84.917	28.269	7.60
72	38.26	29.64	19.39	73.224	28.016	7.00
73	40.72	34.89	19.83	74.726	30.428	9.00
74	43.64	33.24	18.52	68.630	29.950	10.80
75	35.29	30.29	22.79	82.145	28.989	8.30
76	33.24	29.50	19.45	80.378	26.718	8.30
77	42.23	31.25	23.97	74.890	31.626	7.30
78	34.75	27.93	18.98	76.001	26.410	7.60
79	38.36	30.25	20.02	74.384	28.534	7.90
80	34.58	30.26	18.24	77.283	26.724	7.30
81	40.26	30.86	18.97	71.215	28.671	9.00
82	37.77	31.61	18.11	73.759	27.859	9.20
83	44.22	32.10	18.72	67.482	29.841	9.50
84	38.41	29.67	20.22	74.086	28.456	7.60
85	42.41	31.90	17.47	67.668	28.698	9.40
86	35.46	26.54	17.27	71.434	25.331	6.10
87	40.75	32.10	18.05	70.400	28.688	8.90
88	33.55	29.58	19.48	79.996	26.839	6.80
89	39.31	33.88	19.21	74.959	29.466	10.00
90	37.62	30.72	18.61	73.923	27.810	8.70
91	35.47	31.48	20.08	79.498	28.198	7.20
92	37.58	33.37	19.34	77.025	28.946	9.90
93	36.38	29.97	18.87	75.320	27.401	8.40
94	40.34	30.40	18.35	69.986	28.232	7.40
95	37.81	32.47	16.77	72.488	27.408	9.40
96	34.73	28.00	19.91	77.317	26.852	6.10
97	39.33	30.67	19.32	72.626	28.564	7.20
98	41.24	30.32	19.07	69.793	28.783	8.90
99	38.82	31.21	20.47	75.122	29.162	7.50
100	35.41	27.75	20.01	76.223	26.991	5.90
Mean	38.51	31.28	19.69	74.74	28.69	8.57

Table A2: Axial Dimensions of *Irvingia gabonensis* seed for moisture content 20% (d.b)

S/N	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
	a	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
1	41.93	30.19	19.15	28.941	69.023	8.30
2	36.36	31.04	19.73	28.134	77.375	9.40
3	36.53	33.46	20.56	29.291	80.183	10.00
4	37.83	32.18	19.73	28.852	76.269	8.80
5	39.96	31.48	20.69	29.635	74.162	11.30
6	30.30	25.09	21.19	25.256	83.352	5.60
7	39.97	30.87	19.16	28.700	71.805	9.60
8	36.04	30.19	18.66	27.281	75.695	9.20
9	35.84	30.05	19.44	27.562	76.902	7.50
10	38.74	29.52	18.87	27.841	71.866	8.30
11	40.10	32.08	19.79	29.418	73.361	10.20
12	35.80	29.27	18.32	26.776	74.793	6.40
13	38.21	32.02	20.41	29.229	76.496	9.30
14	42.49	34.79	20.74	31.298	73.660	12.20
15	33.90	29.27	19.45	26.823	79.125	6.40
16	38.47	32.62	20.88	29.702	77.207	10.50
17	34.32	29.59	19.20	26.915	78.424	7.80
18	37.76	32.70	20.42	29.323	77.657	10.20
19	33.04	27.17	16.58	24.598	74.450	7.20
20	40.18	32.33	20.10	29.667	73.835	9.80
21	36.26	32.62	19.76	28.591	78.851	9.90
22	30.26	26.34	16.27	23.494	77.641	5.70
23	40.90	32.32	20.77	30.168	73.760	10.30
24	40.29	32.91	20.31	29.974	74.396	10.50
25	38.16	30.58	20.31	28.724	75.274	9.90
26	38.43	31.79	19.37	28.710	74.707	9.30
27	40.55	30.49	20.26	29.259	72.156	8.90
28	35.69	30.08	19.19	27.414	76.810	8.90
29	40.39	31.23	24.31	31.300	77.494	11.60
30	37.33	31.90	20.78	29.141	78.062	9.60
31	40.79	30.36	19.27	28.790	70.582	8.80
32	37.29	29.68	17.94	27.079	72.616	8.70
33	37.15	29.71	18.70	27.431	73.837	7.40
34	37.09	31.31	18.71	27.904	75.234	8.00
35	35.97	30.43	20.00	27.974	77.771	8.80
36	41.91	32.73	21.46	30.877	73.674	10.80
37	39.75	28.94	19.33	28.120	70.743	8.60
38	43.79	32.75	19.52	30.364	69.339	10.20
39	39.07	32.41	20.18	29.454	75.388	10.20
40	40.60	33.82	20.37	30.355	74.766	11.10
41	35.86	32.63	19.23	28.232	78.727	10.00
42	41.31	31.72	20.48	29.939	72.474	9.00
43	34.99	31.21	19.57	27.751	79.311	8.40
44	42.88	31.06	19.43	29.579	68.980	10.40
45	37.03	31.29	18.94	27.997	75.607	9.10
46	35.59	31.47	18.25	27.342	76.825	8.50
47	38.27	32.59	20.45	29.436	76.917	9.90
48	38.81	30.18	19.21	28.231	72.742	9.30
49	38.93	32.62	19.87	29.331	75.342	10.30
50	38.44	32.52	19.93	29.207	75.980	10.20
51	35.68	30.41	19.72	27.762	77.808	9.40
52	37.75	33.22	18.01	28.267	74.879	9.20

S/N	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
	a	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
53	36.21	31.49	20.27	28.485	78.666	7.50
54	34.71	28.79	18.84	26.603	76.643	7.50
55	38.48	31.90	19.62	28.879	75.048	9.20
56	36.69	31.41	18.69	27.823	75.833	9.30
57	38.63	30.44	19.61	28.463	73.681	8.50
58	39.65	32.07	21.03	29.904	75.420	9.60
59	36.15	31.59	20.15	28.443	78.681	9.20
60	31.56	27.61	18.70	25.352	80.330	6.80
61	37.14	31.86	20.36	28.882	77.764	9.70
62	38.50	32.69	19.95	29.282	76.058	9.80
63	39.28	31.06	19.17	28.598	72.805	8.50
64	36.69	28.98	18.40	26.946	73.441	5.90
65	34.52	29.24	17.49	26.038	75.430	7.80
66	36.80	30.35	25.04	30.354	82.483	9.90
67	36.17	27.45	17.20	25.752	71.196	5.50
68	34.71	27.86	19.29	26.521	76.407	6.70
69	36.16	29.36	26.69	30.487	84.311	10.80
70	39.14	32.77	19.78	29.384	75.074	9.70
71	38.95	32.05	20.39	29.416	75.523	9.40
72	38.08	30.25	18.97	27.957	73.418	9.40
73	35.13	30.22	18.84	27.145	77.269	8.80
74	41.86	35.80	22.45	32.282	77.120	13.30
75	43.10	30.45	19.05	29.241	67.844	8.40
76	40.23	31.47	19.70	29.217	72.625	9.90
77	34.36	27.79	18.99	26.272	76.460	7.20
78	37.17	31.09	20.33	28.641	77.053	10.20
79	35.68	23.59	15.80	23.692	66.402	5.40
80	35.43	31.02	18.86	27.470	77.532	9.20
81	36.70	32.16	19.84	28.609	77.955	9.10
82	36.91	30.53	19.50	28.009	75.885	8.90
83	39.98	28.78	22.40	29.539	73.884	10.10
84	38.52	31.03	19.07	28.353	73.607	9.50
85	37.63	30.77	19.33	28.182	74.891	9.40
86	38.07	31.11	19.65	28.551	74.995	9.60
87	39.00	30.73	19.12	28.403	72.829	8.40
88	35.35	29.44	19.71	27.374	77.437	9.40
89	33.37	29.56	22.84	28.244	84.637	8.90
90	39.09	37.13	20.18	30.825	78.857	10.80
91	35.51	30.12	20.13	27.820	78.343	9.00
92	39.24	30.70	19.29	28.536	72.723	8.10
93	37.12	38.81	18.46	29.849	80.412	8.90
94	36.14	31.04	20.23	28.312	78.339	10.10
95	37.22	30.57	19.40	28.052	75.367	10.20
96	35.47	30.77	18.83	27.391	77.224	8.60
97	38.07	32.17	20.42	29.244	76.815	9.20
98	35.69	31.27	19.98	28.146	78.864	9.30
99	35.61	26.72	16.35	24.964	70.103	4.30
100	34.80	29.92	19.48	27.272	78.367	8.10
Mean	37.56	30.93	19.71	28.37	75.66	9.02

Table A3: Axial Dimensions of *Irvingia gabonensis* seed for moisture content 30% (d.b)

S/N	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
	a	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
1	34.85	30.64	20.25	27.859	79.941	8.80
2	36.56	31.18	19.27	28.006	76.603	9.40
3	37.56	31.57	20.23	28.840	76.784	9.50
4	37.75	31.98	19.60	28.709	76.050	9.50
5	42.57	31.25	18.89	29.291	68.806	10.30
6	40.66	32.96	21.38	30.600	75.258	11.10
7	35.03	30.52	19.14	27.352	78.082	8.50
8	36.15	30.13	20.47	28.145	77.857	8.20
9	34.31	28.52	19.69	26.808	78.136	7.80
10	39.12	31.86	20.81	29.601	75.667	8.30
11	39.00	32.22	19.51	29.050	74.488	10.00
12	37.41	30.40	18.70	27.706	74.059	10.40
13	38.49	31.09	20.35	28.985	75.306	10.50
14	36.81	32.21	20.00	28.730	78.048	9.50
15	35.41	30.37	19.07	27.372	77.300	9.00
16	38.31	32.03	20.32	29.214	76.258	10.70
17	30.34	26.12	19.50	24.908	82.097	5.70
18	37.46	30.19	19.11	27.855	74.358	10.40
19	35.63	32.11	19.10	27.957	78.466	10.50
20	38.71	30.95	19.73	28.699	74.139	9.20
21	39.06	31.49	20.12	29.141	74.607	10.50
22	30.36	23.14	19.59	23.964	78.934	6.30
23	36.20	30.49	18.47	27.318	75.463	5.80
24	34.08	26.68	20.25	26.406	77.483	4.50
25	37.30	32.26	19.56	28.658	76.831	10.30
26	39.87	32.83	18.98	29.179	73.185	10.70
27	34.48	28.23	19.37	26.616	77.191	7.40
28	33.43	29.82	22.01	27.995	83.744	8.40
29	36.04	30.69	18.77	27.484	76.260	9.30
30	38.47	28.86	19.59	27.914	72.560	9.70
31	35.90	31.94	15.73	26.225	73.051	9.90
32	36.36	31.28	19.17	27.936	76.833	9.40
33	39.52	32.32	19.78	29.343	74.249	10.40
34	37.09	30.73	19.75	28.236	76.127	9.50
35	37.02	31.19	18.82	27.906	75.380	9.60
36	36.00	31.40	20.39	28.459	79.052	9.60
37	34.44	29.99	16.33	25.645	74.464	8.30
38	40.62	31.40	18.75	28.811	70.928	9.70
39	38.34	33.14	19.94	29.370	76.605	10.30
40	41.37	30.81	19.47	29.169	70.506	11.60
41	34.61	27.41	19.85	26.605	76.870	7.30
42	37.70	32.41	18.65	28.351	75.201	10.80
43	35.99	29.25	19.75	27.497	76.403	10.00
44	38.86	32.59	20.18	29.456	75.800	10.80
45	40.05	32.15	18.67	28.861	72.062	10.10
46	36.04	32.58	26.04	31.270	86.764	10.40
47	37.63	31.13	19.60	28.422	75.530	11.00
48	37.93	31.88	20.14	28.986	76.419	9.00
49	36.80	31.61	20.41	28.741	78.101	10.90
50	38.47	29.22	30.37	32.440	84.326	9.00
51	37.23	30.77	19.26	28.047	75.335	8.60
52	38.59	37.27	19.77	30.522	79.093	9.60
53	34.43	30.95	18.65	27.087	78.672	9.40

S/N	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
	a	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
54	35.94	30.15	19.75	27.764	77.250	9.40
55	32.62	30.07	20.27	27.091	83.050	8.80
56	37.04	30.90	17.00	26.896	72.614	8.80
57	33.06	29.18	19.60	26.641	80.583	6.70
58	31.92	27.85	21.98	26.934	84.381	6.80
59	38.91	32.54	20.36	29.541	75.920	10.70
60	39.35	31.49	19.94	29.126	74.018	10.50
61	38.45	33.50	24.56	31.627	82.255	11.60
62	38.20	32.61	19.40	28.912	75.685	10.80
63	39.43	30.13	19.43	28.473	72.211	9.60
64	36.04	31.41	20.48	28.514	79.118	10.40
65	38.24	30.42	19.23	28.176	73.683	9.70
66	36.91	31.23	19.28	28.115	76.172	11.10
67	36.43	29.70	17.19	26.495	72.729	7.60
68	42.48	29.86	18.23	28.490	67.066	8.00
69	39.67	32.39	20.55	29.778	75.064	10.60
70	43.40	34.52	18.93	30.496	70.266	12.40
71	42.42	36.03	18.69	30.569	72.063	13.90
72	35.85	30.55	18.92	27.467	76.616	9.20
73	40.64	32.63	20.35	29.995	73.806	10.70
74	37.10	29.24	19.35	27.585	74.354	6.20
75	38.76	29.33	20.22	28.433	73.357	10.50
76	35.02	31.31	18.92	27.477	78.462	8.70
77	37.40	30.79	18.03	27.485	73.489	10.00
78	38.65	30.09	18.41	27.768	71.844	9.80
79	36.54	31.56	22.56	29.631	81.092	8.10
80	35.31	30.47	22.72	29.022	82.192	8.80
81	34.74	30.32	19.08	27.188	78.262	8.50
82	37.05	29.19	20.38	28.038	75.675	9.00
83	35.68	30.48	19.75	27.797	77.907	9.20
84	37.84	32.23	19.76	28.885	76.333	10.70
85	34.39	29.31	20.42	27.405	79.690	8.30
86	36.55	27.54	19.38	26.920	73.651	5.40
87	37.27	31.59	20.29	28.800	77.275	9.70
88	37.71	30.50	17.51	27.207	72.148	8.60
89	37.52	31.14	18.98	28.095	74.880	9.70
90	36.33	30.54	19.94	28.073	77.272	8.90
91	35.67	31.39	18.43	27.429	76.896	9.80
92	36.96	30.85	22.59	29.533	79.904	10.10
93	34.87	29.81	19.28	27.163	77.897	8.80
94	34.11	29.25	18.27	26.318	77.156	7.00
95	33.42	27.69	16.10	24.607	73.628	7.00
96	37.01	30.61	19.04	27.837	75.214	10.10
97	37.05	31.85	20.04	28.703	77.472	9.90
98	35.72	30.60	20.00	27.961	78.279	9.50
99	38.63	32.39	19.77	29.137	75.426	10.10
100	37.03	31.83	23.85	30.406	82.112	10.10
Mean	37.04	30.85	19.79	28.24	76.38	9.35

Table A4: Axial Dimensions of *Irvingia gabonensis* seed for moisture content 40% (d.b)

S/N	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
	a	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
1	37.57	32.43	19.37	28.684	76.348	11.60
2	36.55	30.66	20.15	28.265	77.332	12.00
3	36.14	31.31	19.73	28.158	77.913	11.60
4	34.18	30.98	20.63	27.954	81.786	9.70
5	35.70	30.56	19.58	27.747	77.722	9.40
6	40.91	32.79	16.72	28.201	68.935	12.80
7	34.41	29.75	19.51	27.132	78.848	9.20
8	37.28	31.89	19.67	28.596	76.707	10.00
9	41.40	31.30	19.89	29.539	71.350	11.50
10	36.51	31.02	19.76	28.180	77.185	10.70
11	34.70	32.09	21.60	28.866	83.187	10.90
12	37.25	29.70	22.69	29.280	78.604	10.50
13	36.47	31.92	19.96	28.536	78.244	11.00
14	41.77	34.21	20.62	30.887	73.944	13.70
15	35.43	30.73	18.86	27.384	77.290	10.40
16	37.50	33.37	19.72	29.114	77.637	11.40
17	34.93	31.47	19.33	27.698	79.295	10.00
18	34.88	30.19	19.23	27.257	78.144	9.80
19	35.31	30.95	18.72	27.350	77.456	9.80
20	37.48	32.07	20.70	29.194	77.891	11.10
21	35.24	31.85	19.70	28.068	79.647	10.80
22	36.16	32.26	18.81	27.996	77.422	10.70
23	34.56	30.89	19.42	27.471	79.489	9.40
24	35.37	32.57	20.00	28.455	80.450	11.10
25	37.17	30.55	19.34	28.004	75.340	11.80
26	33.56	29.41	23.87	28.667	85.422	8.70
27	32.31	29.04	18.10	25.704	79.555	7.60
28	28.57	21.57	20.50	23.290	81.519	6.20
29	34.19	28.07	19.96	26.757	78.259	7.90
30	34.81	31.19	22.75	29.123	83.662	10.00
31	32.07	23.44	20.49	24.881	77.583	5.20
32	34.33	27.90	19.91	26.717	77.823	7.70
33	37.98	31.38	18.95	28.267	74.425	11.20
34	34.48	30.61	19.21	27.268	79.083	8.40
35	36.32	28.99	20.70	27.933	76.909	10.20
36	39.41	32.07	18.88	28.790	73.052	9.90
37	34.09	26.62	20.69	26.579	77.966	5.40
38	36.86	30.78	19.25	27.952	75.834	10.40
39	35.68	30.49	19.29	27.583	77.306	9.80
40	36.69	30.32	20.06	28.154	76.734	11.00
41	38.46	32.41	18.82	28.627	74.432	11.50
42	34.70	29.91	18.93	26.984	77.762	9.00
43	35.35	29.68	17.76	26.511	74.997	9.60
44	36.62	32.50	18.93	28.243	77.126	10.00
45	31.42	27.71	18.96	25.462	81.038	7.50
46	34.85	29.85	21.89	28.344	81.332	13.00
47	36.74	31.52	18.67	27.858	75.826	10.20
48	36.71	31.02	19.47	28.093	76.527	10.40
49	35.47	31.96	20.14	28.369	79.980	10.20
50	38.79	32.75	19.45	29.126	75.087	11.50
51	39.04	31.34	18.76	28.419	72.795	8.90
52	36.91	30.39	19.83	28.123	76.194	11.30
53	34.12	29.95	19.67	27.190	79.688	8.70
54	34.58	28.25	26.96	29.752	86.039	9.00

S/N	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
	a	b	c	Dp (mm) = $(abc)^{1/3}$	ϕ = $\{(abc^{1/3})\}/a$	Kg
55	36.53	31.54	23.19	29.895	81.838	11.10
56	37.45	32.53	19.05	28.524	76.166	11.20
57	32.10	27.17	20.41	26.110	81.341	8.10
58	37.10	30.31	20.53	28.474	76.750	10.50
59	37.92	33.93	20.58	29.806	78.602	11.60
60	35.53	31.54	20.99	28.652	80.642	9.80
61	38.04	32.15	19.78	28.921	76.028	11.40
62	36.26	30.40	19.47	27.790	76.641	12.80
63	38.32	30.12	19.13	28.054	73.210	10.60
64	36.02	30.58	20.43	28.233	78.380	9.00
65	36.83	30.67	18.70	27.643	75.056	11.00
66	36.57	30.49	20.71	28.477	77.869	9.40
67	35.23	27.23	20.24	26.878	76.292	7.00
68	35.44	28.99	19.53	27.174	76.675	10.40
69	36.09	31.04	19.46	27.935	77.404	12.60
70	40.54	29.72	16.61	27.150	66.971	9.70
71	35.47	29.69	18.41	26.864	75.738	9.40
72	37.43	30.00	18.88	27.677	73.943	10.40
73	38.44	31.79	18.53	28.291	73.598	10.60
74	35.68	32.11	20.21	28.502	79.883	11.80
75	36.47	31.57	19.09	28.012	76.807	10.70
76	34.67	29.85	19.87	27.397	79.021	8.90
77	37.40	31.32	20.46	28.831	77.089	10.90
78	35.95	29.32	20.05	27.648	76.906	6.40
79	40.79	36.06	19.64	30.684	75.223	14.60
80	32.35	29.24	19.15	26.263	81.183	9.70
81	25.12	29.41	16.45	22.991	91.525	9.70
82	35.64	31.34	23.63	29.774	83.540	11.30
83	35.21	32.49	23.63	30.012	85.237	11.50
84	37.05	32.60	19.25	28.542	77.035	11.70
85	40.04	32.69	20.18	29.781	74.379	11.90
86	36.24	30.65	20.97	28.559	78.804	11.00
87	38.18	31.17	19.61	28.577	74.848	11.60
88	33.88	29.20	18.29	26.253	77.488	8.40
89	35.67	30.37	19.60	27.691	77.630	10.00
90	37.40	32.13	20.39	29.045	77.660	11.70
91	35.46	29.27	19.48	27.243	76.827	10.70
92	38.24	29.12	18.88	27.600	72.175	10.40
93	34.86	30.15	19.24	27.244	78.153	9.60
94	33.90	29.68	19.73	27.077	79.872	9.20
95	30.05	26.30	20.54	25.320	84.260	6.80
96	35.88	30.84	19.79	27.977	77.974	9.70
97	38.51	32.46	19.56	29.024	75.369	13.40
98	37.23	33.30	18.84	28.585	76.780	13.50
99	37.64	32.38	19.49	28.746	76.371	11.10
100	36.63	31.07	16.47	26.564	72.519	12.70
Mean	36.03	30.65	19.82	27.93	77.70	10.27

Table A5: Axial Dimensions of *Irvingia gabonensis* seed for moisture content 50% (d.b)

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	a	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
1	36.51	32.21	20.14	28.718	78.658	13.30
2	39.08	33.10	18.54	28.838	73.792	14.80
3	35.40	10.86	20.05	19.754	55.802	12.40
4	34.91	31.48	20.11	28.063	80.386	12.80
5	37.09	31.98	20.40	28.924	77.983	13.20
6	30.94	27.15	22.07	26.467	85.542	8.20
7	34.09	32.19	19.34	27.687	81.216	12.90
8	36.80	32.42	19.92	28.751	78.127	13.70
9	33.97	31.95	18.32	27.091	79.751	12.90
10	36.58	31.88	20.31	28.718	78.508	12.50
11	39.21	32.61	18.67	28.794	73.435	15.80
12	33.52	28.51	22.38	27.758	82.810	14.10
13	37.17	31.94	20.24	28.857	77.634	13.50
14	35.73	31.86	19.49	28.099	78.644	13.60
15	35.63	29.74	20.46	27.884	78.260	11.20
16	35.63	32.21	21.13	28.945	81.237	13.10
17	38.99	31.26	18.58	28.292	72.562	13.60
18	35.59	31.10	20.25	28.195	79.222	11.70
19	33.33	30.06	19.80	27.071	81.220	10.70
20	35.77	31.49	19.36	27.938	78.105	13.40
21	33.36	31.23	19.31	27.197	81.527	11.90
22	34.37	30.09	19.33	27.140	78.964	11.00
23	36.46	31.68	18.13	27.563	75.599	12.65
24	35.39	32.60	18.26	27.618	78.040	13.00
25	34.22	28.53	31.36	31.284	91.420	11.40
26	31.38	30.37	31.09	30.944	98.610	15.70
27	36.84	29.43	19.48	27.642	75.032	12.00
28	37.04	31.94	21.79	29.541	79.754	13.90
29	34.59	31.64	19.88	27.917	80.708	13.40
30	31.87	28.87	19.51	26.184	82.157	12.50
31	36.19	31.32	19.24	27.939	77.200	13.00
32	34.26	31.89	20.08	27.994	81.711	10.30
33	34.71	30.06	20.43	27.727	79.882	10.20
34	31.90	29.33	17.56	25.422	79.693	8.80
35	35.19	30.58	28.52	31.309	88.971	12.70
36	35.91	30.69	19.95	28.015	78.013	11.10
37	36.48	32.54	17.92	27.708	75.954	12.10
38	35.59	29.37	19.12	27.138	76.251	10.70
39	36.87	29.82	21.02	28.484	77.256	12.00
40	34.10	31.15	27.11	30.651	89.886	11.30
41	34.41	30.23	19.96	27.485	79.875	11.30
42	33.46	28.45	18.12	25.838	77.220	9.80
43	33.33	29.29	20.63	27.207	81.630	10.20
44	31.11	27.05	20.37	25.784	82.881	8.10
45	33.42	29.70	20.62	27.354	81.849	11.00
46	27.30	22.12	20.04	22.959	84.098	8.30
47	34.40	30.31	22.77	28.741	83.550	11.30
48	33.12	29.97	18.80	26.524	80.086	11.00
49	36.98	32.29	20.01	28.802	77.886	13.80
50	35.51	29.98	18.12	26.819	75.526	11.40
51	34.59	29.21	20.44	27.436	79.318	10.70
52	36.50	29.79	20.89	28.320	77.590	11.30
53	33.63	28.72	19.72	26.706	79.411	10.90
54	32.44	29.53	21.67	27.483	84.720	14.30

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	a	b	c	Dp (mm) = $(abc)^{1/3}$	ϕ = $\{(abc^{1/3})\}/a$	Kg
55	34.82	29.02	19.87	27.179	78.057	14.60
56	33.96	30.39	20.44	27.631	81.363	11.10
57	36.40	33.21	19.16	28.505	78.311	14.00
58	35.79	30.33	17.57	26.718	74.652	11.60
59	35.84	31.95	20.71	28.730	80.163	13.00
60	33.01	30.80	20.84	27.671	83.827	11.90
61	34.41	30.54	20.39	27.775	80.718	12.40
62	34.69	29.85	19.36	27.166	78.309	11.50
63	35.11	28.66	20.93	27.616	78.655	10.90
64	33.24	30.79	20.19	27.441	82.555	11.30
65	33.91	29.66	16.09	25.294	74.592	9.10
66	35.08	31.24	25.66	30.409	86.686	11.10
67	33.67	27.90	21.06	27.046	80.326	8.20
68	32.34	28.88	21.23	27.066	83.693	10.50
69	34.84	32.07	19.50	27.930	80.166	12.00
70	29.45	26.28	20.22	25.013	84.933	6.80
71	34.62	31.09	21.38	28.444	82.160	11.70
72	33.36	27.93	18.55	25.855	77.503	9.60
73	33.63	29.92	22.29	28.201	83.857	11.10
74	34.51	30.00	22.85	28.707	83.184	10.00
75	34.51	30.50	18.63	26.966	78.140	9.70
76	37.66	31.29	18.20	27.783	73.774	12.30
77	34.94	31.31	20.16	28.043	80.262	12.10
78	35.77	30.82	18.34	27.243	76.161	12.30
79	35.43	31.00	18.61	27.342	77.171	11.30
80	32.99	29.12	18.67	26.176	79.346	10.00
81	32.95	26.35	19.64	25.739	78.115	7.90
82	37.75	35.18	20.02	29.846	79.063	16.90
83	37.75	35.18	19.75	29.712	78.706	16.90
84	33.65	29.53	19.04	26.646	79.187	9.80
85	37.27	31.83	20.14	28.802	77.279	13.80
86	34.32	32.55	16.78	26.564	77.402	12.50
87	32.81	29.50	19.14	26.460	80.646	11.10
88	32.44	29.30	16.99	25.276	77.917	9.20
89	33.96	31.44	19.69	27.599	81.270	11.10
90	34.98	31.67	20.18	28.171	80.533	12.40
91	35.11	30.10	19.65	27.487	78.287	12.40
92	35.13	29.60	21.00	27.951	79.564	10.30
93	35.48	30.30	19.02	27.345	77.072	11.30
94	35.60	31.92	19.04	27.865	78.273	12.40
95	35.18	33.07	19.26	28.192	80.137	13.10
96	33.43	30.69	17.98	26.423	79.038	11.20
97	34.50	29.55	19.68	27.173	78.762	10.90
98	33.02	30.53	19.20	26.849	81.313	11.00
99	35.29	30.52	19.55	27.614	78.248	12.40
100	32.58	27.21	19.97	26.063	79.996	8.40
Mean	34.70	30.26	20.17	27.59	79.65	11.76

Table A6: Axial Dimensions of *Irvingia wombolu* seed for moisture content 10% (d.b)

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	a	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
1	59.90	39.36	25.86	39.358	65.707	18.30
2	42.76	39.93	21.97	33.475	78.286	12.80
3	60.15	41.51	21.62	37.793	62.832	16.50
4	45.26	36.76	24.36	34.350	75.894	15.50
5	72.14	46.22	21.68	41.657	57.745	21.40
6	45.01	39.65	20.13	32.996	73.309	25.20
7	55.71	38.74	23.03	36.767	65.998	15.00
8	51.83	39.63	21.51	35.352	68.208	11.90
9	56.72	35.11	19.98	34.139	60.189	13.40
10	50.53	39.61	21.22	34.890	69.048	13.40
11	51.26	33.68	24.83	34.998	68.275	16.60
12	52.56	42.60	20.89	36.030	68.551	10.80
13	43.20	40.62	22.44	34.021	78.753	12.60
14	53.04	43.39	21.38	36.644	69.087	17.50
15	50.47	42.97	32.01	41.099	81.432	12.60
16	52.16	45.97	20.63	36.709	70.377	12.50
17	52.78	34.23	21.68	33.961	64.344	11.70
18	54.16	34.44	21.68	34.324	63.376	13.10
19	54.26	43.03	22.39	37.391	68.911	14.20
20	56.22	42.87	21.19	37.102	65.993	23.70
21	48.44	37.56	22.51	34.470	71.159	16.60
22	49.09	38.90	21.02	34.239	69.748	12.60
23	54.36	29.36	18.71	31.024	57.072	21.30
24	51.22	38.98	19.73	34.025	66.430	14.40
25	62.52	41.18	21.91	38.352	61.343	11.80
26	58.34	40.56	26.78	39.868	68.337	17.20
27	56.57	37.90	20.52	35.302	62.404	16.00
28	52.01	40.81	26.12	38.131	73.314	10.80
29	56.55	29.65	19.93	32.210	56.958	27.70
30	42.73	31.89	19.10	29.635	69.354	15.20
31	56.99	38.42	22.28	36.539	64.115	8.90
32	66.55	38.00	20.75	37.438	56.256	15.70
33	58.38	37.22	19.62	34.934	59.839	14.20
34	57.12	34.14	20.73	34.320	60.084	18.40
35	55.31	31.93	20.83	33.258	60.130	22.10
36	45.87	37.62	21.49	33.347	72.700	14.50
37	58.63	42.19	19.00	36.088	61.552	35.80
38	70.92	42.94	21.97	40.596	57.242	12.80
39	51.25	46.32	24.47	38.729	75.568	16.30
40	47.25	35.71	18.09	31.252	66.142	17.40
41	57.03	39.25	26.77	39.132	68.616	17.20
42	55.08	44.10	23.36	38.427	69.766	15.10
43	53.67	39.87	24.25	37.299	69.497	25.50
44	50.31	36.56	23.53	35.110	69.787	14.80
45	51.93	48.82	24.76	39.743	76.531	16.30
46	55.62	35.37	19.99	34.006	61.140	13.40
47	54.79	34.57	23.19	35.283	64.397	14.30
48	47.58	40.02	22.18	34.825	73.192	18.30
49	49.25	38.81	22.53	35.051	71.170	13.20
50	46.46	36.85	23.36	34.198	73.607	13.50
51	44.27	35.08	22.00	32.449	73.297	14.00
52	49.65	45.88	18.58	34.849	70.190	9.80
53	52.86	44.48	30.72	41.646	78.785	18.70
54	54.84	40.67	28.03	39.689	72.371	13.20

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	a	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
55	55.33	33.14	23.22	34.919	63.110	16.80
56	54.20	40.47	22.38	36.615	67.556	14.60
57	55.20	32.85	21.90	34.117	61.806	18.40
58	55.09	41.29	16.64	33.576	60.947	13.70
59	48.44	38.29	21.03	33.914	70.012	12.80
60	55.27	37.70	19.98	34.658	62.707	20.10
61	55.26	40.44	21.44	36.320	65.726	6.90
62	48.73	37.41	23.00	34.741	71.292	13.50
63	51.25	38.89	19.87	34.086	66.509	14.80
64	53.61	34.24	22.38	34.505	64.363	18.00
65	54.51	44.73	19.92	36.486	66.934	15.30
66	52.75	35.90	21.89	34.609	65.609	10.40
67	60.41	27.97	19.20	31.893	52.795	10.20
68	53.06	34.80	20.70	33.685	63.485	18.00
69	58.73	40.02	22.71	37.652	64.110	17.00
70	59.94	34.11	22.41	35.783	59.698	10.20
71	60.77	43.77	19.97	37.591	61.857	11.30
72	43.98	35.28	22.20	32.537	73.982	14.40
73	53.46	38.94	25.53	37.597	70.328	16.40
74	48.47	42.49	20.31	34.713	71.617	13.40
75	59.57	42.65	23.98	39.349	66.055	14.98
76	49.12	35.24	17.43	31.131	63.378	16.40
77	40.99	37.18	25.38	33.819	82.505	12.60
78	58.13	55.05	24.59	42.852	73.718	15.50
79	56.86	28.71	24.08	34.002	59.799	13.60
80	47.64	39.74	20.07	33.619	70.568	18.30
81	55.17	42.27	21.93	37.119	67.280	18.60
82	68.21	36.00	22.79	38.250	56.077	13.00
83	51.43	35.34	20.81	33.567	65.268	9.60
84	52.63	36.96	18.63	33.092	62.877	14.20
85	49.84	28.82	23.05	32.111	64.427	13.10
86	48.92	37.86	22.54	34.690	70.912	12.90
87	57.59	38.77	17.01	33.614	58.367	10.80
88	55.07	33.55	22.55	34.667	62.951	14.80
89	47.03	35.19	20.48	32.362	68.812	15.10
90	62.05	38.75	21.69	37.362	60.212	14.60
91	53.12	37.63	16.40	32.005	60.250	12.90
92	56.92	53.71	19.16	38.836	68.230	17.10
93	53.02	44.10	21.02	36.630	69.087	16.70
94	52.17	29.20	22.67	32.565	62.421	13.40
95	52.22	30.58	23.97	33.701	64.537	16.80
96	48.60	39.90	22.05	34.968	71.951	15.20
97	49.24	33.29	19.50	31.736	64.452	9.90
98	58.85	37.56	18.65	34.545	58.700	16.30
99	52.61	36.21	34.49	40.352	76.700	16.70
100	53.54	31.52	19.57	32.084	59.925	14.40
Mean	53.53	38.40	22.00	35.48	66.72	15.29

Table A7: Axial Dimensions of *Irvingia wombolu* seed for moisture content 20% (d.b)

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	a	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
1	49.30	44.77	22.66	36.844	74.734	17.20
2	43.95	34.58	23.08	32.735	74.481	13.00
3	53.06	33.42	22.27	34.054	64.180	16.50
4	52.88	29.29	17.94	30.288	57.278	10.90
5	45.31	43.42	26.80	37.498	82.758	36.20
6	56.54	54.37	32.40	46.354	81.984	12.90
7	46.07	40.01	24.94	35.823	77.758	16.70
8	42.92	27.24	21.32	29.211	68.060	11.90
9	43.95	33.43	24.95	33.219	75.584	16.70
10	49.56	38.07	21.70	34.466	69.544	13.70
11	53.58	35.50	24.53	36.001	67.190	9.90
12	46.98	28.19	21.10	30.346	64.593	16.80
13	31.67	14.95	28.86	23.907	75.488	14.90
14	36.27	23.32	26.14	28.067	77.383	12.80
15	56.24	29.75	24.40	34.433	61.225	14.70
16	51.33	32.11	21.44	32.815	63.930	14.80
17	50.51	39.08	18.80	33.355	66.037	14.20
18	49.92	32.15	20.80	32.199	64.501	14.40
19	51.65	33.90	22.63	34.092	66.006	21.80
20	61.70	39.13	26.83	40.161	65.091	13.10
21	49.74	45.60	24.98	38.408	77.217	11.00
22	53.16	37.62	19.33	33.813	63.605	16.50
23	54.12	43.59	24.88	38.863	71.808	11.50
24	52.53	35.95	18.94	32.948	62.722	15.70
25	45.28	37.97	29.51	37.020	81.758	24.00
26	58.45	38.26	23.91	37.674	64.454	15.20
27	55.86	36.81	22.58	35.942	64.342	18.60
28	44.71	32.81	29.19	34.985	78.249	13.80
29	57.05	53.11	25.35	42.508	74.510	15.40
30	53.96	28.41	24.31	33.402	61.902	10.60
31	51.85	37.23	22.38	35.089	67.673	16.20
32	53.46	30.82	23.52	33.840	63.300	22.30
33	48.53	38.39	21.90	34.426	70.938	13.60
34	57.97	43.74	23.85	39.252	67.710	14.40
35	65.17	38.03	22.95	38.458	59.012	12.60
36	49.10	40.14	26.70	37.473	76.321	12.80
37	71.95	42.19	23.96	41.742	58.016	20.20
38	48.50	33.76	25.49	34.687	71.520	25.90
39	58.13	37.11	23.22	36.862	63.414	10.30
40	54.95	37.54	22.99	36.197	65.872	14.00
41	68.61	35.74	20.45	36.876	53.747	15.70
42	48.10	40.52	21.05	34.490	71.704	15.40
43	67.67	41.70	24.50	41.042	60.651	14.60
44	44.05	36.64	22.01	32.873	74.627	13.00
45	49.08	33.62	23.86	34.019	69.314	18.10
46	50.79	34.35	23.22	34.344	67.620	16.30
47	41.47	39.48	19.03	31.467	75.878	13.80
48	49.32	36.95	23.94	35.204	71.378	11.90
49	48.06	35.02	20.74	32.682	68.002	13.70
50	49.35	39.58	20.97	34.471	69.850	12.60
51	55.15	33.42	25.49	36.083	65.428	13.00
52	52.45	28.44	24.96	33.392	63.664	16.70
53	52.76	42.41	22.84	37.110	70.337	18.90
54	49.22	33.29	23.98	33.997	69.071	19.70

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	a	b	c	Dp (mm) = $(abc)^{1/3}$	ϕ = $\{(abc^{1/3})\}/a$	Kg
55	59.93	37.60	22.49	37.006	61.749	14.30
56	48.38	39.69	28.45	37.944	78.429	15.10
57	51.44	47.69	26.84	40.380	78.500	13.30
58	48.73	36.51	22.78	34.350	70.489	18.20
59	43.26	39.46	21.70	33.335	77.057	17.70
60	57.71	38.24	24.23	37.674	65.281	14.70
61	49.52	28.31	24.08	32.319	65.265	9.50
62	51.71	32.12	23.38	33.863	65.487	14.10
63	51.49	43.88	28.39	40.030	77.743	16.60
64	54.04	40.03	24.46	37.542	69.471	17.30
65	49.32	39.30	21.29	34.557	70.066	21.50
66	43.57	32.99	25.25	33.109	75.990	12.10
67	50.21	40.69	26.44	37.802	75.288	14.50
68	56.73	37.17	19.63	34.592	60.976	13.70
69	48.32	36.94	22.75	34.372	71.134	14.00
70	40.14	31.07	23.26	30.726	76.548	17.30
71	51.73	30.28	24.96	33.940	65.610	23.70
72	47.20	43.45	24.76	37.031	78.455	10.50
73	50.40	40.09	24.13	36.532	72.484	20.40
74	58.64	33.02	23.85	35.877	61.182	15.20
75	56.43	43.53	22.18	37.910	67.181	17.00
76	58.34	37.86	22.15	36.574	62.691	15.40
77	42.25	38.29	24.68	34.178	80.896	15.00
78	55.84	40.27	21.77	36.582	65.511	25.40
79	53.72	34.17	21.04	33.802	62.923	12.10
80	55.03	36.52	25.87	37.323	67.823	11.40
81	52.23	44.11	23.10	37.615	72.017	18.20
82	43.88	36.03	25.15	34.132	77.784	17.30
83	50.49	32.31	25.68	34.731	68.787	13.00
84	54.58	33.84	24.79	35.775	65.546	12.20
85	55.63	30.55	23.18	34.026	61.165	6.80
86	55.78	36.52	23.85	36.489	65.417	13.50
87	48.08	39.38	25.58	36.451	75.814	18.20
88	48.34	34.39	23.40	33.883	70.094	15.60
89	55.81	39.03	22.32	36.498	65.397	13.60
90	54.34	35.09	25.83	36.656	67.456	18.20
91	49.96	34.77	18.62	31.862	63.774	12.70
92	59.35	34.54	22.94	36.095	60.817	28.30
93	57.42	38.38	21.15	35.988	62.675	18.90
94	52.01	31.77	21.98	33.116	63.673	8.10
95	53.36	37.38	21.51	35.008	65.607	10.10
96	46.72	35.34	22.72	33.475	71.651	15.90
97	42.14	31.48	24.41	31.874	75.638	14.90
98	54.98	33.99	27.09	36.993	67.285	17.60
99	58.73	41.66	20.93	37.135	63.230	13.80
100	59.56	29.52	25.92	35.719	59.972	13.00
Mean	51.71	36.56	23.62	35.30	68.81	15.51

Table A8: Axial Dimensions of *Irvingia wombolu* seed for moisture content 30% (d.b)

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	a	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
1	55.83	29.39	21.51	32.802	58.754	22.90
2	51.50	29.11	22.06	32.099	62.327	13.20
3	43.95	38.76	22.74	33.836	76.987	14.40
4	52.36	34.15	25.25	35.608	68.007	14.60
5	49.28	39.72	38.82	42.356	85.949	18.70
6	44.82	32.68	23.58	32.566	72.660	21.80
7	52.76	35.16	25.39	36.114	68.449	21.30
8	57.26	37.11	23.48	36.814	64.293	18.80
9	49.22	27.43	19.47	29.733	60.409	12.90
10	54.57	36.42	24.05	36.291	66.504	19.90
11	49.71	39.79	21.70	35.013	70.434	15.80
12	51.40	33.50	17.63	31.195	60.691	10.10
13	48.56	42.74	20.20	34.739	71.539	18.80
14	42.43	39.37	24.31	34.372	81.009	13.90
15	42.38	35.13	19.60	30.787	72.645	15.70
16	50.08	34.14	22.51	33.762	67.417	14.60
17	53.69	30.63	20.88	32.503	60.538	14.60
18	65.56	36.07	21.12	36.826	56.172	26.00
19	63.71	38.29	24.97	39.346	61.758	30.20
20	58.18	37.55	26.31	38.592	66.333	22.80
21	50.31	34.26	29.07	36.866	73.278	15.00
22	42.97	33.02	23.18	32.039	74.562	14.30
23	53.43	36.19	27.03	37.389	69.977	16.80
24	49.89	45.56	23.87	37.857	75.882	21.40
25	43.74	34.14	20.42	31.242	71.426	11.90
26	54.42	48.48	22.48	38.998	71.661	29.70
27	55.54	28.98	24.52	34.047	61.301	16.80
28	49.77	33.40	22.64	33.512	67.333	15.20
29	47.48	38.13	30.26	37.979	79.990	16.20
30	51.48	37.56	22.55	35.197	68.370	15.10
31	53.48	33.83	20.13	33.147	61.980	16.30
32	50.36	32.36	21.51	32.727	64.987	17.70
33	50.23	42.47	25.42	37.851	75.355	11.90
34	46.44	25.79	23.78	30.539	65.760	9.70
35	50.04	31.85	25.82	34.525	68.994	17.40
36	52.76	29.25	35.15	37.855	71.749	10.60
37	50.85	37.65	31.45	39.195	77.079	22.00
38	57.34	34.42	23.89	36.127	63.004	16.00
39	50.09	40.10	21.21	34.926	69.726	17.80
40	51.86	39.34	30.14	39.470	76.109	20.40
41	51.80	30.18	26.54	34.619	66.832	15.60
42	45.97	36.50	24.98	34.737	75.564	12.70
43	46.34	36.23	25.77	35.106	75.757	12.60
44	43.95	29.75	26.28	32.511	73.972	14.50
45	56.57	38.41	27.31	39.005	68.950	22.60
46	52.24	39.97	23.97	36.853	70.545	26.40
47	48.22	33.37	35.57	38.538	79.921	18.70
48	51.02	36.06	27.31	36.900	72.325	15.80
49	55.97	39.94	24.91	38.187	68.227	18.70
50	52.03	41.25	25.44	37.937	72.914	20.20
51	53.10	38.00	22.30	35.568	66.983	13.20
52	55.31	43.27	19.20	35.818	64.758	17.60
53	47.65	42.97	23.50	36.372	76.331	31.80
54	60.67	33.48	23.52	36.285	59.808	21.90

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	a	b	c	Dp (mm) = $(abc)^{1/3}$	ϕ = $\{(abc^{1/3})\}/a$	Kg
55	49.15	32.51	26.82	34.994	71.199	15.60
56	47.90	32.67	23.94	33.461	69.856	22.40
57	48.89	33.54	22.82	33.448	68.414	21.60
58	55.79	35.60	24.09	36.303	65.072	26.80
59	56.23	42.60	25.95	39.613	70.448	20.60
60	46.04	35.07	26.04	34.773	75.527	16.20
61	61.75	35.03	19.96	35.082	56.812	20.00
62	49.88	31.27	21.47	32.233	64.620	11.90
63	54.26	31.11	24.22	34.450	63.490	15.10
64	68.25	43.23	25.45	42.188	61.814	19.00
65	49.85	37.88	22.23	34.754	69.717	16.60
66	58.10	36.87	22.74	36.521	62.859	17.60
67	50.13	38.47	17.97	32.603	65.037	22.70
68	52.28	33.48	27.75	36.486	69.790	18.70
69	54.40	28.79	24.84	33.884	62.287	16.30
70	56.13	35.99	23.01	35.955	64.057	24.90
71	54.12	32.32	21.48	33.493	61.887	13.80
72	54.10	41.57	24.06	37.823	69.913	20.90
73	51.33	34.15	29.19	37.125	72.326	17.50
74	48.95	36.37	20.79	33.326	68.082	16.70
75	52.80	40.97	28.38	39.449	74.714	15.70
76	46.28	30.07	22.58	31.556	68.185	15.60
77	54.63	37.91	22.33	35.894	65.704	17.00
78	50.58	39.69	28.19	38.393	75.905	17.60
79	54.11	36.92	23.30	35.972	66.479	19.70
80	47.67	24.74	28.22	32.166	67.477	7.90
81	53.05	31.36	26.90	35.504	66.925	17.90
82	50.77	43.80	23.94	37.619	74.096	27.50
83	43.46	31.39	21.46	30.820	70.916	16.00
84	46.81	38.19	24.98	35.478	75.792	22.40
85	33.88	34.02	21.46	29.136	85.999	28.10
86	51.07	34.18	20.49	32.948	64.515	14.80
87	49.37	48.94	20.30	36.605	74.144	31.50
88	53.12	32.94	25.90	35.653	67.117	16.20
89	39.60	27.84	25.76	30.510	77.044	12.10
90	40.53	27.97	24.76	30.391	74.983	18.50
91	48.92	33.43	27.24	35.449	72.464	20.80
92	50.61	31.56	25.69	34.492	68.152	20.50
93	53.23	44.18	23.63	38.161	71.690	22.60
94	59.55	42.84	23.06	38.892	65.310	51.70
95	54.53	34.18	26.56	36.718	67.335	20.30
96	36.92	32.90	27.08	32.041	86.784	21.20
97	50.53	36.17	19.32	32.807	64.926	22.20
98	44.92	34.40	23.74	33.227	73.970	19.90
99	60.19	38.05	24.67	38.372	63.752	32.30
100	51.73	35.73	24.17	35.483	68.592	24.50
Mean	51.17	35.76	24.36	35.28	69.40	18.85

Table A9: Axial Dimensions of *Irvingia wombolu* seed for moisture content 40% (d.b)

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	a	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
1	47.66	32.09	24.72	33.563	70.421	16.60
2	51.10	33.28	21.07	32.968	64.516	16.90
3	48.65	41.89	22.27	35.670	73.320	19.20
4	45.23	26.11	23.79	30.400	67.212	9.10
5	56.89	37.23	27.38	38.707	68.038	22.60
6	37.86	34.28	30.54	34.095	90.057	19.30
7	48.11	34.69	27.40	35.760	74.330	18.70
8	51.36	29.43	22.62	32.457	63.194	16.90
9	45.55	33.29	20.61	31.499	69.152	16.20
10	41.47	32.26	25.34	32.364	78.043	15.60
11	51.35	31.38	24.56	34.078	66.364	18.40
12	48.60	31.41	21.66	32.096	66.042	16.00
13	56.56	40.18	23.23	37.514	66.325	32.10
14	46.69	32.64	25.19	33.734	72.251	16.70
15	47.74	40.18	25.82	36.724	76.925	23.60
16	50.66	33.48	23.34	34.081	67.275	14.30
17	47.91	39.42	20.27	33.703	70.346	12.10
18	44.42	34.84	25.43	34.015	76.575	14.10
19	43.43	33.92	25.92	33.674	77.536	14.60
20	49.34	40.63	25.38	37.055	75.101	21.00
21	63.48	39.25	22.93	38.515	60.672	33.30
22	50.03	35.58	21.92	33.918	67.795	16.50
23	50.51	35.41	24.58	35.294	69.874	18.90
24	45.23	26.77	24.75	31.061	68.674	10.30
25	66.93	40.71	25.50	41.111	61.423	42.90
26	56.35	38.90	26.48	38.719	68.711	42.20
27	43.91	38.54	23.21	33.993	77.414	15.40
28	52.40	35.07	22.01	34.326	65.509	24.70
29	48.99	40.75	24.16	36.401	74.302	17.30
30	52.23	31.61	24.38	34.271	65.615	18.30
31	49.35	36.65	23.63	34.963	70.847	19.20
32	50.26	35.96	25.87	36.026	71.679	21.60
33	47.35	30.95	19.39	30.515	64.447	17.90
34	52.76	36.18	18.68	32.914	62.385	24.00
35	42.53	43.85	24.00	35.505	83.483	23.10
36	47.35	41.95	20.28	34.280	72.397	21.10
37	47.49	37.54	25.22	35.559	74.876	20.10
38	52.35	38.39	21.05	34.844	66.560	18.10
39	46.43	31.31	24.83	33.049	71.179	17.70
40	37.70	27.86	27.35	30.626	81.237	15.20
41	48.95	28.60	21.65	31.179	63.695	15.70
42	47.37	32.01	21.86	32.123	67.812	13.20
43	44.91	33.66	19.66	30.975	68.972	20.50
44	50.34	31.76	22.88	33.196	65.943	16.00
45	55.58	35.02	27.19	37.545	67.551	21.20
46	47.88	38.76	38.31	41.427	86.523	15.70
47	50.84	29.14	25.97	33.759	66.402	16.40
48	63.83	34.90	23.07	37.179	58.247	19.40
49	49.79	39.83	25.87	37.158	74.629	14.70
50	52.49	32.91	24.72	34.953	66.590	15.00
51	57.53	37.95	19.65	35.007	60.850	32.70
52	58.98	39.70	28.03	40.337	68.391	20.60
53	55.50	39.45	26.94	38.927	70.138	18.40
54	43.45	32.55	27.06	33.699	77.559	14.50

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	a	b	c	Dp (mm) = $(abc)^{1/3}$	ϕ = $\{(abc^{1/3})\}/a$	Kg
55	54.55	34.28	19.63	33.234	60.924	18.80
56	50.74	44.72	23.64	37.714	74.327	27.50
57	56.57	57.05	25.29	43.377	76.679	29.50
58	59.11	41.99	22.70	38.336	64.856	23.60
59	51.15	37.12	25.36	36.380	71.125	16.60
60	48.44	37.32	26.44	36.291	74.920	25.80
61	46.41	38.44	28.09	36.868	79.440	20.50
62	49.47	34.62	20.15	32.557	65.812	16.50
63	45.39	33.44	21.32	31.867	70.207	22.50
64	50.48	34.35	24.23	34.764	68.867	19.90
65	54.54	34.42	25.21	36.171	66.321	18.90
66	51.97	38.90	22.22	35.548	68.401	15.90
67	43.47	35.17	25.75	34.018	78.257	17.30
68	44.25	32.38	23.08	32.098	72.537	14.40
69	50.92	29.41	22.72	32.404	63.637	17.00
70	40.88	38.43	21.90	32.524	79.561	18.00
71	53.55	32.69	21.88	33.709	62.948	23.50
72	50.61	36.94	23.29	35.180	69.513	22.40
73	54.19	33.51	21.84	34.102	62.931	19.80
74	48.73	37.90	26.53	36.592	75.092	22.20
75	54.33	34.94	27.30	37.283	68.623	21.50
76	49.72	35.11	22.68	34.083	68.549	16.30
77	64.17	35.51	23.84	37.873	59.020	31.70
78	49.07	29.42	22.72	32.010	65.234	14.00
79	51.29	30.52	26.71	34.708	67.670	15.50
80	49.17	37.71	19.77	33.219	67.560	22.20
81	52.50	32.86	26.19	35.617	67.841	24.80
82	52.99	36.27	31.14	39.116	73.818	25.30
83	42.91	35.91	22.82	32.761	76.349	24.60
84	52.15	31.90	24.13	34.240	65.657	16.60
85	51.92	29.36	31.01	36.157	69.641	20.20
86	42.16	33.92	21.33	31.245	74.111	18.60
87	46.86	36.59	31.32	37.728	80.512	19.20
88	49.04	36.84	22.00	34.127	69.590	16.90
89	53.81	36.00	24.98	36.441	67.721	20.50
90	53.11	35.00	19.00	32.809	61.776	27.50
91	48.59	29.20	21.45	31.221	64.255	13.80
92	43.15	30.12	24.18	31.557	73.134	14.50
93	50.38	33.62	24.84	34.781	69.036	17.70
94	51.40	33.38	33.18	38.469	74.842	20.20
95	57.04	35.88	23.87	36.556	64.089	22.80
96	54.96	33.06	33.70	39.415	71.716	24.80
97	53.72	36.31	25.37	36.714	68.343	24.50
98	44.87	34.53	26.76	34.611	77.136	18.70
99	48.15	34.70	26.15	35.221	73.148	16.10
100	52.59	36.68	24.44	36.125	68.692	28.40
Mean	50.17	35.31	24.42	34.95	70.10	19.93

Table A10: Axial Dimensions of *Irvingia wombolu* seed for moisture content 50% (d.b)

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	a	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
1	52.86	33.96	23.58	34.851	65.930	33.60
2	47.80	35.18	22.43	33.536	70.160	25.50
3	46.19	37.46	21.65	33.460	72.440	28.00
4	39.15	33.26	25.13	31.985	81.699	27.00
5	42.68	37.38	33.15	37.536	87.948	23.00
6	40.19	30.78	25.42	31.564	78.536	25.10
7	53.15	38.42	24.17	36.681	69.015	32.70
8	42.90	33.03	22.01	31.477	73.373	22.50
9	39.77	31.60	25.54	31.780	79.910	19.00
10	36.93	31.65	26.15	31.266	84.663	19.30
11	40.66	34.03	22.52	31.468	77.392	27.50
12	41.09	32.24	30.33	34.251	83.355	20.70
13	41.33	31.12	25.90	32.176	77.852	24.30
14	37.15	34.56	23.61	31.180	83.930	21.60
15	38.71	27.03	23.40	29.038	75.013	20.50
16	43.14	32.79	23.61	32.204	74.649	23.20
17	40.83	35.42	23.66	32.465	79.512	25.70
18	43.22	34.00	24.30	32.930	76.191	23.50
19	44.51	38.05	27.27	35.878	80.607	30.50
20	38.88	34.92	23.85	31.873	81.979	25.40
21	40.76	34.04	21.44	30.985	76.018	24.10
22	33.86	29.30	29.68	30.880	91.198	15.50
23	36.78	26.02	21.27	27.304	74.236	11.60
24	39.33	31.31	22.30	30.170	76.709	18.90
25	36.68	28.09	27.15	30.356	82.760	16.90
26	40.31	39.81	22.54	33.071	82.043	42.60
27	36.78	27.37	20.96	27.633	75.130	20.60
28	41.95	41.74	23.02	34.287	81.733	35.70
29	41.74	29.22	23.90	30.776	73.732	18.50
30	39.56	32.24	25.78	32.036	80.982	18.50
31	41.43	34.64	24.74	32.867	79.332	24.30
32	43.79	32.34	27.21	33.776	77.133	22.90
33	44.34	30.66	21.70	30.899	69.686	20.10
34	41.70	29.12	22.12	29.948	71.818	16.60
35	38.62	29.36	19.68	28.153	72.899	19.20
36	45.61	32.97	23.78	32.946	72.233	24.10
37	46.79	35.00	26.42	35.106	75.029	23.00
38	46.98	31.81	26.47	34.073	72.527	32.00
39	40.00	29.22	18.88	28.049	70.122	22.60
40	37.86	29.82	27.18	31.307	82.692	16.70
41	44.59	29.04	26.05	32.311	72.462	27.30
42	42.55	30.33	25.45	32.025	75.264	23.90
43	48.51	33.30	25.29	34.441	70.998	28.30
44	42.59	30.98	24.66	31.925	74.958	20.10
45	36.45	32.54	30.65	33.127	90.883	25.80
46	35.98	28.84	24.03	29.215	81.197	16.10
47	40.40	31.78	21.52	30.231	74.830	22.90
48	41.00	36.68	21.24	31.729	77.388	25.50
49	48.12	36.48	25.91	35.696	74.181	26.60
50	46.98	29.15	26.06	32.924	70.080	23.10
51	47.90	33.29	24.04	33.718	70.392	24.70
52	42.59	25.14	30.29	31.890	74.877	15.70
53	37.88	30.72	27.16	31.617	83.466	19.00
54	59.19	38.16	27.23	39.473	66.689	48.80

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	a	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
55	38.05	31.47	25.18	31.124	81.799	24.50
56	36.55	31.81	25.49	30.946	84.668	21.00
57	40.32	29.33	22.09	29.672	73.591	21.70
58	40.63	31.82	34.79	35.563	87.529	15.40
59	45.09	30.02	25.27	32.461	71.992	18.60
60	38.33	29.50	31.48	32.895	85.821	18.10
61	39.00	31.52	24.42	31.079	79.689	23.80
62	38.10	34.68	19.47	29.520	77.482	24.20
63	40.69	33.80	26.26	33.055	81.235	22.15
64	42.33	31.13	29.23	33.772	79.782	24.45
65	40.68	33.22	36.65	36.724	90.276	22.10
66	37.90	29.27	19.53	27.878	73.556	19.10
67	45.16	27.26	23.32	30.620	67.803	17.20
68	40.54	27.35	22.13	29.059	71.679	21.50
69	37.24	29.60	20.49	28.267	75.905	18.10
70	45.56	22.64	25.74	29.832	65.480	21.80
71	39.58	26.38	26.62	30.291	76.532	18.90
72	44.42	34.46	22.54	32.555	73.289	25.60
73	37.86	34.59	26.80	32.741	86.478	31.40
74	41.31	31.05	27.86	32.938	79.734	20.50
75	35.44	33.06	25.33	30.961	87.361	21.10
76	35.10	27.29	27.09	29.606	84.346	14.30
77	37.83	30.68	36.16	34.751	91.862	21.20
78	34.82	29.81	26.30	30.110	86.474	18.55
79	34.27	33.90	22.94	29.870	87.161	22.75
80	36.31	30.37	20.78	28.404	78.225	18.75
81	39.36	28.30	25.08	30.343	77.091	19.40
82	39.38	33.00	26.14	32.387	82.241	23.90
83	36.89	22.42	22.16	26.366	71.471	21.00
84	35.62	29.11	21.95	28.339	79.560	15.60
85	37.97	37.57	21.21	31.161	82.067	27.60
86	36.86	32.66	23.20	30.340	82.312	22.00
87	36.99	20.33	27.27	27.372	73.998	10.90
88	38.93	30.59	27.33	31.928	82.013	25.00
89	38.20	28.23	24.33	29.715	77.787	14.50
90	30.68	25.55	23.92	26.567	86.593	15.10
91	37.66	21.56	25.59	27.492	72.999	14.00
92	40.06	31.16	29.90	33.419	83.422	19.10
93	45.38	33.20	24.25	33.182	73.121	20.75
94	34.38	28.12	20.74	27.167	79.020	18.20
95	40.32	31.01	21.73	30.063	74.560	25.10
96	45.55	26.83	30.48	33.397	73.320	20.60
97	38.09	29.47	26.59	31.020	81.438	20.40
98	40.95	28.42	23.61	30.176	73.689	17.30
99	40.45	36.90	23.83	32.887	81.303	22.60
100	33.10	26.45	20.64	26.241	79.279	17.30
Mean	40.71	31.34	24.97	31.57	77.97	22.28

Table A11: Independent samples t-test of the difference between axial dimensions of *Irvingia wombolu* and *Irvingia gabonensis* seed

(a) Length (mm)

Moisture	Specie		t-test for Equality of Means		
Content	*Irvingia wombolu*	*Irvingia gabonensis*	t	P-value	tcritical
10%	53.5256	38.5052	23.1471**	9.84E-42	1.984217
20%	51.7141	37.5565	0.0268**	1.35E-36	1.984217
30%	51.1696	37.0374	24.4519**	9.61E-44	1.984217
40%	50.1712	36.0343	23.2014**	8.09E-42	1.984217
50%	40.7067	34.7004	12.4807**	4.86E-22	1.984217

** Mean difference Significant at 0.05 levels

(b) Width (mm)

Moisture	Specie		t-test for Equality of Means		
Content	*Irvingia wombolu*	*Irvingia gabonensis*	t	P-value	tcritical
10%	38.4044	31.2785	13.8491**	6.72E-25	1.984217
20%	36.5617	30.9321	8.85940**	3.35E-14	1.984217
30%	35.7619	30.8527	10.1035**	6.51E-17	1.984217
40%	35.3052	30.6461	9.1426**	8.11E-15	1.984217
50%	31.3428	30.2634	2.33667**	0.021471	1.984217

** Mean difference Significant at 0.05 levels

(c) Thickness (mm)

Moisture	Specie		t-test for Equality of Means		
Content	*Irvingia wombolu*	*Irvingia gabonensis*	t	P-value	tcritical
10%	22.0046	19.6877	7.3343**	6.21E-11	1.984217
20%	23.6153	19.7084	14.3856**	5.38E-26	1.984217
30%	24.3563	19.7851	11.5172**	5.57E-20	1.984217
40%	24.4177	19.8168	13.5943**	2.26E-24	1.984217
50%	24.9739	20.1743	11.0979**	4.48E-19	1.984217

** Mean difference Significant at 0.05 levels

(d) Geometric mean diameter

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia wombolu	*Irvingia gabonensis*	t	P-value	tcritical
10%	35.475	28.688	23.576**	2.11E-42	1.984217
20%	35.304	28.366	19.922**	2.05E-36	1.984217
30%	35.275	28.237	24.983**	1.54E-44	1.984217
40%	34.953	27.933	23.807**	9.25E-43	1.984217
50%	31.568	27.594	13.401**	5.69E-24	1.984217

** Mean difference Significant at 0.05 levels

(d) Sphericity (%)

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia wombolu	*Irvingia gabonensis*	t	P-value	tcritical
10%	66.7231	74.7404	-11.3162**	1.51E-19	1.984217
20%	68.8145	75.6638	-9.4859**	1.45E-15	1.984217
30%	69.4047	76.3815	-9.6050**	7.96E-16	1.984217
40%	70.0982	77.6982	-10.8241**	1.76E-18	1.984217
50%	77.9687	79.6453	-2.3112**	0.022898	1.984217

** Mean difference Significant at 0.05 levels

(e) 1000 seed weight

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia wombolu	*Irvingia gabonensis*	t	P-value	tcritical
10%	15.2938	8.5669	15.85486**	9.69E-26	1.984217
20%	15.51	9.019	14.25983**	9.69E-26	1.984217
30%	18.849	9.352	15.16804**	1.44E-27	1.984217
40%	19.933	10.268	16.09441**	2.17E-29	1.984217
50%	19.933	10.268	19.38588**	1.77E-35	1.984217

** Mean difference Significant at 0.05 levels

Table A-12: Parameter Estimates for *Irvingia gabonensis* and *Irvingia wombolu* Size

(a) *Irvingia gabonensis*

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	Intercept	1	0.04197	0.01083	3.87	0.0001	0
MASS	MASS	1	0.00509	0.00021627	23.55	<.0001	0.69629
SPH	SPH	1	0.00098443	0.00009561	10.30	<.0001	0.28361
GMD	GMD	1	-0.00488	0.00028593	-17.07	<.0001	-0.49904

(b)

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	Intercept	1	0.02110	0.00748	2.82	0.0050	0
MASS	MASS	1	0.00105	0.00007964	13.15	<.0001	0.42983
SPH	SPH	1	0.00067112	0.00006558	10.23	<.0001	0.33796
GMD	GMD	1	-0.00167	0.00015130	-11.05	<.0001	-0.36202

Table A13: True and bulk density, porosity of *Irvingia gabonensis* and *Irvingia wombolu* seed for moisture content 10% (d. b)

		Irvingia wombolu			*Irvingia gabonensis*		
S/N	Moisture content	True density (kgm^{-3})	Bulk density (kgm^{-3})	Porosity (%)	True density (kgm^{-3})	Bulk density (kgm^{-3})	Porosity (%)
1	10%	1.0240	0.4476	47.0830	0.84587	0.3644	64.4054
2		0.8738	0.4542	48.2343	0.8775	0.3637	58.3785
3		1.0605	0.4534	54.0206	0.9860	0.3661	65.4762
4		1.0262	0.4526	60.4220	1.1435	0.3607	64.8421
5		1.0042	0.4523	41.4723	0.7729	0.3646	63.6844
6		1.0890	0.4454	61.3712	1.1531	0.3633	66.6385
7		0.7730	0.4457	50.8048	0.9060	0.3696	52.1797
8		1.0229	0.4561	43.3162	0.8048	0.3687	63.9499
9		0.9225	0.4456	34.9849	0.6854	0.3634	60.6089
10		1.0579	0.4526	52.7418	0.9578	0.3619	65.7881
11		1.0436	0.4480	54.6195	0.9872	0.3662	64.9081
12		0.9626	0.4454	51.5543	0.9195	0.3601	62.5926
13		0.9299	0.4538	50.3124	0.9134	0.3630	60.9609
14		0.9474	0.4547	43.6112	0.8064	0.3660	61.3637
15		0.9395	0.4583	49.8689	0.9143	0.3626	61.4038
16		0.9762	0.4564	43.4406	0.8069	0.3704	62.0544
17		1.0470	0.4536	56.4313	1.0410	0.3601	65.6063
18		1.0953	0.4595	55.0477	1.0222	0.3619	66.9562
19		0.9829	0.4469	51.9096	0.9293	0.3630	63.0675
20		0.9488	0.4504	54.3175	0.98602	0.3674	61.2762
Mean		0.9863	0.4517	51.0655	0.9230	0.3644	63.0579
1	20%	0.9783	0.4895	49.9660	0.8902	0.3927	55.8904
2		0.9914	0.4840	51.1791	1.0714	0.3676	65.6898
3		0.9896	0.4916	50.3215	0.9770	0.4030	58.7493
4		1.0108	0.4887	51.6516	1.0460	0.3826	63.4185
5		0.9054	0.4915	45.7136	0.8770	0.3595	59.0068
6		0.9032	0.4917	45.5610	1.0692	0.3979	62.7878
7		0.8833	0.4832	45.2959	1.0515	0.3804	63.8230
8		0.9222	0.4898	46.8939	1.1250	0.3884	65.4764
9		1.0109	0.4870	51.8212	1.0539	0.3973	62.3057
10		0.9528	0.4909	48.4770	1.0864	0.3878	64.3043
11		0.8909	0.4861	45.4435	1.0080	0.4040	59.9206
12		0.9810	0.4899	50.0635	1.0114	0.3823	62.1955
13		0.9490	0.4879	48.5866	0.9839	0.3897	60.3954
14		0.8889	0.4897	44.9134	1.0207	0.4026	60.5527

		Irvingia wombolu			*Irvingia gabonensis*		
S/N	Moisture content	True density (kgm^{-3})	Bulk density (kgm^{-3})	Porosity (%)	True density (kgm^{-3})	Bulk density (kgm^{-3})	Porosity (%)
15		1.0000	0.4831	51.6878	1.0840	0.3911	63.9198
16		0.9434	0.4839	48.7063	0.9945	0.4088	58.8949
17		1.2159	0.4842	60.1784	1.0123	0.3662	63.8292
18		0.9730	0.4868	49.9648	1.0659	0.3632	65.9248
19		1.0000	0.4811	51.8927	1.0630	0.3708	65.1146
20		1.0825	0.4672	56.8378	0.9932	0.3670	63.0479
Mean		0.9736	0.4864	50.0435	1.0242	0.3852	62.3963
1	30%	1.0546	0.5360	49.1724	1.1450	0.4764	58.3938
2		1.0170	0.5362	47.2742	1.0909	0.4781	56.1788
3		1.0357	0.5364	48.2106	1.2000	0.4656	61.2033
4		1.0899	0.5299	51.3846	1.2696	0.4875	61.6000
5		1.0444	0.5380	48.4940	1.1131	0.4050	63.6172
6		1.0756	0.5308	50.6495	1.2386	0.4487	63.7761
7		1.0824	0.5310	50.9380	1.1211	0.4306	61.5866
8		1.0526	0.5367	49.0151	1.0682	0.4674	56.2420
9		1.0455	0.5376	48.5811	1.1727	0.4791	59.1446
10		1.0094	0.5625	44.2721	1.0585	0.4845	54.2293
11		1.1848	0.5413	54.3150	1.1617	0.4674	59.7668
12		1.0500	0.5648	46.2114	1.0100	0.4929	51.2002
13		1.0377	0.5696	45.1150	1.1258	0.4753	57.7777
14		1.0960	0.5637	48.5669	1.3628	0.4706	65.4643
15		1.1304	0.5675	49.7970	1.0129	0.4426	56.3005
16		1.0556	0.5611	46.846	1.3905	0.4744	65.8794
17		1.0526	0.5619	46.624	1.3273	0.4865	63.3431
18		1.0889	0.5546	49.0642	1.1207	0.4788	57.2737
19		1.2099	0.5623	53.5208	1.1890	0.4938	58.4722
20		1.1100	0.5531	50.1734	1.0857	0.4919	54.6932
Mean		1.0762	0.5487	49.0087	1.1632	0.4699	59.6063
1	40%	1.0778	0.5905	45.2079	1.1556	0.4822	58.2674
2		1.0909	0.5911	45.8138	1.1622	0.4996	57.0103
3		1.0543	0.5942	43.6387	1.1636	0.5079	56.3521
4		1.1842	0.5915	50.0501	1.0111	0.5009	50.4626
5		1.1630	0.5929	49.0236	1.1300	0.4778	57.7207
6		0.9821	0.5901	39.9124	1.0722	0.4808	55.1604
7		0.8778	0.5942	32.3013	1.1548	0.4889	57.6670
8		1.3200	0.5916	55.1811	1.1805	0.5023	57.4450
9		1.1111	0.5932	46.6146	1.2180	0.5125	57.9254
10		1.2933	0.5981	53.7516	1.1680	0.4934	57.7598

		Irvingia wombolu			*Irvingia gabonensis*		
S/N	Moisture content	True density (kgm^{-3})	Bulk density (kgm^{-3})	Porosity (%)	True density (kgm^{-3})	Bulk density (kgm^{-3})	Porosity (%)
11		1.1364	0.5948	47.6550	1.1358	0.5063	55.4199
12		1.3088	0.5904	54.8878	1.2308	0.5123	58.3762
13		1.1724	0.5978	49.0149	1.0700	0.5012	53.1616
14		1.1778	0.5932	49.6364	1.3577	0.5045	62.8431
15		1.0682	0.5970	44.1129	1.1512	0.4847	57.8983
16		1.1159	0.5922	46.9332	1.2883	0.4960	61.4993
17		1.1277	0.5754	48.9727	1.1863	0.5104	56.9713
18		1.0072	0.5929	41.1357	1.2500	0.5185	58.5171
19		1.3030	0.5920	54.5674	1.2435	0.4998	59.8059
20		1.1833	0.5980	49.4607	1.1263	0.5090	54.8084
Mean		1.1378	0.5926	47.9186	1.1728	0.4994	57.4137
1	50%	1.0556	0.6482	38.5920	1.2361	0.6427	48.0037
2		0.9136	0.6794	25.6316	1.2212	0.6374	47.8082
3		2.1379	0.6598	69.1382	1.1915	0.6334	46.8425
4		1.1228	0.6473	42.3483	1.1638	0.6804	41.5368
5		1.1186	0.6625	40.7732	1.2432	0.6277	49.5105
6		1.1884	0.6563	44.7754	1.1567	0.6624	42.7294
7		1.2404	0.6626	46.5783	1.1567	0.6373	44.9048
8		1.1810	0.6655	43.6542	1.2097	0.6302	47.8998
9		1.4176	0.6597	53.4625	1.2195	0.6223	48.9680
10		1.1364	0.6486	42.9245	1.2867	0.6500	49.4781
11		1.1880	0.6704	43.5643	1.1803	0.6561	44.4106
12		1.1789	0.6411	45.6233	1.2035	0.6185	48.6047
13		1.0714	0.6700	37.4712	1.2056	0.6509	46.0084
14		1.2364	0.6367	48.5036	1.1739	0.6094	48.0911
15		1.1789	0.6615	43.8937	1.2500	0.6171	50.6341
16		1.2018	0.6562	45.4006	1.1878	0.6221	47.6217
17		1.1826	0.6541	44.6862	1.1473	0.6495	43.3931
18		1.1700	0.6668	43.0060	1.2113	0.6322	47.8103
19		1.1889	0.6571	44.7322	1.1754	0.6844	41.7725
20		1.2182	0.6573	46.0451	1.1339	0.6618	41.6404
Mean		1.2164	0.6581	45.9003	1.1977	0.6413	46.4565

Table A14: Independent samples t-test of the difference between densities and porosity of *Irvingia wombolu* and *Irvingia gabonensis* seed

(a) True density

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia wombolu	*Irvingia gabonensis*	t	P-value	tcritical
10%	0.986395	0.922986	2.61198**	0.0171	2.093024
20%	1.024225	0.973617	2.2832**	0.0341	2.093024
30%	1.163198	1.076148	3.3442**	0.0034	2.093024
40%	1.172792	1.137769	1.2148^{NS}	0.2393	2.093024
50%	1.197703	1.216373	0.3405^{NS}	0.7372	2.093024

** Mean difference Significant at 0.05 levels, NS not significant at 0.05 levels

(b) Bulk density

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia wombolu	*Irvingia gabonensis*	t	P-value	tcritical
10%	0.364395	0.451659	-73.7354**	8.04E-25	2.093024
20%	0.385146	0.486385	-31.9193**	5.69E-18	2.093024
30%	0.469859	0.548741	-15.9963**	1.77E-12	2.093024
40%	0.499449	0.592566	-31.5755**	6.97E-18	2.093024
50%	0.641293	0.658054	-3.36201**	0.003274	2.093024

** Mean difference Significant at 0.05 levels

(b) Porosity

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia wombolu	*Irvingia gabonensis*	t	P-value	tcritical
10%	62.80711	50.27825	9.073515**	2.46E-08	2.093024
20%	62.26236	49.75778	13.50086**	3.45E-11	2.093024
30%	59.30714	48.91124	10.82768**	1.44E-09	2.093024
40%	57.25359	47.39359	7.252223**	6.97E-07	2.093024
50%	46.38343	44.54022	0.974086^{NS}	0.342253	2.093024

** Mean difference Significant at 0.05 levels, NS not significant at 0.05 levels

Table A-15: Parameter estimates for Irvingia gabonensis and Irvingia wombolu seed density

(a) Irvingia gabonensis

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	Intercept	1	-0.08490	0.00632	-13.44	<.0001	0
TD	TD	1	-0.00626	0.00476	-1.32	0.1911	-0.07405
BD	BD	1	0.20342	0.01028	19.78	<.0001	1.06721
PORO	PORO	1	0.00021175	0.00011650	1.82	0.0721	0.08558

(b) Irvingia wombolu

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	Intercept	1	0.06862	0.05044	1.36	0.1767	0
TD	TD	1	0.08811	0.03016	2.92	0.0043	0.70290
BD	BD	1	-0.04949	0.07334	-0.67	0.5013	-0.34896
PORO	PORO	1	-0.00196	0.00084627	-2.32	0.0225	-0.92685

Table B1: Axial Dimensions of Irvingia *gabonensis* kernel for moisture content 2.18% (d. b)

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	A	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
1	28.68	16.23	3.70	11.986704	41.79465	1.12
2	26.09	16.73	3.91	11.950395	45.8045	1.23
3	27.14	16.48	3.36	11.454306	42.20452	0.98
4	25.11	15.34	2.97	10.458663	41.65139	0.94
5	24.19	14.02	3.27	10.350879	42.78991	0.83
6	23.04	16.20	3.07	10.464343	45.41815	0.73
7	24.02	17.73	2.84	10.654507	44.35682	0.90
8	26.71	17.68	3.99	12.351215	46.24191	1.13
9	24.55	14.62	2.88	10.11107	41.18562	0.94
10	26.48	16.76	4.10	12.208396	46.10422	0.97
11	24.65	17.35	4.47	12.411034	50.34902	0.88
12	25.55	14.94	3.62	11.138243	43.59391	0.61
13	24.90	15.45	3.25	10.77301	43.2651	0.92
14	24.39	16.52	3.44	11.149621	45.7139	1.05
15	24.32	15.07	3.64	11.008447	45.265	0.96
16	27.77	16.34	3.15	11.264524	40.56364	0.84
17	26.74	13.40	4.11	11.377216	42.54755	0.67
18	27.98	16.31	4.15	12.372285	44.21832	0.85
19	25.09	14.29	3.13	10.391839	41.41825	0.84
20	24.06	17.87	4.10	12.08003	50.20794	0.93
21	26.74	14.81	3.59	11.244418	42.05093	0.78
22	24.31	13.56	4.07	11.029259	45.36923	0.65
23	26.79	15.36	3.47	11.260676	42.03313	1.02
24	25.99	14.44	2.91	10.298062	39.62317	0.75
25	23.07	16.50	3.21	10.690849	46.34091	0.76
26	25.41	15.00	3.83	11.343966	44.64371	0.85
27	23.49	17.94	3.69	11.585389	49.32051	0.87
28	25.15	15.92	2.92	10.534679	41.88739	0.90
29	26.69	16.11	3.60	11.567749	43.34114	0.95
30	26.06	16.12	3.41	11.272786	43.25705	0.92
31	26.45	15.59	3.96	11.775761	44.52084	0.81
32	23.82	15.80	3.67	11.13666	46.7534	0.62
33	27.06	13.80	3.26	10.677629	39.45909	0.86
34	25.00	15.22	4.39	11.865145	47.46058	0.80
35	23.22	15.95	3.27	10.659174	45.90514	0.90
36	27.81	14.01	2.90	10.415474	37.45226	0.90
37	27.81	14.01	3.35	10.928519	39.29708	0.90
38	26.41	15.73	3.91	11.755054	44.50986	0.91
39	25.69	16.45	3.20	11.058426	43.04565	1.12
40	26.86	13.52	2.68	9.9099736	36.89491	0.52
41	25.63	17.62	3.87	12.045417	46.99733	0.73
42	23.01	16.02	3.70	11.089883	48.19593	0.83
43	25.68	13.45	3.12	10.252363	39.92353	0.56
44	23.19	17.55	3.29	11.021937	47.52884	0.89
45	24.70	16.73	3.99	11.813772	47.82904	0.82
46	27.56	15.44	2.86	10.676548	38.73929	0.68
47	24.85	12.60	3.61	10.416809	41.91875	0.57
48	26.86	15.70	3.44	11.320216	42.14526	0.69
49	24.56	16.66	3.12	10.848074	44.16968	0.88
50	27.94	15.03	4.28	12.158399	43.5161	0.92
51	26.78	16.72	3.69	11.822003	44.1449	0.84
52	24.48	15.73	3.37	10.907453	44.55659	0.83
53	25.58	15.00	3.39	10.916008	42.67399	0.96
54	28.31	14.85	3.87	11.761402	41.54504	0.78
55	27.49	15.16	4.02	11.876815	43.20413	0.61

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	A	b	c	Dp (mm) = $(abc)^{1/3}$	ϕ = $\{(abc^{1/3})\}/a$	Kg
56	26.77	12.85	3.72	10.856708	40.5555	0.62
57	27.62	16.45	3.73	11.922467	43.16607	1.06
58	26.39	16.90	4.19	12.317239	46.67389	0.73
59	26.73	13.31	2.78	9.9633932	37.2742	0.61
60	28.41	16.19	3.58	11.808653	41.56513	1.12
61	27.81	15.01	3.00	10.778731	38.75847	0.89
62	25.96	14.08	3.61	10.968271	42.25066	0.60
63	25.63	13.20	3.38	10.457144	40.8004	0.60
64	27.97	14.45	3.62	11.352451	40.58795	0.79
65	26.49	18.89	3.24	11.747703	44.34769	1.16
66	24.20	17.51	2.92	10.735644	44.36217	1.03
67	25.51	13.34	3.96	11.045545	43.29888	0.74
68	30.13	15.53	3.80	12.114851	40.2086	1.20
69	28.23	16.47	3.02	11.197914	39.66672	1.10
70	25.24	15.63	3.12	10.716862	42.45983	0.65
71	26.36	16.87	2.40	10.219365	38.76846	0.85
72	27.91	16.33	3.50	11.684354	41.8644	0.97
73	22.93	18.99	3.46	11.46397	49.99551	1.04
74	24.62	16.81	3.73	11.557259	46.94256	0.93
75	25.35	14.75	3.14	10.549532	41.61551	0.70
76	24.99	16.32	3.21	10.939492	43.77548	1.07
77	26.78	16.60	3.86	11.972054	44.7052	0.73
78	25.87	14.58	3.88	11.353469	43.88662	0.62
79	26.65	16.62	3.60	11.68271	43.83756	0.88
80	25.14	14.91	3.39	10.831307	43.08396	0.75
81	25.31	14.94	2.99	10.417687	41.16036	0.65
82	24.86	16.18	2.32	9.7721294	39.30865	0.98
83	27.09	15.36	3.14	10.93226	40.35533	0.64
84	26.41	15.79	3.10	10.893583	41.24795	0.91
85	27.63	16.98	3.82	12.146765	43.96223	0.93
86	26.61	17.02	3.87	12.056978	45.30995	0.80
87	25.12	16.20	3.79	11.553794	45.9944	0.71
88	24.64	14.96	4.38	11.731372	47.61109	0.83
89	25.78	15.92	2.71	10.360922	40.18977	0.96
90	27.48	16.59	3.23	11.376846	41.40046	1.09
91	27.20	14.71	3.40	11.08035	40.73658	1.03
92	26.67	13.93	3.43	10.841501	40.65055	0.74
93	24.58	14.77	3.83	11.161444	45.40864	0.88
94	27.69	13.23	3.56	10.925574	39.45675	0.83
95	26.06	19.34	3.80	12.418567	47.65375	1.04
96	26.07	17.17	3.00	11.032591	42.31911	1.00
97	25.10	13.95	3.05	10.22153	40.72323	0.84
98	25.31	15.26	3.47	11.025342	43.56121	1.01
99	23.93	15.13	3.39	10.706819	44.74224	0.70
100	25.86	16.78	3.25	11.214191	43.36501	1.02
Mean	25.91	15.66	3.47	11.18	43.25	0.86

Table B2: Axial Dimensions of Irvingia *gabonensis* kernel for moisture content 3.65% (d. b)

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	A	b	c	Dp (mm) = $(abc)^{1/3}$	ϕ = $\{(abc^{1/3})\}/a$	Kg
1	30.93	20.04	3.62	13.09168	42.3268	1.33
2	29.25	15.60	3.86	12.07663	41.28764	1.84
3	30.08	18.54	3.40	12.37719	41.14758	1.26
4	26.74	15.50	4.22	12.04856	45.05819	1.63
5	31.74	15.58	3.90	12.44743	39.21685	1.98
6	24.19	15.28	3.94	11.33492	46.85788	1.58
7	25.68	16.58	3.70	11.63573	45.31049	1.78
8	27.89	19.97	3.48	12.46815	44.70472	1.26
9	30.32	15.97	4.47	12.93542	42.663	1.65
10	26.60	16.63	3.88	11.97297	45.01116	1.85
11	28.53	17.39	3.22	11.69012	40.97484	1.94
12	26.39	16.23	3.27	11.18841	42.39642	1.82
13	27.03	18.98	3.33	11.95443	44.22652	1.01
14	23.66	13.87	4.52	11.40451	48.20164	1.66
15	25.88	18.01	4.09	12.39939	47.9111	2.00
16	28.75	16.76	3.32	11.69544	40.6798	1.65
17	33.18	17.25	3.58	12.70134	38.28011	1.53
18	29.07	17.17	3.59	12.14609	41.78222	1.18
19	27.92	16.86	4.03	12.3792	44.33812	1.58
20	28.21	15.46	3.52	11.53591	40.89297	1.71
21	30.13	18.50	4.56	13.64725	45.29457	1.09
22	26.20	18.41	3.82	12.2595	46.79199	1.96
23	24.92	17.96	3.71	11.84157	47.51835	1.97
24	24.12	16.28	3.71	11.33623	46.99928	1.59
25	28.09	15.17	3.52	11.44704	40.75131	1.57
26	25.33	15.80	3.57	11.26298	44.465	1.82
27	24.54	17.38	3.93	11.87879	48.40584	1.87
28	27.40	16.06	4.22	12.29144	44.85928	1.75
29	25.59	15.68	3.37	11.05814	43.21274	1.71
30	24.08	15.61	4.04	11.49424	47.73355	1.69
31	28.90	18.69	4.29	13.23289	45.78856	1.16
32	29.68	17.63	3.78	12.55267	42.29335	1.81
33	26.13	16.93	5.68	13.59507	52.0286	1.68
34	24.69	15.63	3.75	11.31107	45.81236	2.00
35	27.96	15.79	3.60	11.67008	41.73849	1.66
36	26.10	15.94	3.61	11.45193	43.87713	1.64
37	25.85	15.49	3.61	11.3068	43.74004	1.63
38	25.18	16.13	4.18	11.9295	47.37687	1.85
39	26.89	16.33	3.69	11.7454	43.67943	1.76
40	26.22	13.99	3.30	10.65749	40.6464	1.60
41	24.78	15.99	3.41	11.05524	44.61355	1.64
42	23.95	15.96	3.65	11.17405	46.65572	1.80
43	24.51	16.22	3.66	11.33161	46.23261	1.78
44	26.44	15.75	3.35	11.17366	42.26045	1.60
45	26.23	14.69	3.00	10.49495	40.01125	1.93
46	22.65	15.34	3.64	10.8143	47.74524	1.53
47	26.69	16.54	3.94	12.02615	45.05865	1.55
48	23 .85	17.88	3.49	11.41722	47.87095	1.87
49	25.37	15.20	3.34	10.8802	42.88608	1.56
50	26.85	17.75	4.09	12.49171	46.52407	1.78
51	27.39	16.59	3.22	11.35267	41.44824	1.09
52	27.52	16.42	3.47	11.61762	42.21517	1.88
53	27.46	15.58	3.64	11.59106	42.2107	1.87
54	23.17	15.54	3.47	10.77049	46.48464	1.76

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	A	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
55	25.14	17.27	3.99	12.01001	47.77253	1.84
56	24.70	18.63	3.41	11.62041	47.04619	1.04
57	26.83	16.11	3.38	11.34691	42.29188	1.65
58	25.44	14.64	3.93	11.35404	44.63064	1.83
59	27.12	14.96	3.21	10.92049	40.26729	1.58
60	23.18	16.20	3.78	11.23846	48.48343	1.69
61	24.03	16.86	4.25	11.98579	49.87845	1.98
62	23.41	17.00	3.35	11.00606	47.01434	1.74
63	21.60	15.80	3.94	11.03746	51.09934	1.68
64	25.54	15.45	4.12	11.75842	46.03922	1.75
65	24.60	15.64	3.90	11.44842	46.53829	1.58
66	29.97	14.67	4.07	12.14051	40.50889	1.52
67	26.41	17.68	3.10	11.31195	42.83207	1.63
68	24.03	17.17	3.37	11.16138	46.4477	1.83
69	20.16	15.10	3.21	9.923332	49.22287	1.67
70	25.62	15.12	3.35	10.9075	42.57416	1.68
71	23.32	14.89	3.64	10.81205	46.36387	1.50
72	23.63	15.08	2.52	9.647657	40.828	1.68
73	30.02	15.78	4.55	12.91744	43.02944	1.69
74	26.98	16.34	3.57	11.63199	43.11339	2.00
75	27.45	16.97	3.72	12.01127	43.75691	1.66
76	26.64	15.03	5.01	12.6118	47.34158	1.61
77	27.46	16.19	2.78	10.73159	39.08081	1.86
78	27.63	16.04	3.31	11.36243	41.12351	1.79
79	26.90	16.58	3.11	11.15233	41.45849	1.74
80	29.06	15.94	3.53	11.78111	40.54064	2.00
81	27.54	16.03	3.11	11.1144	40.35729	1.53
82	26.12	16.72	3.44	11.45309	43.84797	1.58
83	25.33	14.57	3.41	10.7965	42.62338	1.73
84	25.26	15.55	3.60	11.2242	44.43468	1.71
85	25.34	14.29	3.82	11.14211	43.97044	1.67
86	25.16	15.94	2.92	10.54049	41.89382	1.87
87	27.86	15.96	3.80	11.91057	42.75151	1.72
88	26.03	15.09	3.07	10.6439	40.89088	1.83
89	26.56	13.63	3.73	11.05293	41.61496	1.45
90	26.86	15.41	3.37	11.17325	41.5981	1.66
91	25.93	15.45	3.96	11.66296	44.97863	1.45
92	28.54	16.32	3.98	12.28436	43.04259	1.77
93	26.53	15.58	3.26	11.04521	41.63292	1.76
94	25.92	15.32	3.68	11.34786	43.78031	1.68
95	27.54	16.04	3.67	11.74748	42.65607	1.59
96	25.67	15.91	3.32	11.06823	43.11736	1.81
97	26.45	15.00	3.63	11.29296	42.69551	1.83
98	26.59	16.31	3.30	11.26926	42.38157	1.91
99	24.09	15.67	3.37	10.83541	44.97886	1.69
100	25.14	15.81	3.67	11.34108	45.11169	1.83
Mean	26.38	16.20	3.66	11.58	44.06	1.68

Table B3: Axial Dimensions of Irvingia *gabonensis* kernel for moisture content 5.32% (d. b)

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	A	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
1	31.55	20.96	3.69	13.46291	42.67167	1.36
2	29.84	19.95	3.94	13.28656	44.52601	1.88
3	30.68	18.91	3.47	12.62677	41.15634	1.29
4	27.27	17.81	4.30	12.78221	46.87278	1.66
5	32.37	15.89	3.98	12.69745	39.22598	2.02
6	24.67	20.59	4.02	12.68675	51.42584	1.61
7	26.19	16.91	3.74	11.83178	45.17672	1.82
8	28.45	20.37	4.54	13.80521	48.52447	1.29
9	30.93	16.29	4.56	13.19538	42.66208	1.68
10	27.13	16.96	3.96	12.21397	45.02017	1.89
11	29.10	17.74	4.28	13.02403	44.75613	1.98
12	26.92	16.55	3.34	11.41249	42.39411	1.86
13	27.57	19.36	3.40	12.19343	44.22716	2.03
14	24.13	17.15	4.61	12.40281	51.39995	1.69
15	26.40	18.37	4.17	12.64776	47.9082	2.04
16	29.33	17.10	4.39	13.00819	44.35115	1.68
17	33.84	17.60	3.65	12.95491	38.28282	1.56
18	29.65	17.51	3.66	12.38882	41.78354	1.20
19	28.48	17.20	4.11	12.62702	44.33646	1.61
20	28.77	15.77	3.59	11.76605	40.89695	1.74
21	30.73	18.87	4.65	13.91981	45.29712	1.11
22	28.72	18.78	3.90	12.80857	44.59808	2.00
23	25.42	18.32	3.78	12.07866	47.51636	2.01
24	26.40	16.61	3.78	11.83798	44.84083	1.62
25	28.65	16.47	4.59	12.93829	45.15983	1.60
26	25.84	16.12	3.64	11.48875	44.4611	1.86
27	25.03	17.73	4.01	12.11624	48.40687	1.91
28	27.95	16.38	4.30	12.53757	44.85714	1.79
29	26.10	15.99	3.44	11.27904	43.21473	1.74
30	28.56	15.92	4.12	12.32861	43.16742	1.72
31	29.48	19.06	4.38	13.49786	45.78649	1.18
32	30.27	17.98	3.86	12.80321	42.29671	1.85
33	26.65	17.27	5.79	13.86652	52.03199	1.71
34	25.19	15.94	3.83	11.53824	45.80485	2.04
35	28.52	16.11	3.67	11.9036	41.73771	1.69
36	26.62	16.26	3.68	11.68097	43.87713	1.67
37	26.37	15.80	3.68	11.53294	43.74004	1.66
38	25.68	16.45	4.26	12.16809	47.37687	1.89
39	27.43	16.66	3.76	11.98031	43.67943	1.80
40	26.74	15.27	3.37	11.1189	41.5747	1.63
41	25.28	16.31	3.48	11.27634	44.61355	1.67
42	27.43	16.28	3.72	11.84633	43.18751	1.84
43	25.00	16.54	3.73	11.55825	46.23261	1.82
44	26.97	16.07	3.42	11.39714	42.26045	1.63
45	26.75	16.98	3.06	11.16056	41.71453	1.97
46	23.10	15.65	3.71	11.03058	47.74524	1.56
47	27.22	16.87	4.02	12.26668	45.05865	1.58
48	28.33	18.24	3.56	12.25218	43.24807	1.91
49	25.88	15.50	3.41	11.0978	42.88608	1.59
50	27.39	18.11	4.17	12.74155	46.52407	1.82
51	27.94	16.92	3.28	11.57973	41.44824	2.11
52	28.07	16.75	3.54	11.84997	42.21517	1.92
53	28.01	18.89	3.71	12.52405	44.71405	1.91
54	25.63	15.85	3.54	11.28695	44.03803	1.80
55	25.64	17.62	4.07	12.25021	47.77253	1.88

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	A	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
56	25.19	19.00	3.48	11.85282	47.04619	2.06
57	27.37	16.43	3.45	11.57385	42.29188	1.68
58	25.95	17.93	4.01	12.30921	47.43652	1.87
59	27.66	18.26	3.27	11.82584	42.75059	1.61
60	26.64	16.52	3.86	11.92835	44.7761	1.72
61	24.51	17.20	4.34	12.22551	49.87845	2.02
62	23.88	17.34	3.42	11.22618	47.01434	1.77
63	26.03	16.12	4.02	11.90171	45.72304	1.71
64	26.05	15.76	4.20	11.99359	46.03922	1.79
65	25.09	15.95	3.98	11.67739	46.53829	1.61
66	30.57	16.96	4.15	12.91127	42.23594	2.55
67	26.94	18.03	3.16	11.53819	42.83207	1.66
68	24.51	17.51	3.44	11.38461	46.4477	1.87
69	20.56	15.40	3.27	10.1218	49.22287	1.70
70	26.13	15.42	3.42	11.12565	42.57416	1.71
71	25.79	15.19	3.71	11.32964	43.93034	1.53
72	24.10	15.38	3.57	10.97938	45.55269	1.71
73	30.62	16.10	4.64	13.17579	43.02944	1.72
74	27.52	16.67	3.64	11.86463	43.11339	2.04
75	28.00	17.31	3.79	12.2515	43.75691	1.69
76	27.17	15.33	5.11	12.86403	47.34158	1.64
77	28.01	16.51	3.28	11.49054	41.02417	1.90
78	28.18	16.36	3.38	11.58967	41.12351	1.83
79	27.44	16.91	4.17	12.46114	45.41562	1.77
80	29.64	16.26	3.60	12.01673	40.54064	2.04
81	28.09	16.35	4.17	12.41875	44.20932	2.56
82	26.64	17.05	3.51	11.68215	43.84797	1.61
83	25.84	14.86	3.48	11.01243	42.62338	1.76
84	25.77	15.86	3.67	11.44868	44.43468	1.74
85	25.85	14.58	3.90	11.36495	43.97044	1.70
86	25.66	16.26	3.98	11.84207	46.14415	1.91
87	28.42	16.28	3.88	12.14878	42.75151	1.75
88	26.55	15.39	4.13	11.90615	44.84323	1.87
89	27.09	14.90	3.80	11.5374	42.58725	1.48
90	27.40	15.72	3.44	11.39671	41.5981	1.69
91	26.45	18.76	4.04	12.60793	47.66954	2.48
92	29.11	16.65	4.06	12.53004	43.04259	1.81
93	27.06	15.89	3.33	11.26612	41.63292	1.80
94	26.44	15.63	3.75	11.57481	43.78031	2.72
95	28.09	16.36	3.74	11.98243	42.65607	1.62
96	26.18	16.23	3.39	11.28959	43.11736	1.85
97	26.98	15.30	4.70	12.47207	46.22879	1.87
98	27.12	16.64	3.37	11.49465	42.38157	1.95
99	24.57	15.98	3.44	11.05212	44.97886	1.72
100	25.64	16.13	3.74	11.5679	45.11169	1.87
Mean	27.17	16.86	3.84	12.05	44.46	1.78

Table B4: Axial Dimensions of Irvingia *wombolu* kernel for moisture content 2.18% (d. b)

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	A	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
1	28.74	15.58	3.66	11.790	41.023	1.06
2	35.74	19.88	3.97	14.129	39.534	1.16
3	30.85	18.06	3.86	12.908	41.841	1.92
4	26.03	18.47	3.59	11.995	46.083	1.78
5	33.59	19.04	3.88	13.538	40.305	1.62
6	30.94	18.90	3.98	13.252	42.832	1.78
7	26.69	18.43	3.48	11.962	44.820	1.50
8	27.05	21.27	3.86	13.047	48.233	2.03
9	24.49	18.81	3.61	11.848	48.377	1.17
10	32.91	18.61	3.36	12.720	38.649	1.48
11	32.19	21.15	4.33	14.339	44.544	1.54
12	28.31	16.00	3.81	11.995	42.370	1.08
13	35.14	19.69	3.76	13.753	39.139	1.02
14	25.63	14.81	3.57	11.066	43.176	1.02
15	27.83	17.17	3.51	11.881	42.692	1.10
16	40.03	13.11	4.25	13.065	32.639	1.17
17	34.52	18.58	4.31	14.035	40.656	1.72
18	33.72	13.51	4.85	13.025	38.625	1.48
19	25.51	20.00	3.34	11.944	46.822	0.92
20	24.76	18.18	3.90	12.063	48.721	1.17
21	26.34	18.79	3.98	12.536	47.591	1.47
22	26.47	15.47	3.82	11.608	43.855	1.09
23	29.86	17.82	4.44	13.319	44.604	1.58
24	34.40	18.69	3.45	13.042	37.911	1.07
25	25.61	15.27	4.06	11.666	45.553	1.27
26	29.51	20.56	3.68	13.070	44.291	1.23
27	26.60	16.48	3.86	11.916	44.798	1.06
28	24.50	13.40	2.61	9.498	38.768	1.00
29	26.75	17.65	4.53	12.884	48.165	1.22
30	26.83	19.98	4.48	13.392	49.913	1.80
31	26.52	14.87	3.95	11.592	43.711	1.52
32	29.57	19.53	2.75	11.667	39.456	1.37
33	25.87	14.74	4.29	11.783	45.546	1.79
34	23.85	16.68	3.74	11.416	47.866	1.21
35	25.55	19.06	3.98	12.468	48.799	1.42
36	32.36	17.07	4.34	13.384	41.359	1.35
37	33.14	17.06	4.12	13.256	40.000	1.67
38	33.28	19.05	4.56	14.246	42.805	1.60
39	32.55	19.28	3.80	13.360	41.045	1.07
40	27.67	18.71	3.80	12.530	45.284	2.13
41	24.17	15.00	3.61	10.939	45.257	0.98
42	25.22	15.73	4.22	11.874	47.082	1.33
43	26.21	15.36	4.16	11.875	45.309	1.32
44	30.33	17.55	3.99	12.854	42.381	1.18
45	28.20	15.41	3.48	11.478	40.703	1.67
46	26.84	16.17	3.72	11.731	43.708	0.89
47	30.17	17.38	4.71	13.517	44.803	1.21
48	28.96	15.62	2.96	11.022	38.059	0.96
49	26.99	16.78	3.96	12.150	45.015	0.92
50	26.39	17.26	4.67	12.861	48.733	1.48
51	24.48	20.17	3.72	12.247	50.027	1.41
52	34.13	15.47	3.94	12.766	37.403	0.91
53	28.53	16.33	3.78	12.076	42.328	1.11
54	30.24	18.20	3.65	12.618	41.725	1.28
55	22.38	15.37	4.91	11.909	53.212	1.53

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	A	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
56	25.40	16.97	4.06	12.051	47.444	1.34
57	32.48	18.68	4.18	13.637	41.986	1.34
58	30.77	18.94	3.94	13.193	42.875	1.35
59	28.56	20.20	3.55	12.699	44.465	1.05
60	27.99	18.42	3.57	12.255	43.784	1.45
61	29.03	17.93	2.79	11.324	39.009	0.95
62	28.70	19.05	3.47	12.379	43.134	1.20
63	25.53	13.73	3.80	11.003	43.097	1.40
64	25.57	14.82	3.50	10.987	42.969	0.87
65	26.88	16.20	4.47	12.486	46.450	1.62
66	22.53	13.73	4.90	11.487	50.986	0.90
67	36.74	13.61	3.98	12.578	34.236	1.10
68	31.40	15.30	3.62	12.026	38.298	1.37
69	22.19	15.47	3.33	10.456	47.120	1.47
70	24.84	16.80	4.10	11.960	48.150	1.72
71	36.26	19.26	4.24	14.360	39.602	1.58
72	34.17	18.78	4.27	13.993	40.952	1.06
73	26.60	17.75	4.71	13.053	49.070	1.27
74	26.35	18.98	3.49	12.040	45.693	1.71
75	28.91	14.82	4.20	12.163	42.073	1.41
76	31.21	21.53	4.32	14.265	45.707	1.17
77	32.65	18.78	2.87	12.073	36.977	0.46
78	22.84	19.02	4.53	12.531	54.866	1.31
79	24.17	17.78	3.53	11.490	47.539	1.00
80	25.28	14.91	3.33	10.787	42.670	1.18
81	29.58	18.12	4.17	13.075	44.201	1.30
82	34.43	18.95	4.10	13.882	40.319	1.23
83	23.52	15.63	5.14	12.363	52.563	1.59
84	32.63	14.61	3.50	11.861	36.349	1.01
85	27.15	18.64	4.44	13.098	48.242	1.27
86	28.81	18.43	2.45	10.916	37.891	1.14
87	26.42	15.19	3.20	10.870	41.142	0.99
88	24.28	22.18	3.95	12.861	52.969	1.00
89	21.25	13.01	3.16	9.560	44.986	1.28
90	24.50	17.88	3.07	11.038	45.053	1.33
91	28.78	20.83	3.67	13.006	45.192	1.86
92	25.04	15.52	2.83	10.322	41.223	0.82
93	24.33	13.82	4.38	11.377	46.763	1.47
94	29.60	17.70	3.62	12.378	41.818	1.21
95	25.52	14.76	4.12	11.578	45.367	0.92
96	32.94	17.25	3.85	12.981	39.409	0.97
97	25.32	16.52	4.06	11.931	47.120	1.28
98	25.77	20.59	3.81	12.644	49.066	1.16
99	30.05	19.61	2.48	11.348	37.764	0.70
100	38.48	18.47	3.40	13.419	34.873	0.83
Mean	28.51	17.36	3.85	12.327	43.696	1.28

Table B5: Axial Dimensions of Irvingia *wombolu* kernel for moisture content 3.65% (d. b)

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	A	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
1	26.30	16.77	3.16	11.170	42.472	0.83
2	27.06	16.42	4.17	12.282	45.389	1.68
3	33.85	19.52	4.43	14.305	42.259	1.60
4	36.59	18.89	4.15	14.208	38.832	1.34
5	34.97	17.71	4.76	14.339	41.003	1.32
6	34.18	19.68	4.31	14.259	41.718	1.51
7	30.95	18.99	4.11	13.418	43.353	1.32
8	31.46	21.79	5.21	15.286	48.588	1.61
9	33.25	14.63	3.34	11.756	35.356	0.95
10	30.11	19.98	4.34	13.770	45.732	1.63
11	29.30	19.55	4.66	13.872	47.344	1.99
12	28.52	17.54	4.03	12.633	44.294	1.24
13	33.01	18.92	3.31	12.739	38.591	1.79
14	25.95	17.63	3.05	11.175	43.062	1.02
15	25.80	20.37	4.11	12.927	50.103	1.21
16	27.92	20.74	3.99	13.220	47.350	1.21
17	34.89	19.25	5.83	15.762	45.175	1.63
18	28.09	19.44	4.27	13.260	47.207	1.29
19	28.54	16.19	4.66	12.913	45.245	1.42
20	29.60	15.40	3.83	12.041	40.680	1.17
21	28.06	20.88	3.40	12.582	44.841	1.20
22	28.25	19.28	3.63	12.551	44.428	1.12
23	28.78	20.09	3.43	12.564	43.655	1.20
24	27.21	17.53	3.95	12.351	45.391	1.71
25	26.21	18.35	4.02	12.458	47.531	0.93
26	27.46	18.40	4.57	13.217	48.133	1.65
27	25.45	16.36	4.28	12.124	47.638	1.08
28	36.02	13.06	3.86	12.200	33.870	0.71
29	26.45	18.06	3.45	11.812	44.658	1.00
30	31.39	19.42	3.93	13.381	42.627	1.40
31	35.97	17.15	3.87	13.365	37.156	1.08
32	29.24	18.20	4.07	12.938	44.249	1.29
33	30.54	19.19	4.18	13.481	44.141	1.01
34	28.78	18.77	2.96	11.694	40.631	0.67
35	26.09	20.63	4.81	13.731	52.630	1.22
36	28.59	18.20	4.42	13.200	46.169	1.80
37	28.21	21.19	5.11	14.509	51.434	1.66
38	30.68	18.23	4.57	13.673	44.565	1.78
39	28.71	18.30	4.24	13.060	45.490	1.34
40	36.38	18.72	5.70	15.716	43.200	1.26
41	27.28	14.28	3.52	11.110	40.725	0.82
42	27.83	18.15	4.44	13.090	47.034	1.08
43	29.86	19.68	4.04	13.340	44.676	1.03
44	27.56	15.33	4.81	12.666	45.960	1.55
45	33.37	19.09	3.65	13.248	39.700	1.17
46	27.23	15.44	4.00	11.892	43.672	1.05
47	28.16	19.19	4.04	12.973	46.068	1.46
48	27.95	17.76	2.56	10.831	38.753	1.07
49	29.57	15.43	4.56	12.766	43.173	1.33
50	29.46	18.74	3.93	12.946	43.944	1.18
51	26.56	18.93	5.48	14.019	52.783	1.54
52	26.45	14.82	3.25	10.841	40.985	1.29
53	29.24	17.80	4.47	13.251	45.317	1.34
54	26.90	19.30	5.64	14.306	53.184	1.61
55	29.93	18.48	3.48	12.439	41.561	0.80

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	A	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
56	27.65	19.24	4.31	13.186	47.690	1.21
57	27.71	18.99	4.10	12.922	46.631	1.41
58	27.67	18.73	5.88	14.498	52.396	1.87
59	28.31	16.20	4.98	13.169	46.518	1.53
60	26.43	21.64	3.45	12.543	47.456	1.18
61	26.60	16.79	4.30	12.430	46.729	1.12
62	30.16	15.63	4.55	12.896	42.760	1.59
63	30.26	18.78	3.93	13.071	43.197	0.93
64	26.61	15.34	3.75	11.525	43.310	1.09
65	31.29	18.10	4.00	13.134	41.974	1.17
66	27.46	16.54	4.44	12.634	46.009	0.97
67	27.84	17.53	4.02	12.519	44.967	1.42
68	25.77	17.04	3.79	11.851	45.986	1.31
69	31.25	18.92	4.25	13.595	43.505	0.92
70	28.08	17.14	4.02	12.461	44.376	1.06
71	33.75	17.21	4.35	13.620	40.356	1.99
72	26.92	14.26	3.95	11.489	42.677	1.70
73	25.78	16.39	4.72	12.587	48.826	1.55
74	33.38	18.42	5.42	14.937	44.748	1.59
75	30.46	17.21	3.72	12.494	41.016	0.92
76	28.49	18.16	4.83	13.570	47.631	1.84
77	26.55	17.24	4.58	12.798	48.205	1.65
78	27.05	16.63	3.85	12.009	44.396	1.12
79	27.30	16.90	3.87	12.132	44.438	1.14
80	28.08	17.64	3.33	11.815	42.077	0.90
81	29.77	17.47	4.73	13.499	45.345	1.52
82	27.00	14.67	3.83	11.490	42.557	1.36
83	27.34	18.42	5.59	14.120	51.646	1.16
84	29.90	17.89	5.15	14.018	46.884	1.20
85	26.00	18.95	5.02	13.524	52.014	1.38
86	27.00	18.06	4.12	12.618	46.734	1.22
87	34.52	16.27	4.60	13.722	39.750	1.02
88	27.37	15.29	4.64	12.476	45.582	1.46
89	34.46	13.59	3.07	11.286	32.752	0.65
90	34.85	18.74	4.27	14.076	40.389	1.04
91	35.38	17.67	4.63	14.251	40.281	1.80
92	29.48	15.31	3.35	11.478	38.933	0.87
93	31.98	16.02	4.22	12.931	40.433	0.91
94	26.63	18.94	3.69	12.301	46.191	1.12
95	25.39	13.80	3.86	11.059	43.556	1.19
96	26.10	15.51	4.28	12.011	46.018	1.64
97	29.15	17.30	5.01	13.620	46.724	0.99
98	26.48	18.65	5.01	13.525	51.077	1.42
99	26.79	14.93	4.01	11.706	43.694	1.51
100	26.35	13.82	4.20	11.522	43.725	1.99
Mean	29.19	17.70	4.22	12.908	44.459	1.30

Table B6: Axial Dimensions of Irvingia *wombolu* kernel for moisture content 5.32% (d. b)

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	A	b	c	Dp (mm) = $(abc)^{1/3}$	$\phi = \{(abc^{1/3})\}/a$	Kg
1	33.67	20.26	3.78	13.713	40.727	1.91
2	31.77	17.79	4.21	13.350	42.022	1.59
3	32.90	19.71	3.98	13.717	41.693	1.69
4	33.44	21.39	4.37	14.621	43.724	1.90
5	31.65	19.22	3.87	13.303	42.031	1.69
6	30.41	18.72	4.10	13.265	43.620	1.63
7	30.99	24.55	4.87	15.474	49.932	2.10
8	31.41	16.86	3.58	12.377	39.404	1.37
9	31.86	18.84	4.95	14.376	45.123	1.73
10	33.65	19.95	3.89	13.771	40.924	1.99
11	28.57	22.26	5.16	14.860	52.014	1.73
12	31.65	23.04	4.81	15.194	48.006	2.01
13	33.91	20.50	3.51	13.463	39.701	1.65
14	33.60	19.49	4.58	14.421	42.921	1.91
15	31.81	18.77	4.37	13.767	43.279	1.58
16	33.99	19.72	3.72	13.560	39.895	1.88
17	33.07	20.71	3.86	13.827	41.812	1.94
18	32.27	19.17	4.22	13.769	42.669	1.54
19	32.32	18.25	3.04	12.149	37.589	1.66
20	30.38	18.89	5.63	14.783	48.662	1.72
21	33.55	18.34	5.27	14.801	44.117	1.86
22	27.75	15.24	3.65	11.557	41.647	1.02
23	30.80	21.06	4.58	14.376	46.674	1.51
24	31.09	19.80	4.43	13.971	44.938	1.65
25	33.89	20.14	4.25	14.262	42.083	1.95
26	30.44	19.98	4.37	13.852	45.505	1.34
27	33.83	20.61	3.83	13.874	41.010	1.64
28	29.24	20.67	4.13	13.565	46.392	1.52
29	33.88	19.84	3.62	13.450	39.700	1.70
30	28.22	18.49	3.60	12.339	43.723	1.38
31	31.75	19.30	3.69	13.125	41.340	1.96
32	30.19	17.00	4.44	13.159	43.588	2.09
33	30.96	23.05	3.97	14.150	45.704	2.14
34	27.99	18.16	4.60	13.273	47.419	1.32
35	29.99	17.98	4.80	13.730	45.782	1.44
36	30.42	18.51	5.58	14.646	48.148	2.11
37	31.30	20.76	4.57	14.374	45.922	1.55
38	27.72	15.59	3.66	11.651	42.032	1.14
39	26.16	17.13	4.56	12.690	48.508	1.56
40	29.13	18.76	3.97	12.946	44.441	1.29
41	31.69	17.43	5.13	14.151	44.654	1.73
42	32.44	19.36	3.15	12.554	38.698	1.62
43	34.15	19.88	3.84	13.763	40.302	1.72
44	33.85	21.66	4.17	14.514	42.877	2.03
45	33.29	19.26	4.24	13.957	41.924	2.05
46	36.50	18.47	4.47	14.444	39.573	1.88
47	30.13	20.11	4.50	13.970	46.367	1.61
48	29.65	17.87	3.67	12.482	42.097	1.20
49	29.05	19.73	4.90	14.109	48.567	1.13
50	33.93	19.87	4.57	14.551	42.886	1.90
51	29.29	18.06	4.33	13.182	45.004	1.37
52	25.48	19.50	3.51	12.037	47.240	1.20
53	28.46	18.12	4.29	13.030	45.784	1.57
54	28.49	15.27	4.06	12.088	42.429	1.21
55	26.16	20.36	4.85	13.721	52.450	1.65

	Axial Dimensions (mm)			Geometric mean diameter	Sphericity	1000 seed weight
S/N	A	b	c	Dp (mm) = $(abc)^{1/3}$	ϕ = $\{(abc^{1/3})\}/a$	Kg
56	31.86	17.38	3.36	12.299	38.604	1.46
57	31.64	18.74	4.30	13.661	43.177	1.55
58	31.90	15.97	4.07	12.752	39.974	1.32
59	29.74	18.56	3.90	12.912	43.416	1.13
60	30.57	17.06	4.86	13.634	44.601	1.31
61	26.81	18.45	3.83	12.374	46.153	1.11
62	27.78	17.69	4.86	13.367	48.117	1.46
63	27.42	18.59	3.74	12.400	45.221	1.14
64	27.62	19.22	4.30	13.167	47.671	1.41
65	29.43	18.96	4.65	13.741	46.691	1.29
66	28.35	19.44	4.09	13.112	46.249	1.50
67	26.42	18.01	4.51	12.899	48.821	1.40
68	27.55	18.11	5.05	13.607	49.392	1.25
69	27.19	21.71	4.08	13.404	49.299	1.39
70	31.47	18.57	5.32	14.595	46.378	1.88
71	28.62	16.73	4.69	13.095	45.755	1.11
72	31.70	16.67	4.23	13.075	41.246	1.45
73	29.17	21.03	4.73	14.263	48.896	1.47
74	30.62	19.85	5.16	14.638	47.804	1.83
75	26.50	19.97	3.86	12.688	47.880	1.37
76	29.98	17.93	3.69	12.565	41.910	1.37
77	33.69	18.72	3.57	13.107	38.904	1.77
78	27.13	19.07	5.33	14.023	51.688	1.66
79	30.84	19.20	3.63	12.905	41.847	1.60
80	33.02	17.02	4.18	13.293	40.259	1.36
81	27.74	16.52	4.06	12.299	44.338	1.24
82	27.00	20.30	5.59	14.524	53.793	1.53
83	28.62	21.97	4.11	13.723	47.949	1.62
84	27.20	19.23	4.27	13.071	48.057	1.30
85	31.79	18.52	3.81	13.090	41.178	1.48
86	30.02	16.92	3.87	12.527	41.728	1.50
87	30.75	18.25	5.09	14.189	46.142	1.64
88	26.10	19.22	3.76	12.356	47.339	1.10
89	26.77	18.22	5.49	13.886	51.873	1.47
90	33.33	19.02	4.81	14.501	43.507	1.89
91	32.33	20.83	4.09	14.018	43.358	1.98
92	28.54	19.10	3.80	12.747	44.665	1.32
93	28.62	22.84	4.95	14.791	51.680	1.67
94	28.36	18.21	3.42	12.088	42.623	1.15
95	33.35	20.28	4.44	14.427	43.260	2.01
96	27.31	23.11	4.54	14.203	52.008	1.48
97	30.75	19.70	4.26	13.716	44.606	1.36
98	32.94	18.41	3.39	12.715	38.601	1.90
99	30.30	21.68	4.53	14.384	47.471	1.86
100	30.32	17.65	4.34	13.243	43.678	1.82
Mean	30.43	19.16	4.28	13.522	44.631	1.58

Table B7: Independent samples t-test of the difference between axial dimensions of *Irvingia wombolu* and *Irvingia gabonensis* kernel

(a) Length (mm)

	Specie		t-test for Equality of Means		
Moisture Content	*Irvingia wombolu*	*Irvingia gabonensis*	t	P-value	Tcritical
2.18%	28.506	25.910	6.560**	2.47E-09	1.984217
3.65%	29.189	26.382	8.526**	1.77E-13	1.984217
5.32%	30.433	27.168	11.319**	1.49E-19	1.984217

***Mean difference is significant at 0.05 levels*

(b) Width (mm)

	Specie		t-test for Equality of Means		
Moisture Content	*Irvingia wombolu*	*Irvingia gabonensis*	t	P-value	Tcritical
2.18%	17.364	15.662	6.843**	6.54E-10	1.984217
3.65%	17.698	16.203	7.768**	7.5E-12	1.984217
5.32%	19.161	16.862	10.436**	1.22E-17	1.984217

***Mean difference is significant at 0.05 levels*

(c) Thickness (mm)

	Specie		t-test for Equality of Means		
Moisture Content	*Irvingia wombolu*	*Irvingia gabonensis*	t	P-value	Tcritical
2.18%	3.847	3.474	5.693**	1.27E-07	1.984217
3.65%	4.217	3.665	6.602**	2.03E-09	1.984217
5.32%	4.284	1.984	5.725**	1.11E-07	1.984217

***Mean difference is significant at 0.05 levels*

(d) Geometric mean diameter

	Specie		t-test for Equality of Means		
Moisture Content	*Irvingia wombolu*	*Irvingia gabonesis*	t	P-value	tcritical
2.18%	12.327	11.180	9.923**	1.61E-16	1.984217
3.65%	12.908	11.584	10.876**	1.36E-18	1.984217
5.32%	13.522	12.048	13.012**	3.68E-23	1.984217

*****Mean difference is significant at 0.05 levels***

(d) Sphericity (%)

	Specie		t-test for Equality of Means		
Moisture Content	*Irvingia wombolu*	*Irvingia gabonesis*	t	P-value	Tcritical
2.18%	43.696	43.246	0.956^{NS}	0.341557	1.984217
3.65%	44.459	44.061	0.825^{NS}	0.411374	1.984217
5.32%	44.631	44.459	0.380^{NS}	0.704997	1.984217

^{NS}*Mean difference is not significant at 0.05 levels*

(e) 1000 kernel weight

	Specie		t-test for Equality of Means		
Moisture Content	*Irvingia wombolu*	*Irvingia gabonesis*	t	P-value	tcritical
2.18%	1.2846	0.8573	12.65051**	2.13E-22	1.984217
3.65%	1.6798	1.2982	9.72058**	4.45E-16	1.984217
5.32%	1.7836	1.58172	4.930402**	3.31E-06	1.984217

*****Mean difference is significant at 0.05 levels***

Table A-8: Parameter Estimates for *Irvingia gabonensis* and *Irvingia wombolu* kernel

(a) *Irvingia wombolu*

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	Intercept	1	-0.02543	0.00998	-2.55	0.0113	0
GMD	GMD	1	0.00427	0.00071227	5.99	<.0001	0.35660
Sw	Sw	1	-0.00007779	0.00017107	-0.45	0.6496	-0.02372
MASS	MASS	1	0.00788	0.00234	3.36	0.0009	0.20007

(b) *Irvingia gabonensis*

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	Intercept	1	-0.02765	0.00806	-3.43	0.0007	0
GMD	GMD	1	0.00365	0.00060958	5.99	<.0001	0.21880
SHP	SHP	1	-0.00015205	0.00016129	-0.94	0.3466	-0.03285
MASS	MASS	1	0.02021	0.00096666	20.90	<.0001	0.73093

Table B9: True and bulk density, porosity of *Irvingia gabonensis* and *Irvingia wombolu* kernel for moisture content 2.18% (d. b)

		Irvingia gabonensis			*Irvingia wombolu*		
S/N	Moisture content	True density (kgm^{-3})	Bulk density (kgm^{-3})	Porosity (%)	True density (kgm^{-3})	Bulk density (kgm^{-3})	Porosity (%)
1	2.18%	0.7467	0.4273	42.7696	0.9000	0.4316	52.0467
2		0.7029	0.4307	38.7244	0.9500	0.4178	56.0232
3		0.7259	0.4312	40.6000	0.9450	0.4302	54.4741
4		0.5371	0.4222	21.4027	0.9450	0.4317	54.3196
5		0.7545	0.4261	43.5263	0.9900	0.4272	56.8525
6		0.7300	0.4317	40.8685	1.1133	0.4270	61.6431
7		0.7500	0.4266	43.1227	0.7880	0.4217	46.4873
8		0.6848	0.4297	37.2620	0.9650	0.4180	56.6819
9		0.6267	0.4315	31.1468	0.9550	0.4206	55.9539
10		0.7185	0.4330	39.7399	1.1267	0.4168	63.0077
Mean		0.69772	0.4290	38.5158	0.9678	0.4243	56.1626
1	3.65%	0.7050	0.4627	34.3716	1.0753	0.4610	57.1289
2		0.6550	0.4727	27.8351	1.1561	0.4650	59.7792
3		1.0400	0.4754	54.2904	1.0753	0.4591	57.3056
4		0.7100	0.4680	34.0873	0.9174	0.4647	49.3499
5		0.9067	0.4650	48.7156	0.8889	0.4640	47.8023
6		0.9000	0.4659	48.2356	0.9524	0.4593	51.7756
7		0.6700	0.4590	31.4955	0.8000	0.4655	41.8150
8		0.4680	0.4718	-0.8077	1.1429	0.4612	59.6468
9		0.7600	0.4675	38.4895	1.0811	0.4652	56.9709
10		0.6950	0.4562	34.3626	1.1538	0.4648	59.7191
Mean		0.7510	0.4664	37.8934	1.0243	0.4630	54.8027
1	5.32%	1.2100	0.5073	58.0760	0.4989	56.2386	56.2386
2		0.9467	0.4952	47.6924	0.4998	52.8509	52.8509
3		0.6667	0.5056	24.1634	0.4980	52.1173	52.1173
4		0.5400	0.5016	7.1148	0.4977	45.9043	45.9043
5		0.8500	0.5092	40.0965	0.4996	68.3810	68.3810
6		0.5100	0.5148	-0.9373	0.4996	50.0420	50.0420
7		0.5000	0.5278	-5.5560	0.4990	51.5553	51.5553
8		1.5600	0.5293	66.0718	0.5042	39.9786	39.9786
9		0.5133	0.5256	-2.3864	0.5006	48.6585	48.6585
10		0.8500	0.5255	38.1788	0.4952	58.9630	58.9630
Mean		0.8147	0.5142	36.8859	0.4992	53.7384	53.7384

Table B10: Independent samples t-test of the difference between densities and porosity of *Irvingia wombolu* and *Irvingia gabonensis* kernel

(a) True density

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia wombolu	*Irvingia gabonensis*	t	P-value	tcritical
2.18%	0.9678	0.6977	7.21300**	5.01E-05	2.262157
3.65%	1.0243	0.7510	3.76529**	0.004449	2.262157
5.32%	1.0792	0.8147	2.03893^{NS}	0.07189	2.262157

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

(b) Bulk density

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia wombolu	*Irvingia gabonensis*	t	P-value	tcritical
2.18%	0.42426	0.4290	1.810003^{NS}	0.103734	2.262157
3.65%	0.46296	0.4664	1.461158^{NS}	0.177987	2.262157
5.32%	0.49924	0.5142	3.988025**	0.003167	2.262157

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

(b) Porosity

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia wombolu	*Irvingia gabonensis*	t	P-value	tcritical
2.18%	55.74899	37.91629	6.709958**	8.75E-05	2.262157
3.65%	54.12930	35.10755	3.338809**	0.008677	2.262157
5.32%	52.46896	27.25141	3.005543**	0.014823	2.262157

** Mean difference Significant at 0.05 levels, NS not significant at 0.05 levels

Table B-11: Parameter estimates for *Irvingia gabonensis* and *Irvingia wombolu* kernel density

(a) *Irvingia gabonensis*

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	Intercept	1	-0.14451	0.00962	-15.02	<.0001	0
TD	TD	1	-0.01515	0.00700	-2.16	0.0389	-0.24853
BD	BD	1	0.39733	0.02423	16.40	<.0001	1.10343
PORO	PORO	1	0.00018951	0.00008716	2.17	0.0380	0.25071

(b) *Irvingia wombolu*

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	Intercept	1	0.02364	0.00692	3.41	0.0019	0
TD	TD	1	0.10070	0.01352	7.45	<.0001	1.95885
BD	BD	1	0.00135	0.00012472	10.83	<.0001	2.62363
PORO	PORO	1	-0.00174	0.00021830	-7.96	<.0001	-0.79013

Table C1: Angle of repose of *Irvingia gabonensis* and *Irvingia wombolu* seed for moisture content 10, 20, 30, 40 and 50% (d. b)

		Species					
	Moisture content	*Irvingia gabonensis*			*Irvingia wombolu*		
S/N		Glass	Mild Steel	Plywood	Glass	Mild Steel	Plywood
1	10%	29.80094	32.06739	37.85231	35.38253	38.27312	35.63981
2		30.16861	33.08137	37.71598	30.93096	35.17794	38.29016
3		31.36330	32.90524	35.90972	29.98164	37.63892	37.81573
4		31.15930	31.11309	37.04692	33.58785	38.22434	38.65981
5		29.68314	31.48747	34.01935	35.77832	35.58737	37.48241
Mean		30.43506	32.13091	36.50886	33.13226	36.98034	37.57758
1	20%	32.57875	34.69515	38.65981	34.01935	43.48459	42.39047
2		32.31573	34.65394	39.36932	34.76896	42.70939	38.38201
3		31.14269	33.34970	38.90960	35.79274	40.32395	49.44738
4		31.18497	34.04121	38.86778	34.56978	43.24660	42.58049
5		33.35824	34.80850	39.03551	34.24903	40.73648	39.47246
Mean		32.11608	34.30970	38.96840	34.67997	42.10020	42.45456
1	30%	32.55000	30.57923	36.71420	38.82008	43.76802	46.82409
2		37.89642	39.03551	48.93977	33.69007	48.51861	44.05043
3		35.45828	36.60707	37.98814	37.56859	39.69267	46.05440
4		34.17255	39.42780	41.42367	38.65981	44.02898	43.68309
5		32.09893	37.63042	37.67148	35.68522	40.60129	44.11860
Mean		34.43524	36.65601	40.54745	36.88475	43.32192	44.94612
1	40%	44.39265	44.51853	38.29016	42.70939	46.84761	56.30993
2		40.91438	43.93909	50.57220	42.78796	49.39871	54.13715
3		44.11860	44.42127	51.59674	41.58906	49.76364	48.18914
4		44.61547	43.83086	48.75856	40.17923	54.13715	44.34646
5		39.80557	43.83086	54.24611	41.08175	43.64681	56.63363
Mean		42.76933	44.10812	48.69275	41.66948	48.75878	51.92326
1	50%	47.06011	50.75457	55.46288	43.68309	51.49077	55.31815
2		48.81407	47.06551	52.68553	40.03026	49.06337	51.12693
3		53.46289	49.22818	51.67220	47.12110	48.21548	54.59538
4		47.09016	48.13636	53.25944	46.58713	46.53161	50.98612
5		45.67936	50.64825	46.27303	40.28525	47.17052	52.30576
Mean		48.42132	49.16657	51.87061	43.54136	48.49435	52.86647

Table C2: Independent samples t-test of the difference between angle of repose of *Irvingia wombolu* and *Irvingia gabonensis* seed

(a) Plywood

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia gabonesis	*Irvingia wombolu*	t	P-value	tcritical
10%	36.5089	37.5776	-1.13473^{NS}	0.319875	2.776445
20%	38.9684	42.4546	-1.75246^{NS}	0.154572	2.776445
30%	40.5475	44.9461	-1.65600^{NS}	0.173064	2.776445
40%	48.6928	51.9233	-0.80509^{NS}	0.465898	2.776445
50%	51.8706	52.8665	-0.64553^{NS}	0.553749	2.776445

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

(a) Glass

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia gabonesis	*Irvingia wombolu*	t	P-value	tcritical
10%	30.43506	33.13226	-1.89965^{NS}	0.130292	2.776445
20%	32.11608	34.67997	-3.80113**	0.019085	2.776445
30%	34.43524	36.88475	-1.36446^{NS}	0.244144	2.776445
40%	42.76933	41.66948	0.92950^{NS}	0.405243	2.776445
50%	48.42132	43.54136	3.49202**	0.025077	2.776445

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

(a) Mild Steel

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia gabonesis	*Irvingia wombolu*	t	P-value	tcritical
10%	32.1309	36.9803	-5.57943**	0.005059	2.776445
20%	34.3097	42.1002	-12.9795**	0.000203	2.776445
30%	36.6560	43.3219	-3.30784**	0.029715	2.776445
40%	44.1081	48.7588	-2.64389^{NS}	0.057347	2.776445
50%	49.1665	48.4944	0.70918^{NS}	0.517356	2.776445

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

Table C 3: Parameter Estimates for angle of repose of seed

(a) *Irvingia wombolu*

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	Intercept	1	-0.09225	0.00767	-12.02	<.0001	0
GLS	GLS	1	0.00107	0.00037064	2.89	0.0076	0.33306
MS	MS	1	0.00107	0.00025009	4.26	0.0002	0.36867
PW	PW	1	0.00075484	0.00024528	3.08	0.0049	0.34070

(b) *Irvingia gabonensis*

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	Intercept	1	-0.04927	0.00576	-8.55	<.0001	0
GLS	GLS	1	0.00064367	0.00041452	1.55	0.1326	0.32145
MS	MS	1	0.00128	0.00047649	2.68	0.0125	0.59293
PW	PW	1	0.00011078	0.00026680	0.42	0.6814	0.05272

Table C4: Coefficient of static friction of *Irvingia gabonensis* seed

S/N	Moisture content	Glass	Plywood	Stainless	Galvanized Steel	Mild Steel
1	10%	0.2868	0.7269	0.3641	0.4665	0.5320
2		0.3444	0.7006	0.4247	0.4880	0.5208
3		0.3347	0.7006	0.3251	0.4665	0.5432
4		0.2494	0.6497	0.4247	0.4772	0.5661
5		0.3250	0.6749	0.4247	0.5098	0.5320
Mean		0.3081	0.6905	0.3926	0.4816	0.5388
1	20%	0.3444	0.8102	0.4454	0.4988	0.6131
2		0.3250	0.9663	0.4042	0.5432	0.5661
3		0.3543	0.9009	0.3641	0.5546	0.6622
4		0.2681	0.9169	0.4350	0.3840	0.4665
5		0.3059	0.8396	0.4042	0.5320	0.5320
Mean		0.3195	0.8868	0.4106	0.5025	0.5680
1	30%	0.2963	0.9009	0.4559	0.5208	0.6749
2		0.3154	0.8853	0.4988	0.5893	0.6131
3		0.4454	0.9009	0.4665	0.4559	0.6252
4		0.4350	0.8698	0.4988	0.5320	0.5776
5		0.4559	0.9009	0.4665	0.4454	0.5661
Mean		0.3896	0.8916	0.4773	0.5087	0.6114
1	40%	0.3154	0.9331	0.5320	0.4988	0.7269
2		0.4665	0.9663	0.4454	0.6497	0.7137
3		0.3641	0.9833	0.5776	0.7006	0.6497
4		0.4454	0.9331	0.6252	0.6252	0.7269
5		0.4880	0.9496	0.5208	0.6131	0.6252
Mean		0.4159	0.9531	0.5402	0.6175	0.6885
1	50%	0.4350	0.9833	0.5776	0.6497	0.7404
2		0.4454	0.9663	0.6012	0.6374	0.7137
3		0.3840	1.0006	0.5776	0.6497	0.7006
4		0.3741	0.9496	0.5546	0.7006	0.7137
5		0.4665	0.9833	0.5661	0.6876	0.7269
Mean		0.4210	0.9766	0.5754	0.6650	0.7190

Table C5: Coefficient of static friction of *Irvingia wombolu* seed

S/N	Moisture content	Glass	Plywood	Stainless	Galvanized Steel	Mild Steel
1	10%	0.2869	0.6252	0.4559	0.4247	0.6012
2		0.2681	0.6131	0.4665	0.4454	0.5893
3		0.2963	0.6012	0.4454	0.4350	0.6012
4		0.3251	0.6131	0.4665	0.4144	0.6131
5		0.3445	0.6131	0.4247	0.4042	0.5776
Mean		0.3042	0.6131	0.4518	0.4247	0.5965
1	29%	0.4042	0.6131	0.5098	0.4042	0.6131
2		0.3741	0.6374	0.4988	0.5320	0.6374
3		0.3941	0.7006	0.4880	0.4454	0.6252
4		0.3840	0.7006	0.5098	0.4350	0.6131
5		0.3741	0.6374	0.5208	0.3840	0.6252
Mean		0.3861	0.6578	0.5054	0.4401	0.6228
1	39%	0.3641	0.7678	0.3941	0.5208	0.6622
2		0.4772	0.7817	0.5776	0.5098	0.6497
3		0.4880	0.7006	0.4880	0.5098	0.7959
4		0.4665	0.8698	0.5320	0.5546	0.5432
5		0.3840	0.8576	0.5661	0.5320	0.6012
Mean		0.4360	0.7955	0.5115	0.5254	0.6504
1	40%	0.5432	0.8698	0.4772	0.5661	0.7959
2		0.4329	0.8102	0.4559	0.7269	0.7137
3		0.4880	0.9331	0.5776	0.6622	0.8102
4		0.4350	0.8248	0.6622	0.6497	0.6749
5		0.5098	0.7959	0.5546	0.5893	0.7006
Mean		0.4818	0.8468	0.5455	0.6389	0.7390
1	50%	0.5546	1.0362	0.6374	0.8102	0.9331
2		0.4665	1.1512	0.6749	0.9009	0.9663
3		0.5098	1.1512	0.6622	0.7269	0.9496
4		0.5320	1.0731	0.7006	0.7678	0.8396
5		0.4988	1.0362	0.6876	0.8396	0.9331
Mean		0.5123	1.0896	0.6725	0.8091	0.9243

Table C6: Independent samples t-test of the difference between coefficient of static friction of *Irvingia wombolu* and *Irvingia gabonensis* seed

(a) Plywood

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia gabonensis	*Irvingia wombolu*	t	P-value	Tcritical
10%	0.690534	0.613131	6.231429**	0.003378	2.776445
20%	0.886784	0.657807	9.088619**	0.000813	2.776445
30%	0.891571	0.795485	2.755381^{NS}	0.051091	2.776445
40%	0.953061	0.846758	4.822917**	0.008505	2.776445
50%	0.976618	1.089563	-4.28215**	0.012826	2.776445

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

(b) Stainless Steel

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia gabonensis	*Irvingia wombolu*	t	P-value	tcritical
10%	0.392637	0.451815	-2.80351**	0.048637	2.776445
20%	0.410596	0.505423	-8.24076**	0.001183	2.776445
30%	0.477321	0.511537	-1.22325^{NS}	0.288369	2.776445
40%	0.540204	0.545512	-0.32067^{NS}	0.764516	2.776445
50%	0.575408	0.672537	-6.08885**	0.003679	2.776445

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

(c) Galvanized Steel

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia gabonensis	*Irvingia wombolu*	t	P-value	tcritical
10%	0.481592	0.424742	4.309949**	0.012547	2.776445
20%	0.50252	0.440128	1.730187^{NS}	0.158648	2.776445
30%	0.508695	0.525376	-0.5928^{NS}	0.585205	2.776445
40%	0.617483	0.638854	-0.91825^{NS}	0.410447	2.776445
50%	0.665016	0.809086	-4.07551**	0.015154	2.776445

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

(d) Mild Steel

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia gabonesis	*Irvingia wombolu*	t	P-value	Tcritical
10%	0.538799	0.596477	-11.4526**	0.000332	2.776445
20%	0.567972	0.622793	-1.66769^{NS}	0.170703	2.776445
30%	0.611364	0.650442	-1.09612^{NS}	0.334591	2.776445
40%	0.688489	0.739043	-1.39857^{NS}	0.234496	2.776445
50%	0.71904	0.924314	-8.91321**	0.000876	2.776445

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

(e) Glass

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia gabonesis	*Irvingia wombolu*	t	P-value	tcritical
10%	0.308115	0.304161	0.15315^{NS}	0.885696	2.776445
20%	0.319547	0.386084	-5.01909**	0.00739	2.776445
30%	0.389629	0.435968	-1.2385^{NS}	0.283247	2.776445
40%	0.415895	0.481776	-1.35574^{NS}	0.246674	2.776445
50%	0.421009	0.512327	-3.35321**	0.028484	2.776445

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

Table D1: Angle of repose of *Irvingia gabonensis* and *Irvingia wombolu* kernel

		Species					
		Irvingia gabonensis			*Irvingia wombolu*		
S/N	Moisture content	Glass	Mild Steel	Plywood	Glass	Mild Steel	Plywood
1	2.18%	21.55708	24.29260	24.57767	21.21550	25.69370	23.53235
2		21.21550	26.56505	21.94600	22.71441	23.72366	20.73671
3		22.21183	24.35507	22.17321	22.05643	20.79411	19.36476
4		20.52932	25.24597	22.15334	19.82500	20.72556	19.06919
5		20.83516	26.18181	24.74675	23.10633	23.23016	23.13142
6		20.79411	24.86370	25.00449	19.41363	25.82783	23.76711
7		20.91255	23.84292	23.41603	22.15811	24.77514	20.91797
8		19.59228	23.42869	22.33544	19.44003	21.03751	19.94238
9		20.17946	25.26731	21.50702	19.86142	21.53513	20.64047
10		21.38862	24.04715	24.74523	23.76711	20.55605	26.35046
Mean		20.92159	24.80903	23.26052	21.35580	22.78988	21.74528
1	3.65%	22.39250	26.07951	25.17913	24.47372	23.96249	22.60326
2		21.21550	27.60668	25.46335	23.38522	26.80579	24.10223
3		24.50416	25.36740	25.78142	23.16160	23.78867	24.87415
4		20.52932	27.17027	25.57444	23.64228	29.97395	25.38053
5		20.83516	27.15980	24.74675	23.05130	26.04419	23.29155
6		20.79411	26.76751	25.90106	20.47228	24.60512	26.92768
7		20.91255	27.05897	25.17754	24.42062	24.09693	24.87415
8		19.59228	23.42869	25.72561	23.85047	25.00064	23.86442
9		20.17946	27.67451	25.09846	24.56717	25.03071	23.91436
10		21.38862	25.86636	24.74523	23.39587	25.68171	23.13142
Mean		21.23437	26.41797	25.33930	23.44205	25.49902	24.29638
1	5.32%	26.76751	27.49914	25.60666	24.90477	26.05350	25.46335
2		25.87832	26.18181	29.74488	22.54306	29.74488	30.22184
3		25.44375	26.66592	26.13907	24.36245	28.64762	26.14684
4		25.27772	25.87832	25.48413	26.84500	28.52805	26.87531
5		25.36740	28.75962	24.05735	25.98437	27.08591	25.90651
6		27.07661	27.28636	26.67566	26.25590	30.34325	24.90477
7		25.08359	28.68615	24.38637	25.75686	28.01789	26.66961
8		26.0535	26.46125	25.87832	26.28141	27.02158	26.0535
9		25.48227	27.18111	25.70995	26.09542	28.87242	25.05762
10		26.4631	27.88546	26.56505	29.85902	28.21736	25.55997
Mean		25.88938	27.24851	26.02474	25.88883	28.25325	26.28593

Table D2: Independent samples t-test of the difference between angle of repose of *Irvingia wombolu* and *Irvingia gabonensis* kernel

(a) Plywood

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia gabonesis	*Irvingia wombolu*	t	P-value	tcritical
2.18%	23.2605	21.7453	3.54634**	0.006252	2.262157
3.65%	25.3393	24.2964	3.26095**	0.009824	2.262157
5.32%	26.0247	26.2859	-0.6455^{NS}	0.534731	2.262157

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

(a) Glass

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia gabonesis	*Irvingia wombolu*	t	P-value	tcritical
2.18%	20.9216	21.3558	-1.04984^{NS}	0.321164	2.262157
3.65%	21.2344	23.4421	-3.79061**	0.004279	2.262157
5.32%	25.8894	25.8888	0.00093^{NS}	0.999280	2.262157

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

(a) Mild Steel

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia gabonesis	*Irvingia wombolu*	t	P-value	tcritical
2.18%	24.8090	22.7899	2.864188**	0.018653	2.262157
3.65%	26.4180	25.4990	1.560245^{NS}	0.153134	2.262157
5.32%	27.2485	28.2533	-1.69788^{NS}	0.123757	2.262157

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

Table D3: Parameter Estimates for angle of repose of kernel

(a) *Irvingia gabonensis*

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	Intercept	1	-0.15740	0.01857	-8.48	<.0001	0
GLS	GLS	1	0.00277	0.00046881	5.90	<.0001	0.52563
MS	MS	1	0.00286	0.00072202	3.97	0.0004	0.31801
PW	PW	1	0.00229	0.00065111	3.52	0.0015	0.28837

(b) *Irvingia wombolu*

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	Intercept	1	0.09377	0.01135	-8.26	<.0001	0
GlS	GLS	1	0.00231	0.00055089	4.19	0.0002	0.42206
MS	MS	1	0.00165	0.00055675	2.96	0.0060	0.35434
PW	PW	1	0.00143	0.00058389	2.44	0.0209	0.27283

Table D4: Coefficient of static friction of *Irvingia gabonensis* kernel

S/N	Moisture content	Glass	Stainless	Plywood	Galvanized Steel	Mild Steel
1	2.18%	0.4454	0.4350	0.5661	0.4988	0.5320
2		0.4559	0.4247	0.5661	0.4880	0.5546
3		0.4144	0.4454	0.5546	0.4772	0.5546
4		0.4350	0.4247	0.5661	0.4988	0.5546
5		0.4454	0.4350	0.5546	0.4772	0.5320
6		0.4665	0.4454	0.5776	0.4665	0.5208
7		0.4559	0.4350	0.5893	0.4880	0.5432
8		0.4247	0.4247	0.5661	0.4772	0.5661
9		0.4988	0.4454	0.5893	0.4988	0.5546
10		0.4665	0.4247	0.5776	0.4665	0.5320
Mean		0.4509	0.4340	0.5707	0.4837	0.5444
1	3.65%	0.4880	0.4880	0.4665	0.5208	0.5546
2		0.4772	0.4772	0.6012	0.5098	0.6012
3		0.4880	0.4454	0.4880	0.4988	0.5661
4		0.4988	0.4988	0.6252	0.5098	0.6012
5		0.4988	0.4988	0.5776	0.5098	0.5776
6		0.5098	0.4559	0.7006	0.4988	0.5893
7		0.4988	0.4988	0.7269	0.5208	0.6012
8		0.4988	0.4454	0.5661	0.5208	0.5661
9		0.4988	0.4772	0.6252	0.5208	0.6131
10		0.4880	0.4559	0.7006	0.5320	0.5776
Mean		0.4945	0.4742	0.6078	0.5142	0.5848
1	5.32%	0.5320	0.5320	0.6497	0.5546	0.6012
2		0.5546	0.5098	0.6749	0.5546	0.5776
3		0.5320	0.5320	0.6497	0.5660	0.6012
4		0.5320	0.5320	0.6749	0.5546	0.6012
5		0.5098	0.5098	0.6749	0.5546	0.6497
6		0.4880	0.4454	0.6012	0.5546	0.6749
7		0.4880	0.5546	0.6252	0.5320	0.6497
8		0.5546	0.4880	0.6012	0.5661	0.7006
9		0.5098	0.4454	0.6252	0.5546	0.6012
10		0.5546	0.5098	0.6497	0.5546	0.6749
Mean		0.5255	0.5059	0.6427	0.5546	0.6332

Table D5: Coefficient of static friction of *Irvingia wombolu* kernel

S/N	Moisture content	Glass	Stainless	Plywood	Galvanized Steel	Mild Steel
1	2.18%	0.4454	0.4772	0.6131	0.4454	0.4665
2		0.4454	0.3641	0.4665	0.5546	0.4350
3		0.4247	0.4144	0.4665	0.5098	0.5208
4		0.4247	0.2963	0.5432	0.4665	0.4350
5		0.4042	0.3941	0.4350	0.4880	0.4988
6		0.4454	0.4559	0.5208	0.4246	0.5208
7		0.4042	0.3740	0.5661	0.5546	0.6374
8		0.4247	0.3543	0.7959	0.5546	0.4559
9		0.4247	0.3347	0.6876	0.4042	0.4988
10		0.4247	0.3641	0.3941	0.4665	0.6374
Mean		0.4268	0.3829	0.5489	0.4869	0.5107
1	3.65%	0.5546	0.4454	0.5776	0.4880	0.4247
2		0.4454	0.4247	0.4665	0.5098	0.4665
3		0.4042	0.3840	0.5098	0.5320	0.5320
4		0.4454	0.3641	0.4665	0.5098	0.5098
5		0.4042	0.3840	0.5776	0.4880	0.5776
6		0.4247	0.4042	0.4665	0.5320	0.5546
7		0.4042	0.3840	0.6252	0.5320	0.5546
8		0.4454	0.4454	0.6012	0.4880	0.5320
9		0.4454	0.4454	0.5546	0.5098	0.5546
10		0.4454	0.4665	0.6749	0.5098	0.5776
Mean		0.4419	0.4148	0.5520	0.5099	0.5284
1	5.32%	0.4665	0.4880	0.5546	0.5660	0.6252
2		0.4559	0.4880	0.6012	0.7006	0.7006
3		0.8396	0.4880	0.5776	0.4988	0.5546
4		0.4559	0.3840	0.6012	0.4350	0.6497
5		0.5432	0.4247	0.5776	0.4988	0.5776
6		0.4665	0.4454	0.6012	0.6012	0.6012
7		0.4988	0.4247	0.6252	0.5893	0.5776
8		0.4880	0.4247	0.6012	0.5661	0.5546
9		0.4988	0.4454	0.6012	0.6131	0.5776
10		0.4559	0.4042	0.5776	0.3741	0.6497
Mean		0.5169	0.4417	0.5918	0.5443	0.6068

Table D6: Independent samples t-test of the difference between coefficient of static friction of *Irvingia wombolu* and *Irvingia gabonensis* kernel

(a) Plywood

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia gabonesis	*Irvingia wombolu*	t	P-value	Tcritical
2.18%	0.544426	0.548883	-0.12131^{NS}	0.906107	2.262157
3.65%	0.584784	0.552036	1.27903^{NS}	0.232879	2.262157
5.32%	0.633202	0.591844	3.03238**	0.014192	2.262157

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

(b) Glass

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia gabonesis	*Irvingia wombolu*	t	P-value	Tcritical
2.18%	0.450866	0.426803	2.809385**	0.020398	2.262157
3.65%	0.494491	0.441901	3.501118**	0.006712	2.262157
5.32%	0.525506	0.516923	0.226127^{NS}	0.826154	2.262157

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

(c) Stainless

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia gabonesis	*Irvingia wombolu*	t	P-value	Tcritical
2.18%	0.433998	0.382927	3.183221**	0.011127	2.262157
3.65%	0.474152	0.414791	3.850765**	0.003902	2.262157
5.32%	0.505857	0.441697	3.902031**	0.003608	2.262157

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

(d) Galvanized Steel

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia gabonesis	*Irvingia wombolu*	t	P-value	Tcritical
2.18%	0.483699	0.486879	-0.17268^{NS}	0.866726	2.262157
3.65%	0.514213	0.509882	0.56006^{NS}	0.589107	2.262157
5.32%	0.554608	0.544295	0.33802^{NS}	0.743102	2.262157

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

(e) Mild Steel

Moisture Content	Specie		t-test for Equality of Means		
	Irvingia gabonesis	*Irvingia wombolu*	t	P-value	Tcritical
2.18%	0.570727	0.510651	2.786514**	0.021174	2.262157
3.65%	0.607776	0.528386	3.574585**	0.005981	2.262157
5.32%	0.642646	0.606843	2.842559**	0.019322	2.262157

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

Table EI: Mechanical Properties of *Irvingia gabonensis* Seed in Longitudinal Direction

S/N	Moisture content	Rupture Force (N)	Deformation (mm)	Failure stress (Nmm-2)	Modulus of stiffness (Nmm-1)	Modulus of elasticity (Nmm-2)
1	10%	696.92	2.28	1478.00	305.67	8746
2		694.39	2.15	1297.00	322.97	9208
3		689.44	2.07	1369.00	333.06	9786
4		690.67	2.14	1391.00	322.74	8917
5		693.17	2.18	1430.00	317.97	9413
Mean		692.92	2.16	1393.00	320.48	9214.00
1	20%	524.31	2.55	1000.03	205.61	9517
2		571.92	2.61	949.43	219.13	8984
3		462.51	2.28	974.14	202.86	9202
4		451.59	2.30	992.66	196.34	9371
5		490.25	2.45	985.23	200.10	9306
Mean		500.12	2.44	980.30	204.81	9276.00
1	30%	438.17	2.81	929.96	155.93	11784
2		442.05	2.91	897.50	151.91	12265
3		443.93	2.74	915.67	162.02	10993
4		430.40	2.78	920.02	154.82	10642
5		441.41	2.93	928.83	150.65	11641
Mean		439.19	2.83	918.40	155.07	11465.00
1	40%	414.76	3.32	890.45	124.93	14419
2		392.35	3.47	783.71	113.07	10567
3		408.63	3.41	805.68	119.83	12649
4		394.32	3.39	798.34	116.32	11892
5		395.19	3.50	814.32	112.91	12648
Mean		401.05	3.42	818.50	117.41	12435.00
1	50%	498.74	3.74	709.41	133.35	16807
2		511.21	3.64	683.43	140.44	19123
3		478.69	3.72	678.63	128.68	19647
4		493.22	3.56	704.13	138.54	17684
5		482.31	3.68	689.30	131.06	18819
Mean		492.83	3.67	692.98	134.42	18416.00

Table E2: Mechanical Properties of *Irvingia gabonensis* Seed in Axial Direction

S/N	Moisture content	Rupture Force (N)	Deformation (mm)	Failure stress (Nmm-2)	Modulus of stiffness (Nmm-1)	Modulus of elasticity (Nmm-2)
1	10%	599.24	1.46	602.34	410.44	8868
2		598.67	1.46	592.75	410.05	8916
3		602.19	1.47	608.19	409.65	8745
4		597.82	1.41	598.37	423.99	8693
5		596.08	1.40	602.35	425.77	8768
Mean		598.80	1.44	600.80	415.98	8798.00
1	20%	447.51	1.71	535.78	261.70	11005
2		445.26	1.68	473.83	265.04	10965
3		431.74	1.51	461.29	285.92	10893
4		438.91	1.56	493.48	281.35	11094
5		438.28	1.64	489.60	267.24	11008
Mean		440.34	1.62	490.80	272.25	10993.00
1	30%	423.75	1.97	476.92	215.10	12654
2		416.67	2.19	473.36	190.26	12705
3		420.45	2.23	470.93	188.54	12687
4		410.80	2.16	457.74	190.19	12569
5		420.83	2.32	462.64	181.39	12445
Mean		418.50	2.17	468.32	193.10	12612.00
1	40%	397.65	2.58	457.02	154.13	14945
2		398.96	2.66	456.26	149.98	14714
3		399.85	2.58	455.18	154.98	15239
4		396.66	2.46	449.06	161.24	14719
5		398.63	2.53	453.09	157.56	14663
Mean		398.35	2.56	454.12	155.58	14856.00
1	50%	491.35	2.66	443.06	184.72	18437
2		464.94	2.85	442.20	163.14	18396
3		483.83	2.63	438.84	183.97	18204
4		471.42	2.82	441.26	167.17	18348
5		472.56	2.63	440.54	179.68	18470
Mean		476.82	2.72	441.18	175.73	18371.00

Table E3: Mechanical Properties of *Irvingia gabonensis* Seed in Transverse Direction

S/N	Moisture content	Rupture Force (N)	Deformation (mm)	Failure stress (Nmm-2)	Modulus of stiffness (Nmm-1)	Modulus of elasticity (Nmm-2)
1	10%	432.41	1.12	593.56	386.08	6348
2		437.18	1.10	586.09	397.44	6186
3		464.78	1.07	578.15	434.37	6493
4		469.12	1.03	590.65	455.46	5984
5		454.21	1.13	588.79	401.96	6179
Mean		451.54	1.09	587.45	415.06	6238.00
1	20%	320.41	1.72	556.73	186.28	6931
2		304.30	1.40	582.15	217.36	7225
3		296.13	1.67	499.56	177.32	6886
4		294.26	1.53	530.45	192.33	7235
5		321.00	1.83	579.81	175.41	6903
Mean		307.22	1.63	549.740	189.74	7036.00
1	30%	294.64	1.77	467.91	166.46	15242
2		297.51	1.83	462.26	162.57	18114
3		290.84	1.81	444.61	160.69	14649
4		289.95	1.79	453.03	161.98	16319
5		296.51	1.74	446.19	170.41	17016
Mean		293.89	1.79	454.80	164.42	16268.00
1	40%	288.53	2.19	461.84	131.75	19767
2		263.39	1.98	454.09	133.03	18320
3		291.35	2.07	394.56	140.75	19613
4		268.91	1.99	413.10	135.13	19129
5		280.82	2.16	464.31	130.01	19321
Mean		278.60	2.08	437.58	134.13	19230.00
1	50%	432.31	2.98	347.84	145.07	28664
2		378.26	2.68	319.54	141.14	22671
3		457.86	2.54	335.28	180.26	30063
4		397.56	2.73	313.36	145.63	23745
5		475.31	2.64	302.17	180.04	24047
Mean		428.26	2.71	323.64	158.43	25838.00

Table E4: Mechanical Properties of *Irvingia wombolu* Seed in Longitudinal Direction

S/N	Moisture content	Rupture Force (N)	Deformation (mm)	Failure stress (Nmm-2)	Modulus of stiffness (Nmm-1)	Modulus of elasticity (Nmm-2)
1	10%	1795.47	3.53	3218.30	508.63	18839
2		1622.13	3.13	2985.67	518.25	18137
3		1806.93	3.29	2913.78	549.22	15719
4		1942.56	3.48	3156.16	558.21	16562
5		1814.71	3.42	3063.94	530.62	16048
Mean		1796.36	3.37	3067.57	532.99	17061.00
1	20%	1462.50	3.35	3057.02	436.57	22176
2		1621.71	3.67	2812.74	441.88	20874
3		1393.53	3.43	2971.66	406.28	16750
4		1597.09	3.59	2896.57	444.87	18952
5		1791.52	3.31	2830.91	541.24	20548
Mean		1573.27	3.47	2913.78	454.17	19860.00
1	30%	1308.92	3.91	2947.38	334.76	25491
2		1267.49	4.08	2783.57	310.66	21532
3		1276.46	3.85	2963.02	331.55	23476
4		1341.54	3.77	2848.91	355.85	19864
5		1297.71	3.98	2917.77	326.06	22847
Mean		1298.42	3.92	2892.13	331.77	22642.00
1	40%	1138.34	3.37	2881.71	337.79	28564
2		1198.89	4.99	2939.67	240.26	25167
3		1173.11	4.28	2765.61	274.09	23602
4		1116.43	3.76	2702.54	296.92	21865
5		1162.61	4.15	2801.47	280.15	23142
Mean		1157.88	4.11	2818.20	285.84	24468.00
1	50%	1638.34	4.78	1563.14	342.75	27361
2		1598.89	4.80	1782.61	333.10	30715
3		1573.11	4.99	1892.56	315.25	26839
4		1616.43	4.91	1760.85	329.21	27990
5		1362.61	4.84	1699.34	281.53	28310
Mean		1557.88	4.86	1739.70	320.37	28243.00

Table E6: Mechanical Properties of *Irvingia wombolu* Seed in Axial Direction

S/N	Moisture content	Rupture Force (N)	Deformation (mm)	Failure stress (Nmm-2)	Modulus of stiffness (Nmm-1)	Modulus of elasticity (Nmm-2)
1	10%	1554.73	2.56	1723.18	607.32	16245
2		1409.27	2.74	1660.58	514.33	15484
3		1382.14	2.83	1631.23	488.39	13603
4		1444.79	2.64	1563.35	547.27	12338
5		1391.32	2.48	1492.06	561.02	14275
Mean		1436.45	2.65	1614.08	543.66	14389.00
1	20%	1364.12	2.87	1683.71	475.30	13652
2		1331.73	2.73	1569.04	487.81	16937
3		1313.57	2.95	1391.34	445.28	17560
4		1340.45	2.99	1593.47	448.31	15982
5		1356.28	3.03	1628.84	447.62	16184
Mean		1341.23	2.91	1573.28	460.86	16063
1	30%	1242.31	3.61	1558.34	344.13	16328
2		1235.85	3.76	1601.25	328.68	17818
3		1252.64	3.61	1454.07	346.99	19056
4		1300.78	3.76	1427.51	345.95	19470
5		1236.62	3.49	1505.43	354.33	15678
Mean		1253.64	3.65	1509.32	344.02	17670.00
1	40%	1148.22	3.72	1608.82	308.66	20945
2		1150.34	3.82	1532.62	301.14	17712
3		1158.29	3.93	1475.07	294.73	19304
4		1122.17	4.16	1367.34	269.75	20573
5		1108.06	3.96	1278.15	279.81	18861
Mean		1137.42	3.92	1452.40	290.82	19479.00
1	50%	1428.23	3.95	1378.52	361.58	27363
2		1361.19	4.30	1518.61	316.56	23876
3		1371.57	4.20	1459.43	326.56	25589
4		1356.46	3.98	1367.56	340.82	26255
5		1363.35	4.19	1335.38	325.38	24022
Mean		1376.16	4.12	1411.90	334.18	25421.00

Table E7: Mechanical Properties of *Irvingia wombolu* Seed in Transverse Direction

S/N	Moisture content	Rupture Force (N)	Deformation (mm)	Failure stress (Nmm-2)	Modulus of stiffness (Nmm-1)	Modulus of elasticity (Nmm-2)
1	10%	1350.19	2.06	1709.39	655.43	12982
2		1296.23	1.91	1738.24	678.65	16179
3		1159.38	1.94	1492.67	597.62	13864
4		1183.75	1.88	1663.21	629.65	15923
5		1328.80	2.01	1544.54	661.09	13037
Mean		1263.67	1.96	1629.610	644.49	14397.00
1	20%	1034.56	2.06	1606.31	502.21	19982
2		1061.60	2.11	1547.59	503.13	17883
3		1168.37	1.94	1381.65	602.25	14894
4		1257.00	2.18	1318.42	576.61	14997
5		1130.92	2.22	1556.88	509.42	15989
Mean		1130.49	2.10	1482.17	538.72	16749.00
1	30%	972.82	2.62	1583.35	371.31	21925
2		992.76	2.74	1392.18	362.32	19678
3		976.45	2.8	1428.61	348.73	17795
4		991.64	2.77	1246.25	357.99	16844
5		1012.03	2.82	1278.51	358.88	15938
Mean		989.14	2.75	1385.78	359.85	18436.00
1	40%	936.71	2.93	1375.19	319.70	23275
2		859.69	3.05	1178.43	281.87	19534
3		807.58	2.97	1209.62	271.91	21716
4		834.65	3.06	1159.85	272.76	22188
5		925.87	2.90	1123.91	319.27	18352
Mean		872.90	2.98	1209.40	293.10	21013.00
1	50%	1242.24	3.44	964.48	361.12	31070
2		1096.08	3.17	1103.83	345.77	27236
3		1212.43	3.49	1082.18	347.40	28900
4		1141.51	3.41	996.37	334.75	27221
5		1152.74	3.24	1053.64	355.78	30118
Mean		1169.00	3.35	1040.1	348.96	28909

Table E8: Independent Samples t-test of the difference between Mechanical Properties of *Irvingia wombolu* and *Irvingia gabonensis* kernel

(a) Axial

Properties	Moisture Content	Specie		t-test for Equality of Means		
		Irvingia gabonensis	*Irvingia wombolu*	t	P-value	Tcritical
Rupture force	10%	598.8	1436.45	-26.6003	1.19E-05	2.776445
	20%	440.34	1341.23	-120.845	2.81E-08	2.776445
	30%	418.5	1253.64	-59.6516	4.73E-07	2.776445
	40%	398.35	1137.416	-79.6634	1.49E-07	2.776445
	50%	476.82	1376.16	-93.9941	7.68E-08	2.776445
Deformation	10%	1.44	2.65	-22.7052	2.23E-05	2.776445
	20%	1.62	2.914	-16.2693	8.35E-05	2.776445
	30%	2.174	3.646	-16.7815	7.39E-05	2.776445
	40%	2.562	3.918	-13.2674	0.000187	2.776445
	50%	2.718	4.124	-17.6775	6.02E-05	2.776445
Failure stress	10%	600.80	1614.08	-25.2365	1.46E-05	2.776445
	20%	490.80	1573.28	-27.4029	1.05E-05	2.776445
	30%	468.32	1509.32	-35.0839	3.94E-06	2.776445
	40%	454.12	1452.40	-17.3075	6.54E-05	2.776445
	50%	441.18	1411.90	-28.8570	8.58E-06	2.776445
	10%	415.98	543.66	-6.4623	0.002953	2.776445
	20%	272.25	460.86	-14.9479	0.000117	2.776445
	30%	193.10	344.02	-19.4801	4.09E-05	2.776445
	40%	155.58	290.82	-15.4672	0.000102	2.776445
	50%	175.73	334.18	-22.3072	2.39E-05	2.776445
	10%	8798	14389	-8.5886	0.00101	2.776445
	20%	9276	16749	-7.8353	0.001433	2.776445
	30%	12612	18436	-5.6109	0.004957	2.776445
	40%	14856	21013	-7.2499	0.001921	2.776445
	50%	18416	28243	-13.2935	0.000185	2.776445

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

(b) Longitudinal

Properties	Moisture Content	Specie		t-test for Equality of Means		
		Irvingia gabonesis	*Irvingia wombolu*	t	P-value	Tcritical
Rupture force	10%	692.92	1796.36	-21.3434	2.85E-05	2.776445
	20%	500.12	1573.27	-15.4708	0.000102	2.776445
	30%	439.19	1298.42	-56.1063	6.04E-07	2.776445
	40%	401.05	1157.88	-48.0934	1.12E-06	2.776445
	50%	492.83	1557.88	-22.5922	2.27E-05	2.776445
Deformation	10%	1.09	1.96	-41.0122	2.11E-06	2.776445
	20%	1.63	2.10	-5.39156	0.005724	2.776445
	30%	1.79	2.75	-24.7236	1.59E-05	2.776445
	40%	2.08	2.98	-12.2498	0.000255	2.776445
	50%	2.31	3.35	-10.9779	0.000391	2.776445
Failure stress	10%	1393.00	3067.57	-42.3826	1.85E-06	2.776445
	20%	980.30	2913.78	-47.6982	1.16E-06	2.776445
	30%	918.40	2892.13	-67.1965	2.94E-07	2.776445
	40%	818.50	2818.20	-47.5662	1.17E-06	2.776445
	50%	692.98	1739.70	-17.7689	5.89E-05	2.776445
Modulus of stiffness Nmm-1	10%	636.37	917.6789	-11.6036	0.000315	2.776445
	20%	310.67	747.29	-14.8128	0.000121	2.776445
	30%	245.70	472.51	-25.0816	1.5E-05	2.776445
	40%	193.21	388.46	-23.7583	1.86E-05	2.776445
	50%	213.361	465.20	-22.1477	2.46E-05	2.776445
Modulus of elasticity Nmm-2	10%	9214	17061	-10.3989	0.000483	2.776445
	20%	10993	19860	-9.63882	0.000648	2.776445
	30%	16268	22642	-4.62000	0.009881	2.776445
	40%	19230	24468	-4.67723	0.009467	2.776445
	50%	25838	28909	-2.51734	0.065542	2.776445

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

(c) Transverse

		Specie		t-test for Equality of Means		
Properties	Moisture Content	*Irvingia gabonesis*	*Irvingia wombolu*	t	P-value	Tcritical
Rupture force	10%	451.54	1263.67	-18.0286	5.56E-05	2.776445
	20%	307.22	1130.49	-18.8161	4.7E-05	2.776445
	30%	293.89	989.14	-107.493	4.49E-08	2.776445
	40%	278.60	872.90	-23.8742	1.83E-05	2.776445
	50%	428.26	1169.00	-33.9476	4.49E-06	2.776445
Deformation	10%	2.16	3.37	-20.0555	3.65E-05	2.776445
	20%	2.44	3.47	-11.3730	0.000341	2.776445
	30%	2.83	3.92	-35.8164	3.63E-06	2.776445
	40%	3.42	4.11	-2.78489	0.04957	2.776445
	50%	3.67	4.86	-22.5781	2.28E-05	2.776445
Failure stress	10%	587.45	1629.61	-22.6858	2.24E-05	2.776445
	20%	549.74	1482.17	-20.7954	3.16E-05	2.776445
	30%	454.80	1385.78	-16.2619	8.37E-05	2.776445
	40%	437.58	1209.40	-17.8538	5.78E-05	2.776445
	50%	323.64	1040.10	-23.9915	1.79E-05	2.776445
Modulus of stiffness Nmm-1	10%	209.02	375.54	-9.3011	0.000743	2.776445
	20%	126.22	326.11	-21.3594	2.84E-05	2.776445
	30%	103.75	252.61	-46.8641	1.24E-06	2.776445
	40%	81.56	216.80	-7.9679	0.001344	2.776445
	50%	116.68	240.37	-21.4787	2.78E-05	2.776445
Modulus of elasticity Nmm-2	10%	6238.00	13397.00	-31.2873	6.22E-06	2.776445
	20%	7036.00	16063.00	-13.7322	0.000163	2.776445
	30%	11465.00	17670.00	-6.5016	0.002887	2.776445
	40%	12435.00	19479.00	-16.1597	8.58E-05	2.776445
	50%	18371.00	26421.00	-29.6631	7.69E-06	2.776445

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

Table E9: Parameter estimates for mechanical properties of *Irvingia gabonensis* seed

(a) Transverse

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	Intercept	1	0.01948	0.01010	1.93	0.0658	0
RF	RF	1	-0.00005004	0.00002150	-2.33	0.0287	-0.26471
DFM	DFM	1	0.01496	0.00392	3.81	0.0008	0.57397
FS	FS	1	-0.00003599	0.00001347	-2.67	0.0133	-0.24047
MOS	MOS	1	0.00003305	0.00002394	1.38	0.1802	0.24279
MOE	MOE	1	6.84914E-7	1.566557E-7	4.37	0.0002	0.36622

(b) Longitudinal

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	Intercept	1	0.06973	0.02291	3.04	0.0056	0
RF	RF	1	-0.00000801	0.00001715	-0.47	0.6446	-0.13541
DFM	DFM	1	0.00130	0.00518	0.25	0.8045	0.05375
FS	FS	1	-0.00001226	0.00000223	-5.50	<.0001	-0.42273
MOS	MOS	1	-0.00004908	0.00005976	-0.82	0.4195	-0.33630
MOE	MOE	1	8.379631E-7	2.426735E-7	3.45	0.0021	0.24634

(c) Axial

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	Intercept	1	0.00509	0.00564	0.90	0.3751	0
RF	RF	1	0.00009437	0.00002577	3.66	0.0012	0.68879
DFM	DFM	1	-0.00329	0.00513	-0.64	0.5274	-0.10602
FS	FS	1	-0.00002760	0.00001227	-2.25	0.0339	-0.12071
MOS	MOS	1	-0.00012083	0.00003897	-3.10	0.0049	-0.85301
MOE	MOE	1	0.00000228	1.970429E-7	11.59	<.0001	0.66484

Table E10: Parameter estimates for mechanical properties of *Irvingia wombolu* seed

(a) Transverse

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	Intercept	1	0.03508	0.01637	2.14	0.0425	0
RF	RF	1	9.644101E-7	0.00001284	0.08	0.9408	0.01012
DFM	DFM	1	0.00472	0.00556	0.85	0.4036	0.17778
FS	FS	1	-0.00001737	0.00000361	-4.82	<.0001	-0.27528
MOS	MOS	1	-0.00003078	0.00002833	-1.09	0.2881	-0.29277
MOE	MOE	1	9.218245E-7	1.412725E-7	6.53	<.0001	0.34243

(b) Longitudinal

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	Intercept	1	0.06973	0.02291	3.04	0.0056	0
RF	RF	1	-0.00000801	0.00001715	-0.47	0.6446	-0.13541
DFM	DFM	1	0.00130	0.00518	0.25	0.8045	0.05375
FS	FS	1	-0.00001226	0.00000223	-5.50	<.0001	-0.42273
MOS	MOS	1	-0.00004908	0.00005976	-0.82	0.4195	-0.33630
MOE	MOE	1	8.379631E-7	2.426735E-7	3.45	0.0021	0.24634

(c) Axial

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standardized Estimate
Intercept	Intercept	1	-0.02420	0.02688	-0.90	0.3769	0
RF	RF	1	-0.00000720	0.00001932	-0.37	0.7126	-0.05543
DFM	DFM	1	0.01069	0.00667	1.60	0.1221	0.44122
FS	FS	1	0.00000196	0.00000723	0.27	0.7885	0.01518
MOS	MOS	1	-0.00001800	0.00005118	-0.35	0.7282	-0.12161
MOE	MOE	1	0.00000166	3.528628E-7	4.70	<.0001	0.46907

Table F1: Thermal properties of *Irvingia gabonensis* kernel

S/N	Moisture content	Thermal Conductivity ($Wm^{-1}K^{-1}$)	Specific heat capacity ($JkgK^{-1}$)	Thermal Diffusivity ($\times 10^{-4}$ m^2s^{-1})
1	2.18%	0.1567	956.32	0.000383
2		0.1639	894.91	0.000425
3		0.1724	976.43	0.000409
4		0.1809	1038.26	0.000413
5		0.1917	1031.15	0.000436
Mean		0.1731	979.41	0.000413
1	3.65%	0.1563	997.41	0.000340
2		0.1398	813.74	0.000363
3		0.1474	934.56	0.000332
4		0.1623	845.67	0.000410
5		0.1544	840.07	0.000395
Mean		0.1520	886.29	0.000368
1	5.32%	0.1284	789.25	0.000321
2		0.1190	868.15	0.000277
3		0.0987	703.81	0.000277
4		0.1073	694.95	0.000308
5		0.1347	923.67	0.000286
Mean		0.1176	795.97	0.000294

Table F2: Thermal properties of *Irvingia wombolu* kernel

S/N	Moisture content	Thermal Conductivity ($Wm^{-1}K^{-1}$)	Specific heat capacity ($JkgK^{-1}$)	Thermal Diffusivity ($\times 10^{-4}$ m^2s^{-1})
1	2.18%	0.2157	1183.20	0.0004224
2		0.2256	1438.16	0.0003755
3		0.2411	1109.65	0.0005050
4		0.2216	1305.77	0.0003931
5		0.2363	1296.04	0.0004268
Mean		0.2281	1266.56	0.0004246
1	3.65%	0.2047	982.35	0.0004520
2		0.2109	1074.61	0.0004221
3		0.1963	1107.42	0.0003861
4		0.1897	1197.39	0.0003409
5		0.2078	1098.05	0.0004079
Mean		0.2019	1091.96	0.0004018
1	5.32%	0.1852	979.18	0.0003790
2		0.1791	1014.75	0.0003530
3		0.1703	943.81	0.0003620
4		0.1684	928.90	0.0003640
5		0.1629	1047.23	0.0003110
Mean		0.1732	982.77	0.0003540

Table F3: Independent samples t-test of the difference between thermal properties of *Irvingia wombolu* and *Irvingia gabonensis* kernel

Specific heat

	Specie		t-test for Equality of Means		
Moisture Content	*Irvingia gabonesis*	*Irvingia wombolu*	t	P-value	tcritical
2.18%	979.414	1266.564	-4.19308**	0.013772	2.776445
3.65%	886.29	1091.964	-3.31663**	0.029471	2.776445
5.32%	795.966	982.774	-8.08454**	0.001272	2.776445

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

Thermal conductivity

	Specie		t-test for Equality of Means		
Moisture Content	*Irvingia gabonesis*	*Irvingia wombolu*	t	P-value	tcritical
2.18%	0.17312	0.22806	-10.3715**	0.000488	2.776445
3.65%	0.15204	0.20188	-7.15229**	0.002022	2.776445
5.32%	0.11762	0.17318	-7.63647**	0.001579	2.776445

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

Thermal diffussivity

	Specie		t-test for Equality of Means		
Moisture Content	*Irvingia gabonesis*	*Irvingia wombolu*	t	P-value	tcritical
2.18%	0.000413	0.000425	-0.43753^{NS}	0.684312	2.776445
3.65%	0.000368	0.000402	-1.11876^{NS}	0.684312	2.776445
5.32%	0.000294	0.000354	-5.83256**	0.004306	2.776445

** Mean difference Significant at 0.05 levels, ^{NS} not significant at 0.05 levels

Table F4: Parameter estimates for thermal properties of bush mango kernel

(a) *Irvingia gabonensis*

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	0.20624	0.01547	13.33	<.0001
TC	TC	1	0.55599	0.23721	2.34	0.0344
SHC	SHC	1	-0.00012661	0.00002509	-5.05	0.0002
TD	TD	1	-355.47066	88.00283	-4.04	0.0012

(b) *Irvingia wombolu*

Variable	Label	df	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	0.21194	0.01395	15.20	<.0001
TC	TC	1	1.13159	0.19370	5.84	<.0001
SHC	SHC	1	-0.00018182	0.00002513	-7.23	<.0001
TD	TD	1	-503.67568	58.25776	-8.65	<.0001