EFFECT OF MOISTURE ON SELECTED PHYSICAL PROPERTIES OF "*PADI-TUYA*" AND "*SONGOTRA*" COWPEA VARIETIES

BY

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DECLARATION

I, OSEI TWUMASI-ANKRA, author of this thesis titled 'Effect of Moisture on Selected Physical Properties of *Padi-Tuya* and *Songotra* Cowpea Varieties', do hereby declare that apart from the references of other people's work which has been duly acknowledged, the research work presented in this thesis was done entirely by me in the Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology, from August 2011 to August 2013. This work has never been presented in whole or in part for any other degree in this university or elsewhere.

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ABSTRACT

This study assessed the effect of rewetting and drying on some selected physical properties of two cowpea varieties namely-*Padi-Tuya and Songotra* at eight selected moisture contents namely, 9.8, 12.6, 16 and 23%w.b. for rewetting; and 8.4, 13.2, 17.30 and 22%w.b. for drying.

In the moisture content range of 9.8%w.b. to 23.0%w.b., the length, width and thickness of *Padi-Tuya* increased non-linearly from 9.72mm to 10.54mm, 6.84mm to 7.15mm and 5.29mm to 5.4mm respectively. The length, width and thickness of *Songotra* increased non-linearly from 6.98mm to 7.68mm, 5.21mm to 5.99mm and 4.03mm to 4.45mm respectively. *Padi-Tuya* recorded non-linear increases for geometric mean diameter (7.05mm to 7.41mm), surface area (156.32mm^2 to 172.49mm^2) and volume (183.78mm^3 to 213.02mm^3). Geometric mean diameter, surface area and volume for *Songotra* increased non-linearly from 5.27mm to 5.90mm, 87.29mm^2 to 109.23mm^2 and 76.69mm^3 to 107.35mm^{3}respectively. Bulk densities of *Padi-Tuya* and *Songotra* decreased non-linearly from 796.33kgm^{-3} at 9.8%wb to 751.56kgm^{-3} at 23.0%wb and 807.91kgm^{-3} to 728.06kgm^{-3} respectively.

Padi-Tuya and *Songotra* had their true densities decreasing non-linearly from 1210.00kgm^{-3} at 9.8%wb to 1187.30 at 23.0%wb and 1217.61kgm^{-3} to 1206.54kgm^{-3} respectively. For porosity, *Padi-Tuya* increased from 51.95% at 9.8%wb to 57.98% at 23.0%wb and *Songotra* increased from 33.67% to 39.65%. The 1000 Grain mass for *Padi-Tuya* increased non-linearly from 225.03g to 236.05g and *Songotra* increased from 140.21g to 150.63g. *Padi-Tuya* had static coefficient of friction increasing non-linearly on all three surfaces namely plywood (0.29 to 0.35), mild steel (0.37 to 0.59) and rubber (0.35 to 0.48). The static coefficient of friction for *Songotra* increased non-linearly on all the three surfaces namely plywood (0.31 to 0.39), mild steel (0.38 to 0.46) and rubber (0.39 to 0.47). The results obtained for drying showed the following trends:

With decreasing moisture content, length, width and thickness dimensions decreased from 7.91 to 6.97mm, 10.53 to 9.69mm, 7.12 to 6.79mm and 5.43 to 5.26mm respectively for *Padi-Tuya*, and 7.61 to 6.96mm, 5.94 to 5.19mm and 4.44 to 3.99mm respectively for *Songotra*.

Padi-Tuya had geometric mean diameter, surface area and volume decreasing from 7.38mm to 7.01mm, 171.27mm^2 to 154.28mm^2 and 210.71mm^3 to 180.15mm^3 respectively while that of Songotra decreased non-linearly from 5.85mm to 5.24mm, 107.66mm^2 to 86.39mm^2 and 105.04mm^3 to 75.51mm^3 respectively under drying conditions. Bulk density increased non-linearly from 692.52kgm^{-3} to 701.79kgm^{-3} and 727.98kgm^{-3}to 801.55kgm^{-3}with for *Padi-Tuya* and *Songotra* respectively. True density increased non-linearly from 1197.67kgm^{-3} to 1219.78kgm^{-3} and 1201.63kgm^{-3} to 1222.00kgm^{-3} *Padi-Tuya* and *Songotra* respectively. Porosity increased non-linearly from 42.18% to 42.47% for *Padi-Tuya*. It however decreased from 39.42% to 34.41% for *Songotra*.1000 grain mass decreased non-linearly from, 151.08g to 138.69g and 153.79g to 125.72g for *Padi-Tuya* and *Songotra* respectively. Filling angle of repose decreased non-linearly from 29.9^0 to 17.25^0 and 28.4^0 to 21.48^0 for *Padi-Tuya* and *Songotra* respectively.

Padi-Tuya recorded a non-linear decrease in static coefficient of friction on all three surfaces namely plywood (0.35 to 0.28), mild steel (0.54 to 0.37) and rubber (0.48 to 0.34). Highest coefficient was recorded for mild steel followed by rubber and then plywood. *Songotra* also recorded decreases on the three surfaces; plywood (0.39 to 0.31), mild steel (0.46 to 0.37) and rubber (0.46 to 0.36) during drying. For both conditions, rubber offered the maximum friction followed by mild steel and then plywood.

DEDICATION

This project is dedicated to GOD ALMIGHTY.

Papa Kwame, Auntie Rose and the Twumasi-Ankra Family now and generations yet unborn.

All members and partners of Christ-On-The-Move Evangelistic Ministries.

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CHAPTER ONE

1.1 BACKGROUND TO THE STUDY

Cowpea, *Vigna unguiculata* (L.) Walp., is an important grain legume. It is consumed by relatively rural and periurban people of less developed countries. Rural families derive food protein (Bressani, 1985) and animal feed (Tarawali *et al*., 1997; Singh, 1999) from cowpea. Protein content of cowpea seed is among the highest in cultivated legumes (Aremu *et al*., 2007 cited in Basaran *et al*., 2011).

Cowpea plays a critical role in the lives of millions of people in Africa and other parts of the developing world, where it is a major source of dietary protein that nutritionally complements staple low-protein cereal and tuber crops, and is a valuable and dependable commodity that produces income for farmers and traders (Singh, 2002; Langyintuo *et al*., 2003).

The grains contain 25% protein, and several vitamins and minerals. The plant tolerates drought, performs well in a wide variety of soils, and being a legume replenishes low fertility soils when the roots are left to decay. It is grown mainly by small-scale farmers in developing regions where it is often cultivated with other crops as it tolerates shade. It also grows and covers the ground quickly, preventing erosion. (Dugje *et al*., 2009).

According to Henshaw (2008), Nigeria is the largest producer of cowpea. The greater percentage of these productions are being utilized for various food preparations such as bean pudding, bean cake, baked beans, fried beans, bean soup etc. while small quantities are processed for industrial processes.

1.2 STATEMENT OF PROBLEM AND JUSTIFICATION

The design of postharvest handling and processing machinery for cereals, grains and pulses depend greatly on the physical characteristics of the product. The physical characteristics are also in turn dependent on the moisture content and drying time of the grains. The physical properties are indispensable in tackling critical issues that have to do with the design of machines or the behaviour of the grains during processes such as conveying, handling, sorting, drying etc.

It is only until quite recently that research attention has been given to determining physical properties of these food products especially cowpeas. The Crop Research Institute of the Council for Scientific and Industrial Research (CSIR-CRI) has come out with several varieties of cowpeas over the years. Bart-Plange *et al*. (2005) determined physical properties of two varieties of cowpea "*Asetenapa"* and "*Adom"* which were released from the CSIR-CRI. They considered the effect of drying on the physical properties of the two varieties. No work however has been done on the effects of rewetting on the physical properties of the *Nhyira* and *Tona* varieties which were released in 2007 by the CSIR-Crop Research Institute and the *Padi-Tuya* and *Songotra* varieties that were released by the Savannah Agricultural Research Institute of the Council for Scientific and Industrial Research (CSIR-SARI).

Bart-Plange *et al*. (2012) and Ampah *et al*. (2012) measured the physical properties of *"Asontem"*. They considered the effect of drying and rewetting respectively on the physical properties of the *"Asontem"* variety.

This study seeks to examine the effect of moisture size and shape properties, 1000-grain mass, filling and emptying angle of repose, bulk density, true density, static coefficient of friction and porosity of *Padi-Tuya*, *Songotra*, *Nhyira* and *Tona* cowpea varieties.

1.3 AIM AND SPECIFIC OBJECTIVES

The main aim of the study will be to determine the effect of moisture content on the linear size and shape properties and frictional properties of *Padi-Tuya,* and *Songotra* cowpea varieties.

The specific objectives of this study are:

- To determine the effect of rewetting on the linear dimensions, geometric mean diameter, volume, surface area, sphericity, 1000 seed mass, bulk density, true density, porosity, filling angle of repose and static coefficient of friction of the selected cowpea varieties.
- To determine the effect of drying on the linear dimensions, geometric mean diameter, volume, surface area, sphericity, 1000 seed mass, bulk density, true density, porosity, filling angle of repose and static coefficient of friction of the selected cowpea varieties.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

Advances and innovations in technology have led to the manufacture of various agricultural machinery that have enhanced handling and processing of agricultural produce. Hsu (1983) indicated that moisture absorption capacity of most agricultural grains is of both theoretical and practical importance to processing industries. This is rightly so because most processing activities undertaken require initial hydration of the products.

Physical properties are important factors in solving problems associated with the design of specific machines or analysis of the behaviour of the product during agricultural processes such as planting, harvesting, handling, threshing, sorting and drying. Solution to these problems involves having knowledge of physical and engineering properties of products (Irtwange and Ugbeka, 2002).

Information on physical and aerodynamic properties of agricultural products is needed in design and adjustment of machines used during harvesting, separating, cleaning, handling and storing of agricultural materials (Gursoy and Guzel, 2010).

The geometric properties such as size and shape are two of the most important physical properties considered during the separation and cleaning of agricultural grains. In theoretical calculations, agricultural seeds are assumed to be spheres or ellipse because of their irregular shapes (Mohsenin, 1980; Nalbandi *et al*., 2010).With their consumption cutting across all ten regions of Ghana, information on their physical properties relevant to their storage and processing is very crucial.

2.2 COWPEA TAXONOMY AND AGRONOMY

Cowpea (*Vigna unguiculata* L. Walp.) is an annual dicotyledonous crop and is a member of the order *Fabaceae* and *Phaseoleae* tribe of the *Leguminosae* family and subfamily *Faboideae*. It belongs to the genus *Vigna* and Section *Catiang.* Members of the *Phaseoleae* include many of the economically important warm season grain and oilseed legumes such as soybean (*Glycine max*), common bean (*Phaseolus vulgaris*), and mungbean (*Vigna radiata*) (Timko *et al*., 2007; Timko and Singh, 2008). Cowpea is also believed to have originated from West Africa by some workers, because both wild and cultivated species abound in the region (Cowpea Production Guide, 2011).

2.2.1 COWPEA PRODUCTION

Cowpea (*Vigna Unguiculata L. Walp*) is one of the most important indigenous legumes of the tropics and sub tropics (NRC, 2006). An estimated 7.6 million tons of cowpea is produced annually worldwide, estimated to be on about 12.8 million hectares of land of which about 64% is in Africa, 21% in the America‘s and the rest in Europe and Asia. Nigeria is the largest cowpea producer accounting for about 22% of the total, followed by Brazil which produces 10% on 1.144 million hectares of land annually (Pereira, *et al*., 2001).

Cowpea is mainly grown in the Savanna zones (Derived savanna, Southern Guinea savanna and Northern Guinea savanna) of northern Ghana, which constitute about 41% of Ghana’s landmass (SRID, MOFA, 2012).

2.2.1.1 CLIMATIC AND SOIL REQUIREMENTS

Cowpea can be grown under rain-fed conditions and It requires less rainfall than most crops as well as by using irrigation or residual moisture along river or lake flood plains during the dry season, provided that the range of minimum and maximum temperatures is between 28 and 30°C (night and day) during the growing season since it is also a warm weather crop.

Cowpea performs well in agro-ecological zones where the rainfall range is between 500 and 1200 mm/year. However, with the development of extra-early and early maturing cowpea varieties, the crop can thrive in the Sahel where the rainfall is less than 500 mm/year. It is tolerant of drought and well adapted to sandy and poor soils. Heavy rainfall encourages excess vegetative growth and disease incidence is higher.

However, best yields are obtained in well-drained sandy loam to clay loam soils with the pH between 6 and 7 (Dugje *et al*., 2009).

2.2.1.2 LAND PREPARATION

For soils with poor structure, high run-off and low water infiltration, the physical properties can be improved markedly and cowpea yields increased if farmers hoe the land or the land is ploughed. Zero tillage (for example using Roundup spray prior to planting) may be used only where drainage is good (Cowpea Production Guide, 2011).

2.2.1.3 FERTILIZATION

On fairly fertile soils cowpeas do not need nitrogen fertilizer. In nitrogen and phosphorus deficient soils however, application of starter dose of nitrogen up to 20 kg/ha on old land (continuously cropped land) where organic matter content may be as low as 1% is recommended. Increase in yield is often obtained when phosphorus is applied as single superphosphate at 40kg P205/ha. Phosphorus application not only increases yield but nodulation also in cowpea (Cowpea Production Guide, 2011).

2.2.1.4 PLANTING AND SEED RATES

Farmers normally use farm-saved seed for planting. The 1000-seed weight of cowpea is 150–300 g. The seed rate for pure stands is 15–30 kg/ha. Seed dressing with an insecticide and a fungicide (e.g. thiram) prior to planting is recommended (Gruben, 1993 cited in Madamba *et al.*, 2006).

In tropical Africa cowpea is mostly grown intercropped or in relay with other crops such as yam, maize, cassava, groundnut, sorghum or pearl millet. Pure stands are not common except in the coastal areas of East Africa, and also in Asia and Western countries. In the forest and Guinea savanna zones of West Africa cowpea is mainly intercropped with maize, cassava, yam or groundnut, at a very low density (1000–5000 hills/ha) (Brink and Belay, 2006).

Following germination, emergence of the cowpea seedling from the soil is considered epigeal. This type of emergence makes the seedling more susceptible to injury since the plant cannot regenerate buds below the cotyledonary node. The first two true leaves are opposite, sessile, and entire, whereas the remaining leaves are alternate, petiolate, and trifoliate. Structure of the mature plant varies depending on genotype, growth temperature, and the photoperiod in which the plant grows. The major plant growth habits are erect, semi-erect, prostrate (trailing), or climbing.

Cowpea requires soil with fine tilth for good root growth. Generally, deep ploughing followed by harrowing provides an adequate tilth. In intercropping systems, tillage normally follows the crop in which cowpea is interplanted. Peri-urban vegetable farmers use special cultivars for ratoon cropping of the leaves. They broadcast the seed on raised beds, made on well-manured soil, aiming at a dense stand of about 25 plants per m^2.

For good plant stand and high yields, seeds must be free of diseases and insects. Ideally, planting should be timed in relation to the maturity period twice in a year, the first crop may be planted in April, and the second crop in late July to mid -August. When planting the same variety, it is advised that old seed reserves are used, rather than planting of the variety such that the crop is harvested in bright dry weather. Harvesting under humid cloudy weather favours pod rots. Generally, for early maturing types, planting at the beginning of the rains is advised so that the sensitive stages of the crop avoid the peak activity of insect pests (Cowpea Production Guide, 2011).

Seed rate depend on the plant type and seed size. Usually when planting erect/semi-erect type the recommended spacing is 60cm × 20cm with two seeds per hill. At this spacing, up to 28 kg of seeds is required per hectre. Local prostrate varieties should be planted wider spacing of 80 cm × 40 cm. Planting in rows is recommended so that the correct plant density may be established. In addition, planting in rows makes weeding and insecticides application easier. Line planting may be done with the aid of garden lines or sighting poles (Cowpea Production Guide, 2011).

2.2.1.6 WEED MANAGEMENT

It is recommended by the Ministry of Food and Agriculture (MOFA) in their cowpea production guide released in 2005 that;

- One hand-weeding two to three weeks after planting is normally sufficient to control weeds in cowpea.
- A second hand-weeding 5-6 weeks after planting later may be necessary depending on the weed pressure.
- In inter-crop situations, weeding may be carried out two times before mid-podding of the cowpea.

2.2.2 COWPEA PESTS AND DISEASES

2.2.2.1 Bacterial Diseases

These include bacterial blight and bacterial pustule. Bacterial blight is seed borne and using high quality seed may reduce incidence of this disease. The disease also survives on diseased crop residues. Growing cowpea after cowpea may therefore increase diseases prevalence. The initial symptoms appear as tiny dots on the leaves. The area surrounding the spot dies and develops a yellow coloration.

The disease spread rapidly during heavy rainfall. Under such conditions, the dead spots merge and large areas of the leaves are affected. The disease may affect the stem, causing the stem to crack. Affected pods appear water-soaked and from this point, the pathogen enters the seed. First symptoms of the bacterial pustule are tiny dark water-soaked spots on the undersurface of the leaves. Under severe infestation, the spots enlarge becoming dry and sunken in the center, and water-soaked around the margin. The leave turn yellow and fall. Like bacterial blight, use of the clean seed and rotation may reduce the disease incidence (Cowpea Production Guide, 2011).

2.2.2.2 Fungal Diseases

A number of fungal diseases are prevalent in Ghana. Some of the important ones are described below. Anthracnose: it is a stem disease, but may affect all above ground parts. The lesions that are brown to tan in colour appear on affected plant parts. The lesions enlarge to girdle the stem, petioles and peduncles. The disease is seed borne and can be controlled by using clean seed. Although fungicides are not typically used on cowpea, benomyl or mancozeb (0.2% a.i.) is recommended under severe infection. Another disease called blotch show similar symptoms but mainly attacks the pods. Pods become distorted and black spot appear on them (Cowpea Production Guide, 2011).

2.2.2.3 Web blight

Small, circular reddish-brown sports appear on leaves which under humid conditions enlarge into irregular-shaped areas. Leaves become dry. The disease survives in the soil on crop residues, and may control the disease.

2.2.2.4 Stem rots

The disease affects the base of the stem where cotton-like growth of the pathogen can be seen. Infected plants wilt and die. The stem rots are probably not seed borne. Good field hygiene may control the disease (Cowpea Production Guide, 2011).

2.2.3 COMMON INSECT PESTS ON COWPEA

Insect pests are the most important yield reducing factors in cowpea. Farmers who do not spray their crops risk total crops failure. Some of these insect pests are;

Aphids: The cowpea aphid is a major pest common in growing areas. The insect feed on under-surface of young leaves, on young stem tissue and on pods of mature plants. Under severe infestation, there is premature defoliation and death of young seedlings. A more harmful effect is that the insect transmits the aphid-borne mosaic virus. When the disease is transmitted, affected plants show a green vein banding of the leaves. A number of improved varieties recommended for cultivation are resistant to aphids (Cowpea Production Guide, 2011).

Leafhoppers: They can destroy cowpea during the seedling stage. Their feeding causes yellow discoloration of leaf veins and margins, followed by cupping of leaves. Plants become stunted.

Maruca pod borer: This is a pest that causes damage to pods and seeds. The adult is a nocturnal moth. Larvae feed, on tender parts of the stem, peduncles, flowers and pod. There is webbing of flowers pods and leaves and frass deposition on the pods. Varieties that bear pods above the canopy, and separated from each other escape serious damage by this pest (Cowpea Production Guide, 2011).

These can be controlled by cultivating resistant varieties.

2.2.4 HARVESTING

Cowpea leaves are picked in a period from four weeks after emergence of the seedlings to the onset of flowering. In crops grown for the seed, farmers often harvest 10–20% of the leaves before the start of flowering with little detrimental effect on the seed yield. Growers of leafy cowpea types cut the plants at about 10 cm above the ground for a succession of new shoots (ratooning).

Green pods are harvested when the seed is still immature, 12–15 days after flowering. Harvesting of dry seed is done when at least two-thirds of the pods are dry and yellow. In indeterminate types harvesting is complicated by prolonged and uneven ripening; for some landraces harvesting may require 5–7 rounds. Mature seeds are usually harvested by hand. Sometimes plants are pulled out when most of the pods are mature (Madamba *et al.*, 2006).

Matured, dried pods should be harvested promptly, Delayed harvesting will encourage weevil infestation in the field, seed shattering and in humid weather the grains may deteriorate. After harvesting, pods should be sun dried immediately, and then threshed. Drying is important to reduce moisture content of grains significantly before storage in order to avoid seed getting mouldy (Cowpea Production Guide, 2011).

2.3 PROCESSING

CSIR-Savannah Agricultural Research Institute in the cowpea production guide released in 2012 recommended that cowpea should be threshed before storage. Storage in pods makes control of cowpea weevil more difficult.

For seeds: for small quantities of seed, storage in wood ash is effective. The following points should be noted:

1.) Use equal volume of wood ash and cowpea seed.

2.) The ash and seed should be mixed thoroughly and stored in a container.

3.) Cover ash/seed mixture with up to 3 cm of ash.

4.) Close container tightly.

Fine sand may be used in place of wood ash. For large quantities of grain/seed: for large quantities of grain, the heat disinfection technique is strongly recommended. Cowpea weevil, larvae and eggs are killed when exposed to temperature around 57 ^{o}C for one hour. The following steps may be followed:

1) Spread straw or dry grass on a level ground.

2) Spread a black polyethylene sheet over the straw. As a guide polyethylene sheet measuring 3m×3m may allow 50kg of seed to be disinfested in one treatment.

3) Spread the cowpea grains uniformly on the plastic material.

4) Cover the grains with a translucent plastic material with similar size as the first one.

5) Fold the edges of the two plastic sheets under and secure with stones.

6) Leave in the sun for at least two hours.

2.4 USES OF COWPEA

The main use of cowpea as a vegetable crop is as a legume, especially for small scale farmers in rural areas. It is very palatable, highly nutritious and relatively free of metabolites or other toxins and provides an inexpensive source of protein in their diet (Aveling, 2000). Cowpea can be used at all stages of growth as a vegetable crop, and the leaves contain significant nutritional value (Ahenkora *et al*. 1998; Nielson *et al*. 1993).

The tender green leaves are an important food source in Africa and are prepared as a potherb, like spinach. Immature green pods are used in the same way as snap beans, often being mixed with cooked dry cowpeas or with other foods. Nearly mature "fresh-shelled" cowpea grains are boiled as a fresh vegetable or may be canned or frozen. Dry mature seeds are also suitable for boiling and canning. In many areas of the world, cowpea foliage is an important source of high-quality hay for livestock feed (Tarawali *et al*. 1997).

In Ghana, the dry grain with about 23-25% protein serves as a cheap source of protein for both rural and urban consumers whereas livestock benefit from the residue left over after the grain is harvested. Rural families that make up the larger part of the population of northern Ghana derive from its production, food, animal feed and cash income. Cowpea grain is also a rich source of minerals and vitamins (Hall *et al*., 2003) and it has one of the highest levels of any food of folic acid, a crucial B vitamin that helps prevent spinal tube defects in unborn children (Timko *et al*., 2007).The protein found in cowpea is, similar as the one from other legumes, rich in the essential amino acids lysine and tryptophan (Timko and Singh 2008). However, the protein nutritive value of these legumes is lower than that of animal proteins because they are deficient of sulphur amino acids and contain non-nutritional factors (phytates and polyphenols), enzymes inhibitors (against trypsin, chymotrypsin and R-amylase) and haemaglutinins (Jackson, 2009).

Minerals and vitamins are the other nutritionally important constituents of the cowpea seeds. It has been reported that folic acid, a vitamin B necessary during pregnancy to prevent birth defect in the brain and spine content is found in higher quantity in cowpea compared to other plants (Hall *et al*. 2003; Timko and Singh 2008). Total protein content in seed ranges from 23% - 32% of the seed weight (Nielsen *et al*., 1993).

The presence of the high protein content in all cowpea parts consumable by human and animal (leaves, stems, pods and seeds), is the key factor in alleviating the malnutrition among women and children and improvement of healthy status of the livestock in resource limited households where regular access to animal protein is limited due to low economic status.

2.5 COWPEA VARIETIES IN GHANA

A number of landrace types are cultivated. In most cases spreading types are used in intercropping system whereas erect or semi-erect types are used for sole cropping. Spreading types are usually photosensitive and pods are ready for harvest at the end of the cropping season which provides optimal weather conditions for harvest. Higher yields are however obtained under sole cropping, if early maturing (60-70 days) erect or semi-erect types are grown, for which a number of have been bred (Cowpea Production Guide, 2011).

Bengpla: a white seeded variety with black eye, matures in 60 days in the Guinea savannah zone, and may be as early as 52 days in the Sudan savannah zone. It produces good yields in a disease-free environment. The potential yields is 1.5 t/ha. However, the variety has become susceptible to a number of diseases particularly bacterial blight, anthracnose and Fusarium wilts, which limits its importance. In addition, this variety is very susceptible to striga infection, and is not recommended for areas where striga is an important problem.

Vallenga: is a red-seeded variety that matures in about 70 days. It was released in 1986 after testing with farmers. It produces stable high yields, with a yield potential of 2.0 t/ha. Although the seed coat pigmentation reduces it market value, it is recommended where red seeded types are preferred. Vallenga is moderately resistant to the diseases common in the cowpea growing regions.

Apagbaala: this variety has white seed coat with small brown eye. The seeds are small in size. It was released in 2003 for cultivation in the Guinea savannah zone of Ghana. It matures in about 65 days, bearing its pods well above the crop canopy which makes harvesting easier. Under good management and favourable weather conditions, yields as high as 1.8 t/ha can be obtained. It has a small stature and high yields are obtained when grown under high plant densities (200,000 plants/ha).

Because of synchronous pod maturity and long peduncles that carry the pods above the canopy, this variety usually has less damage form the Maruca pod borer. The grains have a short cooking time compared with other varieties. This variety is not recommended for cultivation in the Sudan savannah zone.

Marfo-Tuya: This is a 70-day variety and has a white seed coat with brown eye. It was released in 2003 for general cultivation in Northern Ghana. The yield potential is 2.0 t/ha. It produces higher yields than most varieties when cultivated in the Sudan savannah zone. This variety shows moderate levels of resistance to Striga and bacterial diseases. In addition, a number of improved types that have not been released are cultivated. An example is IT81D-1137, a medium maturing white-seeded line with yield potential of 1.8 t/ha.

Padi-Tuya: SARC-122-2 named Padi-Tuya (shown in Fig. 1) is a medium maturing line and matures in 60-65 days after planting. It was released in 2008 by CSIR-Savannah Agricultural Research Institute. It is an erect type and has moderate resistance to aphids, leaf curl and *Striga*. It is a white seeded variety and has an on-farm yield of 1.8 t/ha. It is good for fodder.

Songotra: IT97K-499-35 called Songotra (Fig. 2) is also a medium maturity variety released in 2008 by CSIR-SARI. It is erect and bears white seeds. It is highly resistant to *Striga* and has moderate resistance to aphids and leaf curl. It has an on-farm yield of 2 t/ha.

Nhyira: IT87D-611-3 named Nhyira was released in 2007 alongside another variety named Tona by the Crop Research Institute of the Council for Scientific and Industrial Research."Nhyira", means "blessing" in Akan. It is early maturing (65-68days), high yielding (2.3t/ha), moderately resistant to virus, resistant to Anthracnose and Cercospora leafspot, high in iron, energy and phosphorus contents, protein, tolerant to leafhoppers, bold, white seed with brown eye and drought tolerant. It can be used for *koose, gari* and beans, rice and beans, cake, *aprepransa,* sausage rolls, jam rolls, pie, chips, etc (Ampah, 2011).

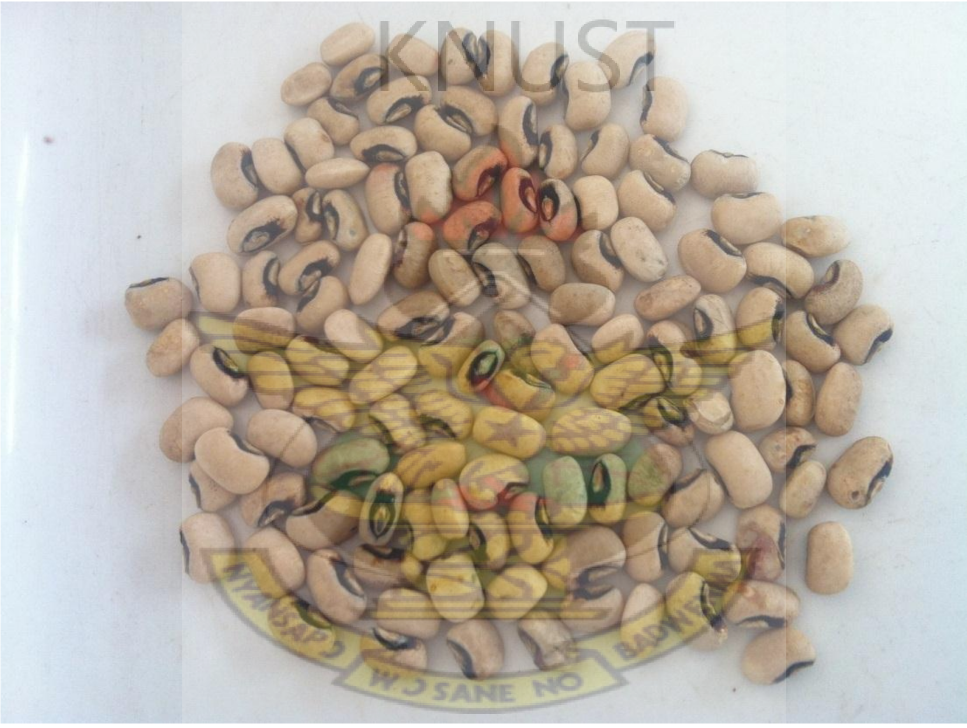

Fig 1. Padi-Tuya variety

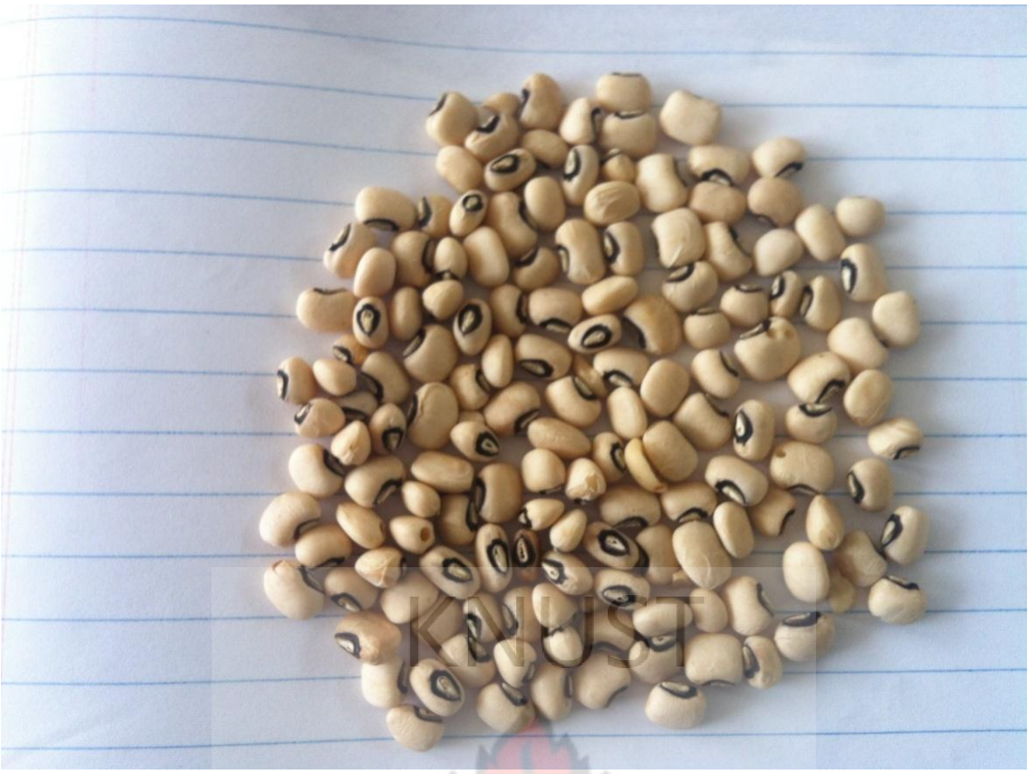

Fig 2. Songotra Variety

2.6 PHYSICAL PROPERTIES OF SEEDS

2.6.1 Size and shape properties

According to Sirisomboon *et al*. (2007) cited in Resende *et al.* (2012), the size (superficial area, projected area and volume) and form (roundness, sphericity) of the fruits, nuts and seeds are important to the peeling process of these products. These data could be used to determine the inferior limit of the transporter size, such as matting, chain bucket and helical transporter.

Stroshine (1998) indicated that shape is important in orienting foods and vegetables prior to mechanised 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 upon proper orientation.

Both size and shape become important in packing of high quality fruits and vegetables. Retail stores often display fruits and vegetables in shallow polystyrenes trays covered with clear plastic wrapping. Sizing of these trays is influenced by size and shape of the fruit or the vegetables for which they are used. Surface areas of leaves and plant components are needed for modelling and prediction of rates of transpiration, respiration and photosynthesis. Size and surface area affect the rate of moisture loss during drying of grains, seeds and other particulate materials (Stroshine, 2008).

2.6.2 Sphericity and Geometric Mean Diameter

Sphericity is one physical property that is often calculated to quantify differences in shapes of fruits, vegetables, grains and seeds. It 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 (i.e. a sphere with diameter equal to the major diameter of the object). Data from sphericity is useful in sieve size determination and in selecting sieve separators.

The geometric mean diameter or equivalent diameter was calculated from equation 1 (Mohsenin, 1970 cited in Ucer *et al.*, 2010)

$$D_g = (LWT)^{1/3} \quad (1)$$

The degree of sphericity is then calculated using equation 2 (Mohsenin, 1970 cited in Ucer *et al.*, 2010)

$$\emptyset = \frac{(LWT)^{1/3}}{L} \times 100 \quad (2)$$

$$\emptyset = \frac{D_g}{L} \times 100 \quad (3)$$

Jain and Bal (1997) have also stated that the Sphericity may be given by:

$$\emptyset = \frac{B(2L-B)^{1/3}}{L} \tag{4}$$

Where $B= (WT)^{0.5}$ (5)

2.6.3 Volume and Surface Area

Volume of solids can be determined experimentally by liquid or gas displacement. Volumes of smaller grains and seeds can also be measured with pycnometers or graduated burettes. When a burette is used, the volume of solid particles, the volume of fluid and the volume after addition of the solid particles are determined from the markings on the burette.

Volume, V and grain surface area, S may be given by equations 6 and 7

$$V = \frac{\pi}{6}\,(D_g^3) \tag{6}$$

$$S = \pi(D_g^2) \tag{7}$$

2.6.7 Angle of Repose

The angle of repose is the angle with the horizontal at which the material will stand when piled (Gharibzahedi *et al*, 2010). Generally, the angle of repose for situations where the material is being emptied from a bin, called the angle of repose for emptying or funneling, will be greater than the angle of repose for filling or piling, which is the angle formed when material is allowed to flow from a spout or elevator outlet so as to form a pile (Stroshine, 1998). Kaleem *et al*. (1993) mentioned that the angle of repose is very important in determining the inclination angle of the machine hopper tank. Bart-Plange and Baryeh (2002) reported that the filling angle of repose increased non-linearly with bean moisture content from an average value of 23.74^o at 5.67% (wb) moisture content to 33.81^oat 22.0% (wb) moisture content for category B cocoa beans. Sezer *et al.* (2011) observed a linear increase in angle of repose for dent corn variety *Simon* from 23.50 to 26.65° from 12.76 to 17.0%.

2.6.8 Coefficient of Static Friction

Frictional characteristics are very important in determining the proper design of conveying, grading and forage chopping machinery (Helmy, 1995). Chakraverty (1972) reported that the coefficient of friction between granular materials is equal to the tangent of the angle of internal friction for the material. The

coefficient of friction depends on grain shape, surface characteristics and grain moisture content.

2.7 Moisture and Moisture Relationships

The amount of moisture in agricultural materials and foods greatly affect properties such as density, force-deformation characteristics, thermal conductivity, heat capacity and electrical resistance. Dry components such as starch and protein have a greater density than water and therefore particle density usually decreases with increasing moisture content (Stroshine, 1998).

In discussion of moisture in agricultural materials and food products, some properties of moisture are worthy of consideration. These include moisture content, equilibrium moisture content and water activity.

2.7.1 Moisture Content

This is essentially the quantity of moisture in a product. Moisture content can be determined as a percentage of total weight which is water, (W_w). It is called the wet basis moisture content (M_w). If it is expressed as a ratio of weight of water to the dry matter (W_d), it is called the dry basis moisture content (M_d). These definitions are described by the following formulas:

$$M_w = 100.\frac{W_w}{W_t} = 100.\frac{W_w}{(W_w+W_d)} \quad (8)$$

$$M_d = 100.\frac{W_w}{W_d} \quad (9)$$

Where W_w= weight of water in the material, W_d= weight of dry matter in the material and W_t = total weight of the sample=W_w +W_d

If either M_w or M_d is known, the other can be calculated using the formulas below;

$$M_d = 100.\frac{M_w}{(100-M_w)} \quad (10)$$

and $M_w = 100.\frac{M_d}{(100+M_d)}$ (11)

The wet basis is usually the format for describing the composition of agricultural materials and food products. When a sample loses or gains moisture the change in dry basis moisture is linearly related to the weight loss or gain. The dry basis moisture is therefore often used for determining moisture changes during drying (Stroshine, 1998).

The moisture in grain creates vapour pressure. In like manner, the moisture in the air around the grain also creates vapour pressure. Moisture moves from areas of high vapour pressure to areas of low vapour pressure. This moisture movement continues until the vapour pressures in the grain and air are equal. The point at which vapour pressure in grain and air are equal is called the Equilibrium Moisture Content (EMC). The EMC is dependent on air temperature and relative humidity.

Another important issue about moisture related to agricultural products is water activity. Jangam and Mujumdar, (2010) defined water activity, a_w, as the ratio of the partial pressure, *P*, of water over the wet solid system to the equilibrium vapor pressure, p_w, of water at the same temperature. Thus, aw, which is also equal to the equilibrium relative humidity of the surrounding humid air, is defined as:

$$a_w = \frac{P}{P_w} = \frac{RH_{eq}}{100}$$

Water activity (*aw*) is one of the most critical factors in determining quality and safety of the goods which are consumed every day. Water activity affects the shelf life, safety, texture, flavour, and smell of foods. It is also important to the stability of pharmaceuticals and cosmetics. While temperature, pH and several other factors can influence if and how fast organisms will grow in a product, water activity may be the most important factor in controlling spoilage. It predicts stability with respect to physical properties, rates of deteriorative reactions, and microbial growth (Okos *et al.*, 1992).

This is because as Stroshine (2008) reports, water activity strongly influences microbial activity and other chemical reactions which take place in foods. Moulds will generally not grow at activities less than 0.7 while yeasts will not grow at activities less than 0.8 and bacteria require activities greater than 0.9.

He concludes therefore that spoilage due to microbial activity and other undesirable chemical reactions can be controlled by adjusting the water activity of foods.

2.9.2 Rewetting

Researchers have applied several methodologies in preparing rewetted materials. Some of the common ones are outlined below. Grain kernels are often rewetted by soaking in water during different periods of time determined by the initial moisture content and the final that must be attained. It is also the practice of some to rewet particles by calculating the amount of moisture to be added and sprinkling it on the mass of grains to be rewetted to reach the desired moisture content. Others rewet by placing grains within an environment of saturated air for the time necessary for them to reach the desired moisture content (Ruiz *et al.*, 2007 cited in Ampah, 2011).

Engels *et al*., (1986) cited in Ampah, 2011 reports that soaking is a slow process controlled by the diffusion of water in the grain. Soaking at room temperature may therefore provoke microbial contamination, which affects quality attributes (such as colour, taste and flavour) of the product (Bello *et al*., 2004). Kashaninejadl and Kashiri (2007) report that warm water soaking is a common method to shorten the soaking time, because higher temperature increases hydration rate.

Moisture content each time after soaking is calculated based on the increase in the sample weight at specific periods. For this purpose, at regular time intervals, kernels are rapidly removed from test tubes and 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 by less than ±1% (Resio *et al*., 2005).

2.9.3 Drying

The term drying generally refers to the removal of relatively small amounts of moisture from a solid or nearly solid material by evaporation. Drying therefore involves both heat and mass transfer processes simultaneously. Drying is the oldest method of preserving food. Drying, however cannot replace the other methods of food preservation like canning and freezing because these methods retain the taste, appearance, and nutritive value of fresh food; but drying is an excellent way to preserve foods that can add variety to meals and provide delicious, nutritious snacks. One of the biggest advantages of dried foods is that they take much less storage space than canned or frozen foods. Drying is a mass transfer process consisting of the removal of water or moisture from another solvent, by evaporation from a solid, semi-solid or liquid (Greensmith, 1998).

Foods are dried commercially, starting either from their natural state (e.g. vegetables, fruits, milk, spices, grains) or after processing (e.g. instant coffee, whey, soup mixes, non-dairy creamers) to addition to preserving the product and extending its shelf life, to obtain desired physical form (e.g. powder, flakes, granules), to reduce volume or weight for transportation and to obtain desired colour, flavour or texture (Methakhup, 2003 cited in Ampah, 2011).

2.9.3.1 Drying Methods

Sun drying is an age old method of drying food and is done even in contemporary times because it uses the heat from the sun and the natural movement of the air. This process is slow and requires a good deal of car e. The food must be protected from insects and covered at night. Sun drying is not as sanitary as other methods of drying (Chemical Engineers' Handbook, 2007). Some of the other methods of drying are outlined below:

- Indirect or contact drying (heating through a hot wall), as drum drying, vacuum drying.

  Again, higher wall temperatures will speed up drying but this is limited by product degradation or case-hardening (Mujumdar, 1998 cited in Ampah, 2011).
- Application of hot air (convective or direct drying). Air heating increases the driving force for heat transfer and accelerates drying. It also reduces air relative humidity, further increasing the driving force for drying.
- Recent studies and research also indicate that drying can also be achieved through exposure of the wet sample to radioactivity and it is claimed that this has the ability to dry the sample uniformly at the same time and not in layers as is done by our current conventional hot-air methods. Issues have however been raised about the safety of foods dried by this method.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 INTRODUCTION

This work was conducted at the laboratories of the Department of Agricultural Engineering, KNUST. Three kilograms each of the "*Padi-Tuya*" and "*Songotra*" varieties obtained from the Legumes Division of CSIR-Savannah Agricultural Research Institute- Nyankpala were used for the measurements of the various properties. All the grains were acquired as part of the 2012 major season produce. The grains were received in clean state and so not much cleaning was done before measurements were taken. The work was done within a moisture range of 23.0% w.b. to 8.0% w.b with four replications at each moisture level.

3.2 Materials

The following were the main materials used in the work:

- Weighing Pans (aluminium)
- Micrometer screw gauge
- Circular wooden plate
- Beaker
- Tilting table Apparatus
- Distilled water
- Toluene (C_7H_8)
- Measuring cylinder
- Electronic Balance
- Protractor

3.3 Physical Properties

The physical properties determined in the study are:

The three linear dimensions namely; length, width and thickness which were used to calculate geometric mean diameter, sphericity, volume and surface area.

The rest of the properties are:

Bulk density, true density, porosity, angle of repose and

Co-efficient of static friction.

3.4 Methods

3.4.1 Moisture Content Determination

The initial moisture content of the beans was determined using the standard oven method. 5 gram samples of the ground beans were heated in an oven for two hours at $130^{o}C \pm 2^{o}C$.The moisture content on wet basis (wb) was then determined by dividing the mass of moisture evaporated from the sample by the initial weight of the samples. The average was then recorded. The moisture content was determined using a Memmert drying oven model 854 Schwabach, made in Germany.

The size and principal axes of the seeds (minor, intermediate and major) were determined using a BILTEMA micrometer screw gauge of precision 0.01mm, model Art.16-1140.The mass of seeds was determined by using a Pioneer (Made in Germany) electronic balance (Fig. 4) of allowable mass 400g (Mettler Toledo GmbH, Greifensee, Switzerland) to an accuracy of 0.0lg. The moisture content was determined using a Memmert drying oven model 854 Schwabach, made in Germany.

3.4.2 Drying

To decrease the moisture content of grains to a lower one after rewetting, sun drying was carried out for about 6hours.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 grains were allowed to cool down to room temperature for about 2 hours before beginning each experiment.

3.4.3 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 Ezeike (1986) cited in 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 8.4%-23.0% by adding calculated amount of distilled water, sealing in low density polythene bags and stored in a refrigerator at a temperature of 5 degrees for 72 hours. This was done to create a favourable environment for the absorption of water by the grains and also to prevent microbial activity 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 (Singh and Goswami, 1996).

3.4.4 Dimensional Characteristics

The linear dimensions of the seeds (length, width and thickness) shown in Fig. 3 were determined using a BILTEMA micrometre screw gauge of precision 0.01 mm, model Art.16-1140 made in Germany. The mass of seeds was determined by using a Pioneer (Made in Germany) electronic balance (Fig. 4) of maximum allowable mass 1000g to an accuracy of 0.0lg.

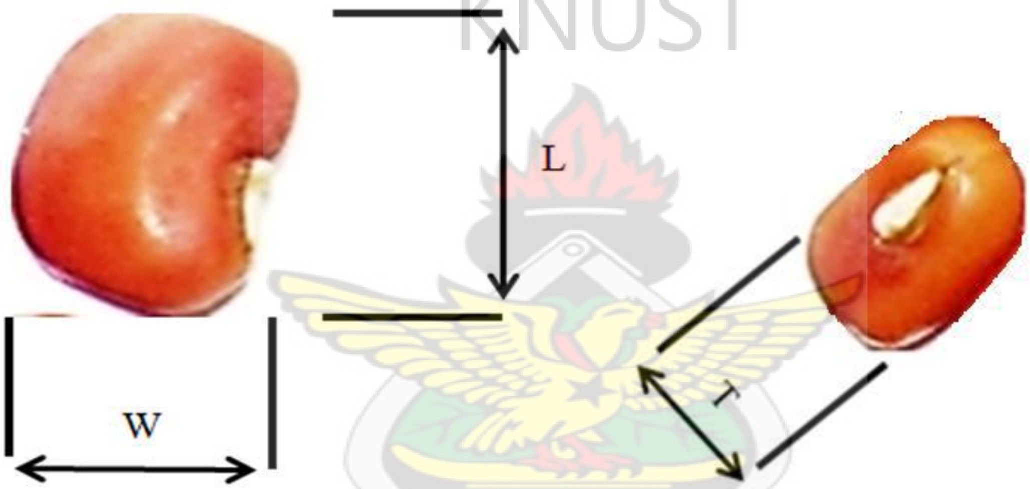

Fig 3. Linear dimensions of cowpea

3.4.5 Geometric Mean Diameter, Volume and Surface Area

The length, width and thickness dimensions were recorded with the micrometer screw gauge. The compressive force of the micrometre was controlled when it made contact with a seed in order to minimize compression.

Based on measurements of the length, width and thickness, data for the geometric mean (D_g) diameter, sphericity (Φ), surface area (S) and volume (V) were determined using the mathematical equations

$$D_g = (LWT)^{0.333} \quad (12)$$

$$\Phi = \frac{(LWT)^{0.333}}{L} \quad (13)$$

$$S = \pi(D_g^2) \quad (14)$$

$$V = \frac{\pi}{6}(D_g^3) \quad (15)$$

3.4.6 Bulk Density, True Density and Porosity

The bulk density was determined using the standard test weight procedure. A standard container (beaker) of known weight and volume of 500ml was filled with grains from a height of 15cm at a constant rate. The grains were then levelled by striking off the top of the container. No additional manual compaction was done. The total weight of grains and cylinder was recorded. Bulk density was determined as the ratio of the mass of grains only to the volume occupied by the grains (500ml).

For true density, 100 grains were picked at random from each sample and the mass determined. Toluene was poured into a measuring cylinder and the volume recorded. The grains were then poured in the cylinder and the volume of displaced toluene recorded. The true density was found as an average of the ratio of the mass of grains to the volume of toluene displaced by grains. Toluene (C_7H_8) was used in place of water because it 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 (Aydın, 2002 cited in Kabas *et al*., 2007; Demir *et al*., 2002 cited in 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 sun flower seeds and kernels.

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

$$\varepsilon = \frac{\rho_p - \rho_b}{\rho_b} \times 100 \qquad (16)$$

Where ρ_b is the bulk density and ρ_p is the true density.

Fig. 4. Electronic balance

3.4.7 Filling Angle of Repose

The filling angle of repose is the angle with the horizontal at which the material will stand when piled. It is illustrated in Fig. 5. This was determined by using a topless and bottomless cylinder of 150 mm diameter and 220 mm height (Razavi and Milani, 2006). The cylinder was placed on a wooden table and was gradually raised from the table as the seeds were poured in until the seeds formed a cone on the wooden surface. The angle of repose was calculated from the measurement of the height (H) and diameter of the cone (D) using the relation;

$$\boldsymbol{\theta_f = tan^{-1} 2H/D} \qquad (17)$$

The angle of repose, the angle between the horizontal and natural slope of the grain when it is piled has also been determined by other researchers using a topless and bottomless cylinder of 150mm diameter and 220mm height. A removable circular plate is placed under the cylinder, the sample is poured into the cylinder and then the cylinder is slowly raised allowing the sample to form a cone on the circular plate. The height of cone is measured and the angle of repose calculated by dividing the height of the cone by the radius of the circular plate. Sezer *et al.,* (2011) used this method to determine angle of repose for indent corn and Davies (2009) used this method for groundnut.

Fig. 5. Angle of repose

In determining the filling angle of repose (Θ_f) for all the varieties in this work, the grains were poured from a height (h) of 15cm unto a circular wooden plate of radius (r)10cm.The height of the heap was measured and the angle of repose was determined from the following equations;

$$tan\gamma = \frac{h}{r}, r = 10, \quad (18)$$

$$\gamma = tan^{-1}\frac{h}{10} \quad (19)$$

Where h, is height of the heap and r, is the radius of the plate.

3.4.8 Static Coefficient of friction

The coefficient of static friction was determined on three different structural surfaces, namely plywood, mild steel and rubber. The tilting table apparatus used is shown in Fig. 6. Each seed was placed on the surface and raised gradually by screw until the seed began to slide. The angle that the inclined surface makes with the horizontal when sliding begins was measured. The coefficient of static friction μ_s was calculated using the following expression:

$$\mu_s = tan\emptyset \qquad (20)$$

Where $\emptyset$= angle that the incline makes with the horizontal when sliding begins. (Abdullah *et al*., 2011).

Fig 6. The tilting table apparatus for measuring static coefficient of friction.

3.5 Experimental Design and Analysis of Data

All tests were conducted at four levels of moisture content with four replications at each level for both rewetting and drying. The experimental design used was the completely randomised design (CRD).The relationships between physical properties of cowpeas and levels of moisture content were determined. Analysis of variance (ANOVA) was carried out on the data using GENSTAT 12.1 where a significant difference existed between treatment means. The Regression Coefficient (R^2) was used to determine the fitness of models to the experimental data.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 PADI-TUYA

4.1.1 Linear Dimensions

During rewetting, length increased non-linearly from 9.72mm at 9.8%wb to 10.54mm at 23%wb representing 8.44% which is the highest increase. Width increased non-linearly from 6.84mm at 9.8%wb to 7.15mm at 23%wb. Thickness also increased non-linearly from5.29mm at 9.8%wb to 5.4mm at 23%wb. All three dimensions recorded significant differences at 5%. Significant differences ($p<0.05$) were recorded for length between all means with the highest occurring between 9.8%wb and 23%wb. Significant differences were recorded between all means for width with the highest occurring between 9.8%wb and 23%wb. Thickness also recorded significant differences between all means. The highest significant difference recorded for thickness was between 9.8%wb and 23%wb.

Table1 . Averages for linear dimensions for Padi-Tuya

Rewetting (%w.b.)	L(mm)	W(mm)	T(mm)	**Drying (%w.b.)**	L(mm)	W(mm)	T(mm)
9.8	9.72	6.84	5.29	**22**	10.52	7.12	5.43
12.6	9.89	6.93	5.31	**17.3**	10.45	7.01	5.36
16	10.4	7	5.35	**13.2**	10.01	6.96	5.32
23	10.54	7.15	5.4	**8.4**	9.68	6.79	5.26

During drying, there was a non-linear decrease from 10.52mm at 22%wb to 9.68mm at 8.4%wb, 7.12mm at 22%wb to 6.79mm at 8.4%wb and 5.43mm at 22%wb to 5.26mm at 8.4%wb for length, width and thickness respectively. All dimensions recorded significant differences at 5%. High significant differences were recorded between all means for length except 22%wb and 17.3%wb which recorded the lowest significant difference. Significant differences were recorded between all means for width except for 12.6%wb and 16%wb where there was no significant difference at 5%. Thickness also recorded low significant differences between all means except for 12.6%wb and 16%wb where there was no significant difference at 5%.

Ozturk *et al*., (2009) made similar findings for the common bean where there were increases in all three dimensions during rewetting. Tavakoli *et al*. (2011) also had similar results for soybean during rewetting.

Table 2. Equations describing rewetting and drying trends for Padi-Tuya

Rewetting Equations	**R^2**	**Drying Equations**	**R^2**
$L=-0.0054M^2+0.2445M + 7.7902$	0.947	$L=-0.0028M^2+0.1494M +8.6041$	0.9651
$W=-0.0004M^2+0.0373M +6.5199$	0.9975	$W=0.3302 \ln(M) +6.091$	0.9846
$T=-0.0001M^2+0.0128M + 5.1744$	0.9932	$T=-0.0002M^2+0.0171M + 5.1324$	0.9998

Where M represents the moisture content (%wb)

The increase in the linear dimensions could be due to an expansion of the grains as a result of the moisture addition. During rewetting, length had the highest increase in dimension of 8.44% from 9.72mm to 10.54mm, followed by thickness of 4.53% and then width of 2.65%. However, there was an almost 8% decrease in length (from 10.52mm to 9.68mm), recorded under drying conditions. For drying also, length recorded the highest decrease in dimension followed by width (4.63%) and then thickness (3.13%). Mollazade *et al*. (2009) made similar observations for cumin seeds during rewetting. Ampah *et al*. (2012) also made similar findings for *Asontem* cowpea variety.

4.1.2 Geometric Mean Diameter

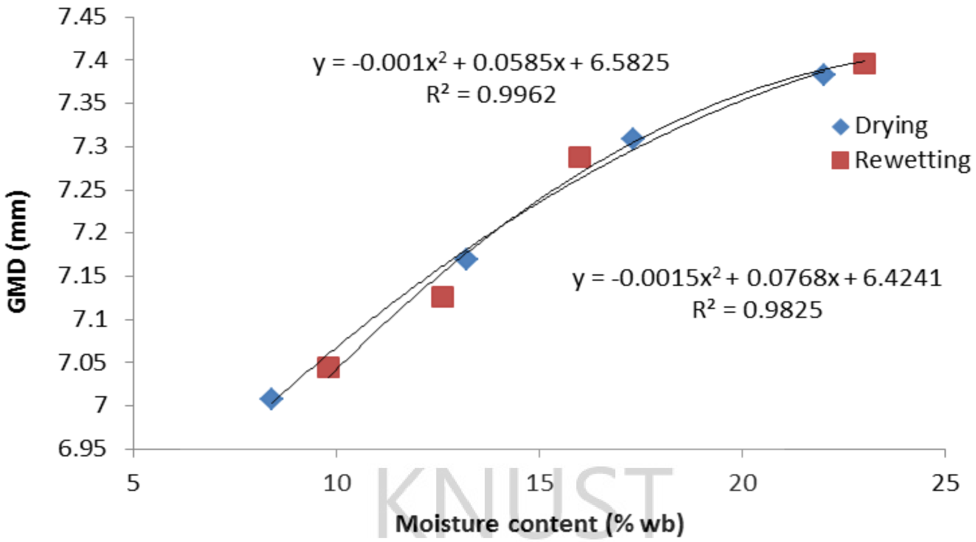

Fig. 7.. Variation of geometric mean diameter of Padi-Tuya with moisture content for drying and rewetting

The geometric mean diameter, sphericity, surface area and volume were calculated from the values of the length, width and thickness. Values for rewetting increased with increasing moisture content while that for drying decreased with decreasing moisture content.

However the decrease in geometric mean diameter during drying (from 7.38mm to 7.01mm) of 0.37mm was marginally higher than the increase in geometric mean diameter for rewetting (from 7.05mm to 7.41mm) of 0.36mm.

There were significant differences between all means for rewetting and the same was recorded for drying. The differences were higher for drying than rewetting. Similar findings were made by Ampah (2011) for rewetting and drying of *Asontem* cowpea variety. Tarighi *et al*., (2011) also found geometric mean diameter to increase non-linearly with increasing moisture for corn.

The following equations describe the trends for geometric mean diameter during rewetting and drying;

Table 3. Equations describing trends for geometric mean diameter for Padi-Tuya

Rewetting Equation	R^2	Drying Equation	R^2
D_g= -0.0015M^2 + 0.0768M + 6.4241	0.9825	D_g = -0.001M^2 + 0.0585M + 6.5825	0.9962

where M represents the moisture content (%wb).

4.1.3 Sphericity

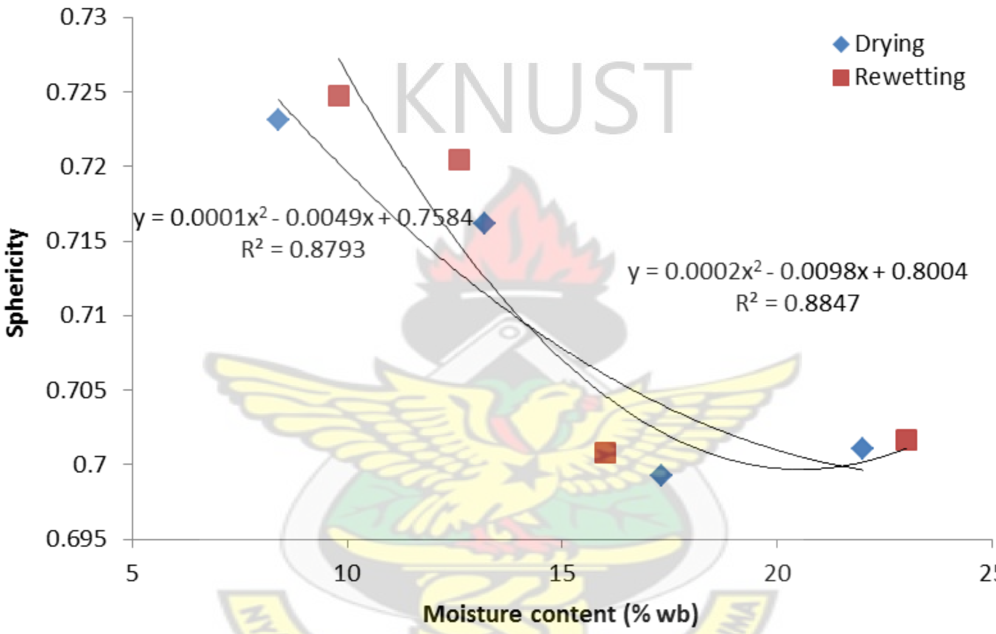

Fig 8. Variation of sphericity of Padi-Tuya with moisture content for drying and rewetting

Sphericity reduced from 0.7261 at 9.8%wb to 0.702 at 16%wb and increased to 0.703 at 23%wb as moisture increased. This suggests a departure from the spherical shape as the seed moisture content increased from 9.8% to 23%, and a return to it again between 16% and 23% wb. This is as a result of changes in the three major dimensions as the grains gained moisture. An increase in sphericity may well be an indication that the rate of increase of width and thickness is higher compared to the length, giving the grain the assumed spherical shape. There were significant differences between all means except 16%wb and 23%wb. During drying also, there was a decrease from 0.7231 at 8.4%wb to 0.6993 at 17.3%wb and then increased to 0.7011 at 22.00%wb. Significant differences were recorded among all treatment means.

The graphs for rewetting and drying cannot be conclusively described as increasing or decreasing and in consequence, it can be suggested that moisture content has little influence on the sphericity of *Padi-Tuya*.

Ampah *et al.* (2012) had similar findings for rewetting of *Asontem* variety. Kiani *et al* (2008) also found the sphericity of red beans to increase slightly with increase in moisture content. Kibar and Öztürk (2008) however found the sphericity of soybean to linearly decrease with increasing moisture content. Milani *et al.* (2007) found the sphericity of curcubit seeds to increase marginally with increasing moisture.

4.1.4 Surface Area

There was a non-linear increase for surface area with increasing moisture and a non-linear decrease during drying. It increased from 156.32mm^2 at 9.8%wb to 172.49mm^2 at 23%wb for rewetting. Increases observed in the surface area could be due to increase in the axial dimensions as a result of moisture increase. Significant differences were recorded across all means with high significant differences occurring between 9.8%wb and 23%wb; 12.6%wb and 23%wb and 9.8%wb and 16%wb.The decrease in surface area during drying was slightly higher than the increase during rewetting. Surface area decreased from 171.27mm^2 at 22%wb to 154.28mm^2 at 8.4%wb. There were significant differences between all means with rather high difference between 22%wb and 8.4%wb.

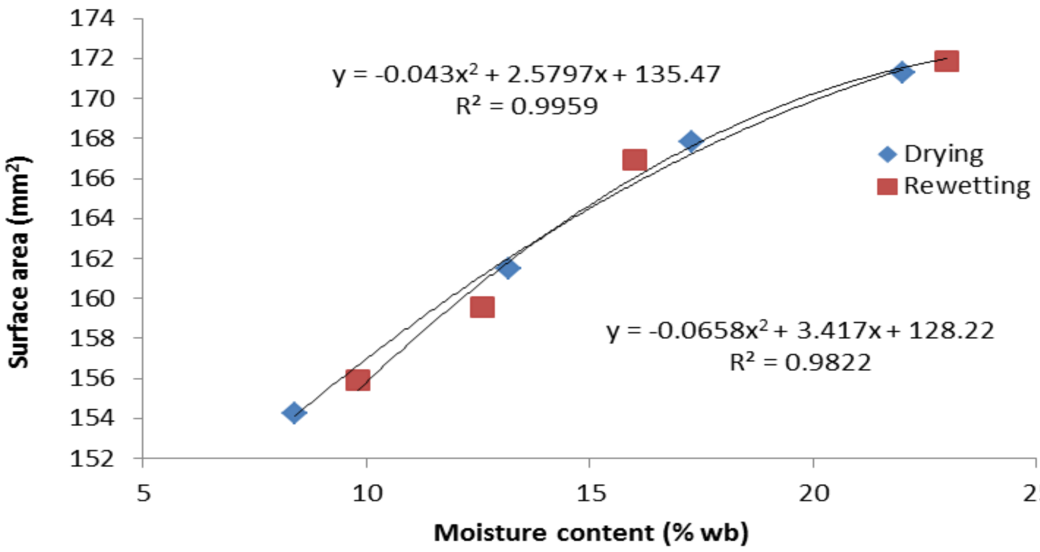

Fig 9. Variation of surface area of Padi-Tuya with moisture content for drying and rewetting

Davies and Zibokere (2011) found surface area increases with increasing moisture content for three cowpea varieties. Seifi and Alimardani (2010) also reported that with an increase in moisture content of corn grains from 4.73 to 22% w.b., the surface area of corn grains increased from 137.69 to 160.09 mm^2.

The findings also agree with those for curcubit seeds as observed by Milani *et al.* (2007) when they reported an increase in surface area of cucurbit seeds of three varieties at different moisture contents in the range of 5.18 - 42.76% (w.b.).

The following equations describe the trends for surface area during rewetting and drying;

Drying $S = -0.043M^2 + 2.5797M + 135.47 \quad R^2 = 0.9959$ (21)

Rewetting $S= -0.0658M^2 + 3.417M + 128.22 \quad R^2 = 0.9822$ (22)

Where M represents the moisture content (%wb)

4.1.5 Volume

The volume was found to increase non-linearly with increasing moisture content for both rewetting and drying as shown in Figure 21.

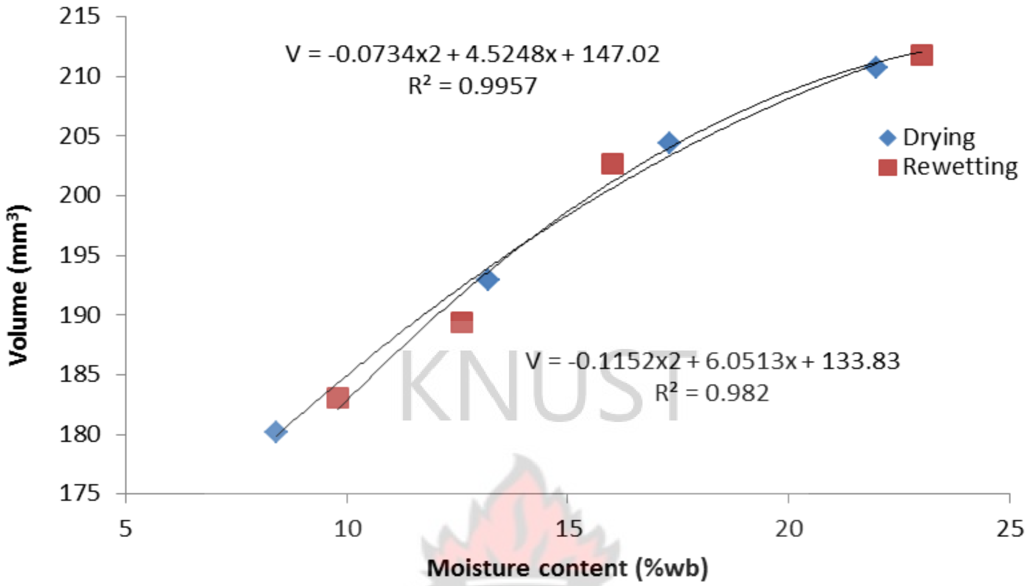

Fig. 10. Variation of volume of Padi-Tuya with moisture content for drying and rewetting

During rewetting, the volume increased from 183.78mm^3 at 9.8%wb to 213.02mm^3 at 23.0%wb, representing a 15.91% increase in the initial volume. Under drying conditions, the volume decreased from 210.71mm^3 at 22.00%wb to180.15mm^3 at 8.4%wb, representing a decrease of 14.50%.

Significant differences existed among all treatment means for drying and rewetting at 5%.

Coskuner and Karababa (2007) and Ozturk *et al.* (2009) also recorded an increase in volume with increasing moisture content for coriander (*Coriandrum sativum L.*) seeds and common beans cv.Elkoca-05 respectively. Gharib-Zahedi *et al.* (2010) also made similar observations for black cumin (*Nigella sativa L.*) seeds.

The variation with moisture content for drying and rewetting can be expressed respectively as follows:

Drying	$V=-0.0734M^2 + 4.5248M + 147.02$	$R^2=0.9957$	(23)
Rewetting	$V =-0.1152M^2 + 6.0513M + 133.83$	$R^2=0.982$	(24)

where M is the moisture content (% wb)

4.1.6 1000-Bean mass

Rewetting showed a non-linear increase for 1000 bean mass with increasing moisture content. Rewetting from 9.8%wb to 23%wb caused an increase in mass from 225.03g to 236.05g while drying recorded a reduction in mass from 234.28g at 22.0%wb to 221.63g at 8.4%wb.

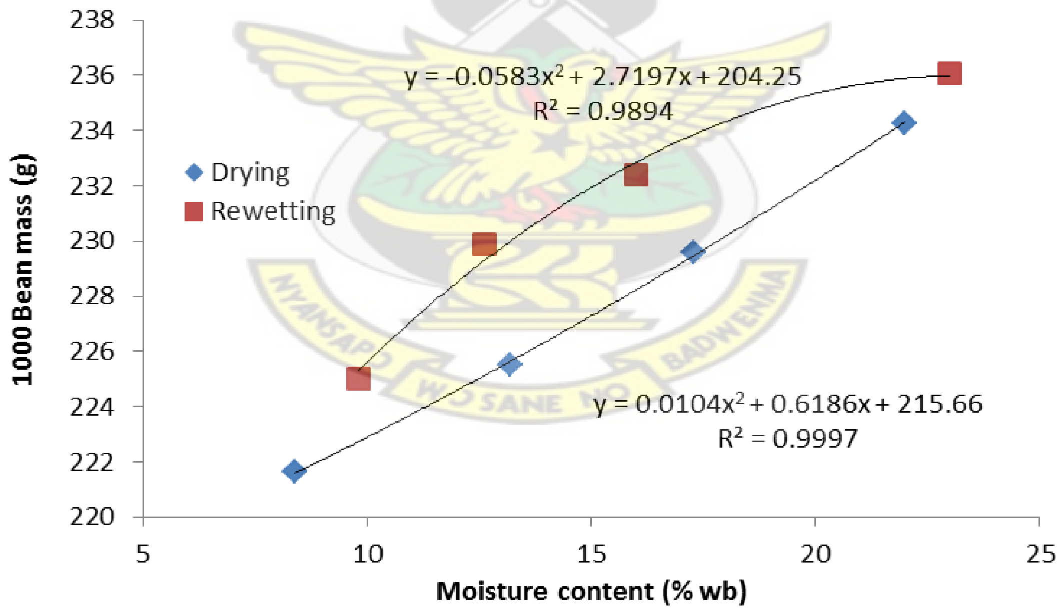

Fig. 11. Variation of 1000-bean mass of Padi-Tuya with moisture content for drying and rewetting

An increase in mass of 4.9% was recorded during rewetting while a reduction in mass of 5.4% was recorded during drying. Significant differences were recorded across all means at 5% for both drying and rewetting. Ampah *et al.* (2012) also found the 1000 seed mass of

Asontem cowpea variety to increase non-linearly with increase in moisture and they observed a non-linear decrease during drying. Bagherpour *et al.* (2010) also found the 1000 grain mass of lentil seeds to increase with increasing moisture content. Singh *et al.* (2010) and Shirkole *et al.* (2011) however, found the 1000 seed weight of barnyard millet and soybean respectively to increase linearly with increase in moisture content.

The variation with moisture content for drying and rewetting can be expressed respectively as follows:

Drying $1000m=0.0104M^2 + 0.6186M + 215.66$ $R^2=0.9997$ (25)

Rewetting $1000m =-0.0583M^2 + 2.7197M + 204.25$ $R^2=0.9894$ (26)

where M is the moisture content (% wb).

4.1.7 Bulk Density

Drying showed a non-linear increase in bulk density. The bulk density increased from 759.52kgm^{-3} at 22.0%wb to 799.79%wb at 8.4%wb during drying. During rewetting however, it decreased from 796.33kgm^{-3} at 9.8%wb to 751.56kgm^{-3} at 23.0%wb. Significant differences were recorded across all the means at 5%. Nalbandi *et al.*, (2010) found that as moisture content increased from 7% to 20.8% w.b., the bulk density of wheat kernels was found to decrease from 889 to 735 kg/m^3.They opine that increase in the moisture content leads to increase in both weight and volume of kernels. But the rate of volume increasing was higher than weight. Therefore, the bulk density of wheat kernels decreased. This probably is the case with *Padi-Tuya* hence the decrease in bulk density with increasing moisture content. Estefania *et al.* (2013) also found the bulk density of *chia (Salvia hispanica* L.*)* seeds to decrease from 0.713 to 0.644gcm^{-3} as moisture content increased.

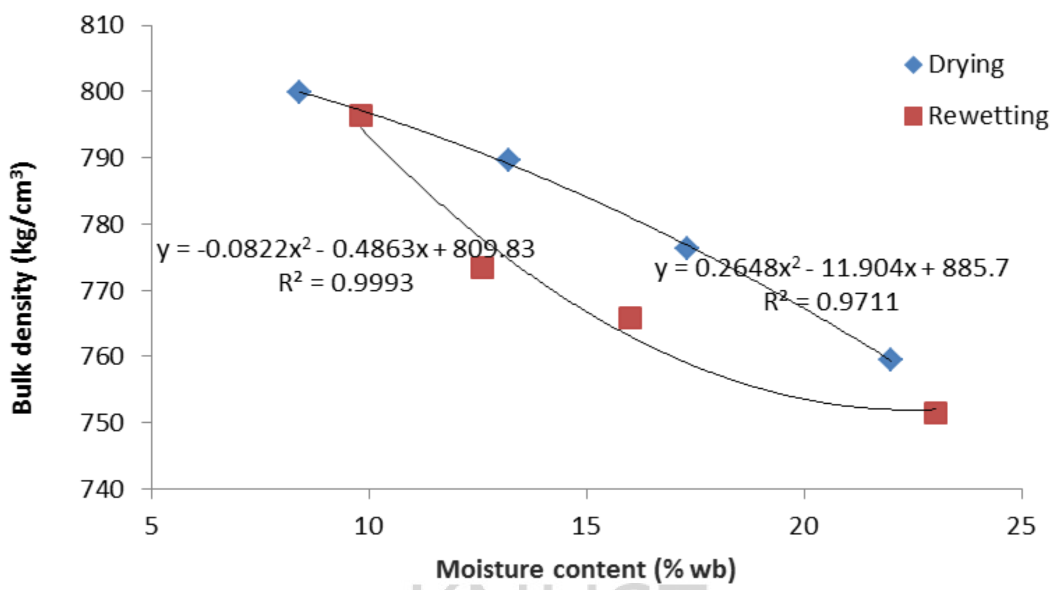

Fig. 12. Variation of bulk density of Padi-Tuya with moisture content for drying and rewetting

Other researchers have found similar results for soybean (Deshpande *et al.*, 1993), green gram (Nimkar and Chattopadhyay, (2001) and *Asontem* cowpea variety (Ampah *et al.*, 2012). The decrease in bulk density during rewetting may also be attributed to an increase in the sizes of the beans resulting in more voids between grains compared to an increase in mass; hence there are fewer grains occupying the same volume.

The following equations describe the relationship between volume and moisture for drying and rewetting respectively:

Drying $\ell_b = 0.2648M^2 - 11.904M + 1059.8$ $R^2 = 0.9711$ (27)

Rewetting $\ell_b = 0.0822M^2 - 0.4863M + 809.83$ $R^2 = 0.9993$ (28)

where M is the moisture content (% wb).

4.1.8 True Density

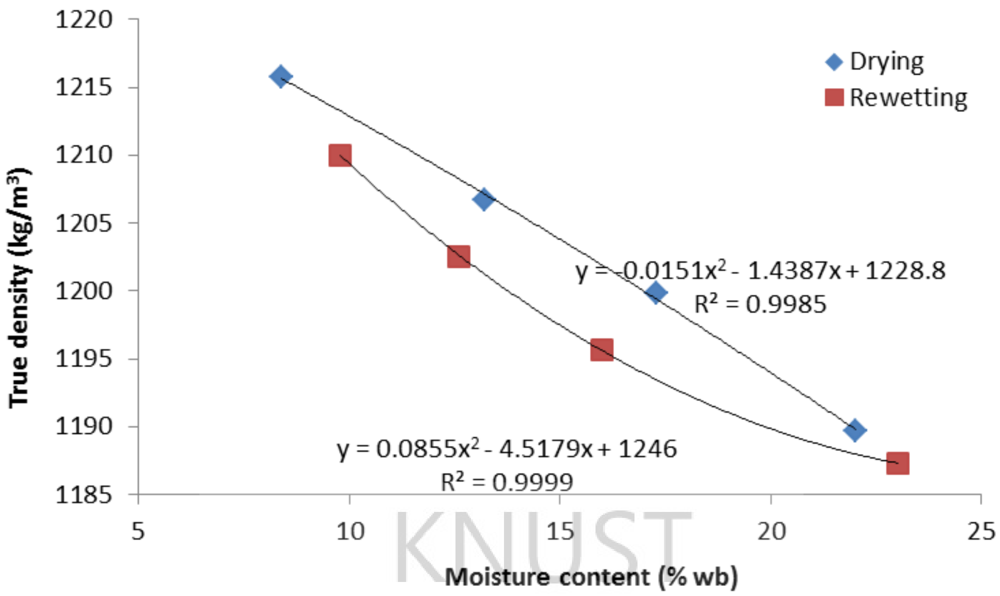

Fig.13. Variation of true density of Padi-Tuya with moisture content for drying and rewetting

True density decreased non-linearly with increasing moisture content during rewetting from 1210.00kgm^{-3} at 9.8%wb to 1187.30 at 23.0%wb. Drying also showed a non-linear increase in true density with decreasing moisture content from 1215.78kgm^{-3} at 8.4%wb to 1189.67kgm^{-3} at 22.0%wb. Significant differences were recorded across all means for both rewetting and drying at 5%.

Shoughy and Amer (2006) reported that the effect of moisture content on kernel density of faba bean seed showed a linear decrease with moisture content ranging from 9.8%db to 26.5%db. The decrease in true density values with increase in moisture content might be attributed to the relatively higher kernel volume as compared to the corresponding mass of the seed attained due to absorption of water. Ampah *et al.* (2012) also found the true density of *Asontem* variety to decrease with increasing moisture. Similar results have been recorded by researchers like Karimi *et al.* (2009) for wheat and Firouzi and Alizadeh (2012) for *Mashhad* cowpea variety.

The following equations describe the relationship between volume and moisture for drying and rewetting respectively:

$$\text{Drying} = -0.0151M^2 - 1.4387M + 1228.8 \qquad R^2 = 0.9985 \qquad (29)$$

$$\text{Rewetting} = 0.0855M^2 - 4.5179M + 1246 \qquad R^2 = 0.9999 \qquad (30)$$

where M is the moisture content (% wb)

4.1.9 Porosity

Porosity increased non-linearly from 51.95% at 9.8%wb to 57.98% at 23.0%wb during rewetting. During drying however, there was a decrease of 56.63% at 22.0%wb to 52.01% at 8.4%wb. Significant differences were recorded across all means for both drying and rewetting.

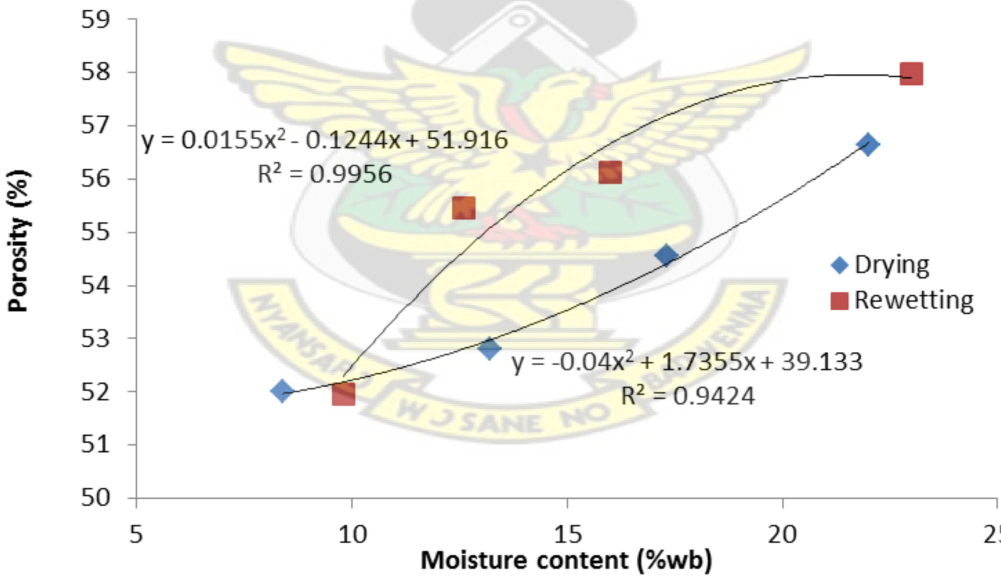

Fig. 14. Variation of porosity of Padi-Tuya with moisture content for drying and rewetting

Gupta and Das (1997) and Kiani *et al.*, (2008) reported the porosity of sunflower seeds and red beans respectively to increase with increase in moisture content. Razavi and Fathi (2009) however found the porosity of seeds of grape to reduce with decreasing moisture content.

The following equations describe the relationship between volume and moisture for drying and rewetting respectively;

Drying $=-0.04M^2 + 1.7355M + 39.133$ $R^2= 0.9424$ (30)

Rewetting $= -0.0155M^2 - 0.1244M + 51.916$ $R^2= 0.9956$ (31)

where M is the moisture content (% wb)

4.1.10 Filling Angle of repose

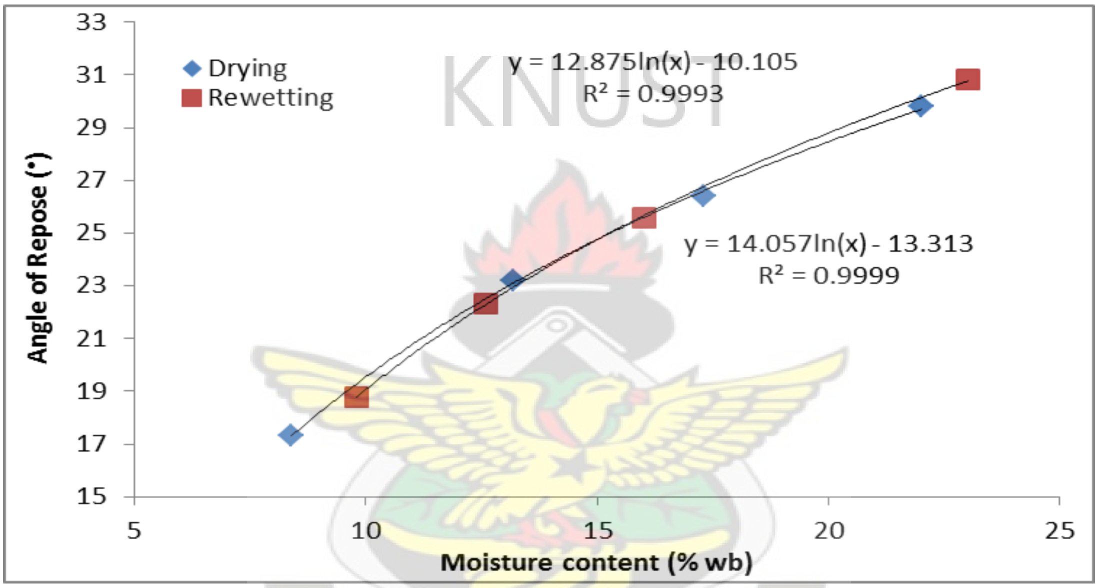

Fig. 15. Variation of filling angle of repose of Padi-Tuya with moisture content for drying and rewetting

The filling angle of repose for both rewetting and drying increased non-linearly with increase in moisture content. The values for rewetting increased from 18.77^0 at 9.8% wb to 30.82^0 at 23% wb. Drying also showed a non-linear reduction in angle of repose with decreasing moisture content. The values for drying decreased from 29.83^0 at 22%wb to 17.25^0 at 8.4%wb. Significant differences were recorded across all means for both rewetting and drying at 5%. The increase in filling angle may be due to an increase in surface roughness as well as size of individual grains which affect their ability to form a heap. Unuigbe *et al.*

(2013) found the angle of repose of *dika nut (Irvingia gabonesis)* to increase with increase in moisture content. They also posit that the increase in angle of repose may be due to the fact that an increase in moisture content increased the cohesion between the seeds, thus increasing inter-seed friction flow/movement.

Davies and Zibokere (2011), found the angle of repose to increase with increase in moisture content for three different cowpea varieties viz- *IAR-339-1, IT86D-1010 and Ife Brown.* Barnwal *et al.* (2012) also found the angle of repose of maize to increase with increase in moisture content.

The following equations describe the relationship between angle of repose and moisture for drying and rewetting respectively;

Drying $\theta_f = 12.875 \ln(M) - 10.105$ $R^2 = 0.9993$ (32)

Rewetting $\theta_f = 14.057 \ln(M) - 13.313$ $R^2 = 0.9999$ (33)

where M represents the moisture content (%wb)

4.1.11 Static Coefficient of Friction

4.1.11.1 Rubber

For rubber, the coefficient of static friction increased from 0.35 at 9.8%wb to 0.48 at 23.0% wb. Drying also recorded a non-linear decrease in static coefficient of friction with increasing moisture content from 0.46 at 22.0% wb to 0.35 at 8.4% wb. Significant differences were recorded for all means during both drying and rewetting at 5%.

The variation with moisture content for drying and rewetting can be expressed respectively as follows;

Drying $\mu_r = 9E\text{-}06M^2 + 0.0077M + 0.2847$ $R^2 = 0.9993$ (34)

Rewetting $\mu_r = E\text{-}05M^2 + 0.0077M + 0.2661$ $R^2 = 0.9971$ (35)

where M is the moisture content.

4.1.11.2 Plywood

The coefficient of friction for plywood increased non-linearly with increasing moisture content during rewetting from0.29 at 9.8%wb to 0.35 at 22.54%wb. Drying showed a decrease from 0.35 at 22.0%wb to 0.28 at 8.4%wb. Results obtained for rewetting and drying showed significant difference at 5%. There were significant differences across all means.

The variation with moisture content for drying and rewetting can be expressed respectively as follows:

Drying $\mu_p = 0.0706 \ln(M) + 0.132$ $R^2 = 0.9808$ (36)

Rewetting $\mu_p = -0.0003M^2 + 0.0133M + 0.1848$ $R^2 = 0.9999$ (37)

where M is the moisture content.

4.1.11.3 Mild Steel

The variation of coefficient of static friction with moisture content during rewetting on mild steel was found to increase non-linearly with increasing moisture content from 0.37 at 9.8%wb to 0.59 at 23%wb. Drying also showed a non-linear decrease with reduction in moisture content. It dropped from 0.54 at 22%wb to 0.37 at 8.4%wb.Significant differences were recorded across all means for both drying and rewetting.

The variation with moisture content for drying and rewetting can be expressed respectively as follows:

Drying $\mu_m = 0.0003M^2 + 0.0051M + 0.3064$ $R^2 = 0.9906$ (38)

Rewetting $\mu_m = 0.0008M^2 - 0.0096M + 0.39797$ $R^2 = 0.9766$ (39)

where M is the moisture content.

4.1.11.4 Overview of Coefficient of Static Friction

The coefficient of static friction for mild steel recorded the highest value followed by rubber and lastly plywood. The increasing coefficient may be due to smoother surface of rubber compared to plywood and mild steel. The increase in static coefficient of friction with increasing moisture content may be due to the increase in weight of grains from moisture absorption which reduces its ability to slide. The grains also possibly become rougher on the surface as the moisture content increases making the coefficient of friction increase. The static coefficient of friction increased with increase in moisture content on all surfaces. The design of the dimension of hoppers, bunker silos and other bulk solid storage and handling structures should ensure non-arching phenomena. The higher the coefficient of friction is, the lower the mobility coefficient is, hence requiring larger hopper opening, larger hopper sidewall slope and steeper angle of inclination in inclined grain transporting equipment like chutes (Irtwange and Igbeka, 2002). According to Fathollahzadeh *et al.* (2008) the reason for the increased coefficient of static friction of barberry at higher moisture content may be due to the higher moisture present in the barberry offering a higher cohesive force on the surface of contact. Bart-Plange *et al.* (2005); Bart-Plange *et al*. (2006); Tavakoli *et al*. (2009) and Gharib-Zahedi *et al*. (2010) also found increasing linear relationships for cowpeas, maize, barley and black cumin grains respectively on plywood, rubber, glass and galvanized iron sheet.

4.2 SONGOTRA

4.2.1 Linear Dimensions

During rewetting, length increased non-linearly from 6.98mm at 9.8%wb to 7.68mm at 23%wb representing 10.03% which is the highest increase. Width increased non-linearly from 5.21mm at 9.8%wb to 5.99mm at 23%wb representing 14.97%. Thickness also increased non-linearly from 4.03mm at 9.8%wb to 4.45mm at 23%wb representing 10.42%.The increase in the linear dimensions can be attributed to the addition of moisture causing a volumetric expansion of the grains.

Table 4. Averages for linear dimensions for Songotra

Rewetting(%w.b.)	L(mm)	W(mm)	T(mm)	**Drying(%w.b.)**	L(mm)	W(mm)	T(mm)
9.8	6.98	5.21	4.03	**22**	7.61	5.94	4.44
12.6	7.11	5.44	4.21	**17.3**	7.46	5.86	4.39
16	7.34	5.87	4.37	**13.2**	7.23	5.47	4.33
23	7.68	5.99	4.45	**8.4**	6.69	5.20	3.99

During drying, length decreased non-linearly from 7.61mm at 8.4%wb to 7.61mm at 22%wb; width also decreased from 5.94mm at 22%wb to 5.20mm at 8.4%wb and thickness decreased non-linearly from 4.44 at 22%wb to 3.99 at 8.4%wb. Thickness appeared to be the least susceptible to moisture changes for both rewetting and and drying whiles width recorded the highest changes. All three dimensions recorded significant differences at 5%. Significant differences ($p<0.05$) were recorded for length, width and thickness across all means for both rewetting and drying.

Said and Pradhan (2013), found the dimensions of *Lagenaria siceraria* (a cucurbit) seeds to increase with increase in moisture content. Similar results have been reported by Deshpande *et al.* (1993) for soybean, Altuntas and Yildiz (2007) for faba bean, Ahmadi *et al.* (2009) for fennel seeds and Gharib-Zahedi et al. (2010) for black cumin seeds.

Table 5. Equations describing rewetting and drying trends for Songotra

Rewetting Equations	R^2	Drying Equations	R^2
$L = -0.0003M^2 + 0.0661M + 6.3552$	0.9969	$L\ -0.0014M^2 + 0.09M + 6.2955$	0.9977
$W = -0.0057M^2 + 0.2483M + 3.2889$	0.9757	$W\ -0.0023M^2 + 0.1282M + 4.2527$	0.9661
$T = -0.0036M^2 + 0.1536M + 2.854$	1	$T\ -0.0033M^2 + 0.1321M + 3.122$	0.9846

Where M represents the moisture content (%wb)

4.2.2 Geometric Mean Diameter

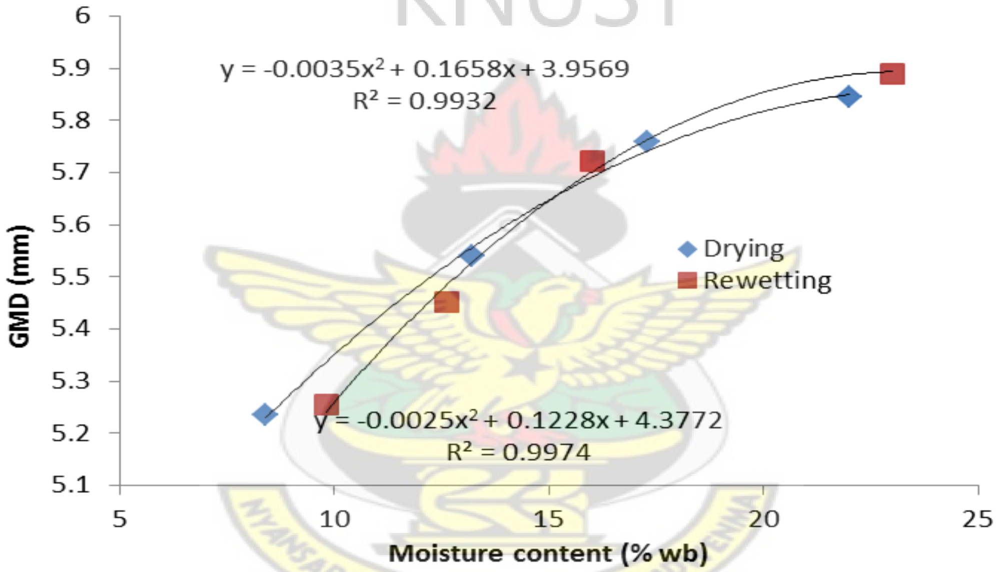

Fig. 16. Variation of geometric mean diameter (mm) of Songotra with moisture content for drying and rewetting

The geometric mean diameter increased during rewetting from 5.27mm at 9.8%wb to 5.90mm at 23%wb. Significant differences were recorded across all means at 5%. An increase in geometric mean diameter could be due to an expansion of the beans resulting in an increase in linear dimensions as a result of the moisture addition.

During drying, it decreased from 5.85mm at 22%wb to 5.24mm at 8.4%wb. Significant differences were recorded across all means at 5%. The percentage increase during rewetting

(11.95%) was however lower than the percentage decrease (10.43%) during drying. There were significant differences between all means for rewetting and the same was recorded for drying. The differences were higher for drying than for rewetting. Similar findings were made by Ampah (2011) for rewetting and drying of Asontem cowpea variety. Shoughy and Amer (2006) and Tarighi *et al.* (2011) also found geometric mean diameter to increase non-linearly with increasing moisture for faba bean and corn respectively.

The following equations describe the drying and rewetting trends;

Drying $D_g = -0.0025M^2 + 0.1228M + 4.3772$ $R^2 = 0.9974$ (40)

Rewetting $D_g = -0.0035M^2 + 0.1658M + 3.9569$ $R^2 = 0.9932$ (41)

Where M represents the moisture content (%wb)

4.2.3 Sphericity

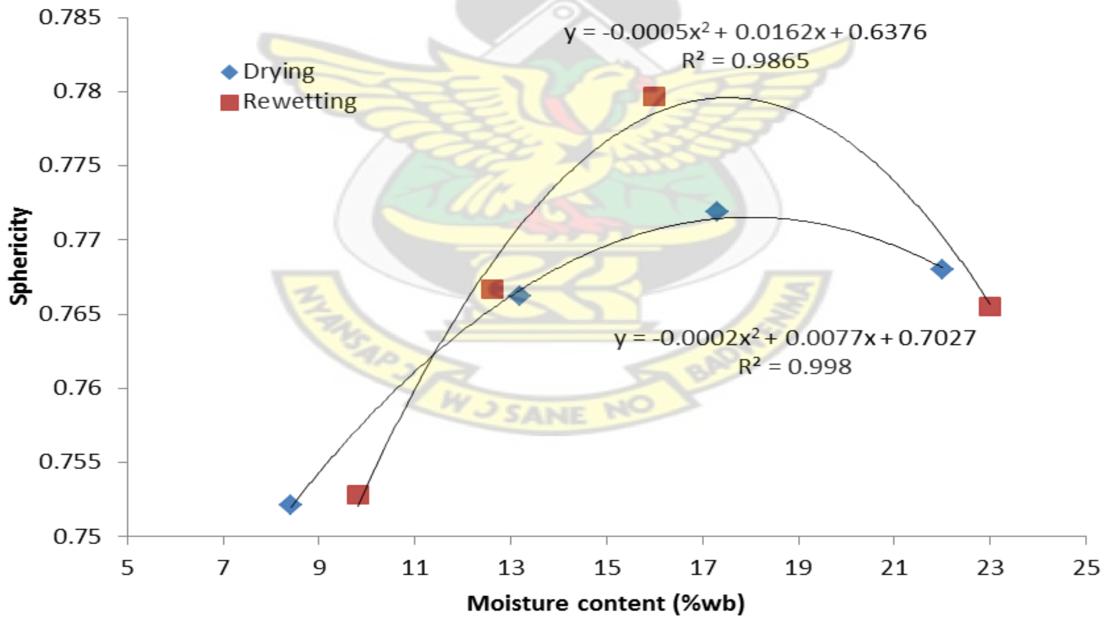

Fig.17. Variation of sphericity of Songotra with moisture content for drying and rewetting

During rewetting sphericity increased from 0.7551 at 9.8%wb to 0.7807 at 16%wb and then decreased to 0.7675 at 23%wb. Significant differences were recorded across all means. This could indicate that sphericity for *Songotra* increases with moisture content to about 16%wb and then departs from the spherical shape. It was observed during drying however that sphericity increased from 0.7697 at 22.0%wb to 0.7733 at 17.3%wb and then there was a steady decrease to 0.7534 at 8.4%wb. All means were significantly different at 5%. The values observed from both rewetting and drying appears to indicate that sphericity for *Songotra* is higher for the moisture content range of 8%wb to 18%wb and then slightly departs fromthe spherical shape again from around 20%wb upwards. Shirkole *et al.* (2011) found sphericity of soybean to increase linearly with increase in moisture content. Similar results were found by Coskuner and Karababa (2007) for coriander seeds and Bamgboye and Adebayo (2012) for *Jatropha curcas* seeds.

The following equations describe the drying and rewetting trends for sphericity;

Drying $\Phi = -0.0002x2 + 0.0077x + 0.7027$ $R^2 = 0.998$ (43)

Rewetting $\Phi= -0.0005x2 + 0.0162x + 0.6376$ $R^2 = 0.9865$ (44)

where M represents the moisture content (%wb).

4.2.4 Surface Area

Surface area increased non-linearly for rewetting and there was also a non-linear reduction for surface area during drying. The surface area increased from 87.292mm^2 at 9.8%wb to 109.232mm^2 at 23%wb during rewetting. Significant differences were recorded across all means with rather high significant difference between 13.2%wb and 16.0%wb. This increase will be as a result of increases in the three linear dimensions. During drying, there was a reduction in surface area from 107.66mm^2 at 22%wb to 86.39mm^2 at 8.4%wb. The increase recorded during rewetting was higher than the reduction recorded during drying. Significant differences were recorded among all the treatment means.

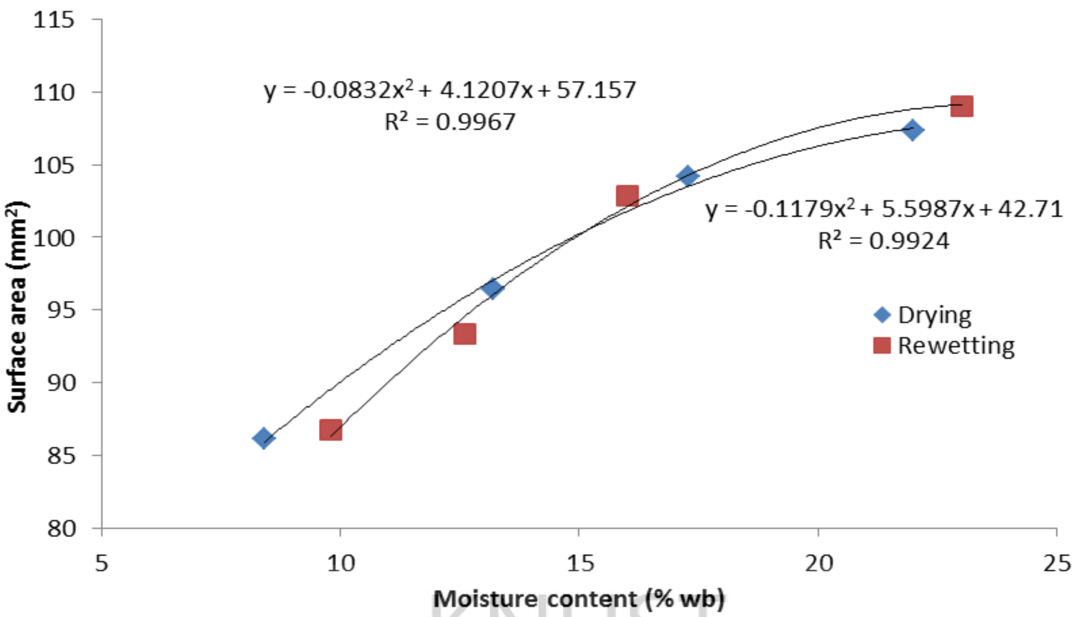

Fig.18. Variation of surface area of Songotra with moisture content for drying and rewetting

Sobukola *et al.* (2013) found the surface area of high quality *Swam 1* maize to increase with increase in moisture content. Tavakoli *et al*. (2009) found the surface area of barley grains to increase linearly from 56.66mm^2 at 7.34%db to 71.09mm^2 at 21.58%db with significant difference at 5%.

The following equations describe the trends for surface area during rewetting and drying;

Drying $S = -0.0832x2 + 4.1207x + 57.157$ $R^2 = 0.9967$ (45)

Rewetting $S=-0.1179x2 + 5.5987x + 42.71$ $R^2 = 0.9924$ (46)

Where M represents the moisture content (%wb)

4.2.5 Volume

Volume was found to increase non-linearly with increasing moisture content during rewetting. Volume increased from 76.69mm^3 at 9.8%wb to 107.35mm^3 at 23.0%wb.Significant differences were recorded for all means. There was a high increase in volume from 13.2%wb to 16%wb. The increase in volume could be due to an increase in the linear dimensions of the beans as they absorbed moisture. Drying showed a decrease in volume with reduction in moisture content. The volume reduced from 104.04mm^3 at 22.0%wb down to 75.506 at 8.4%wb.

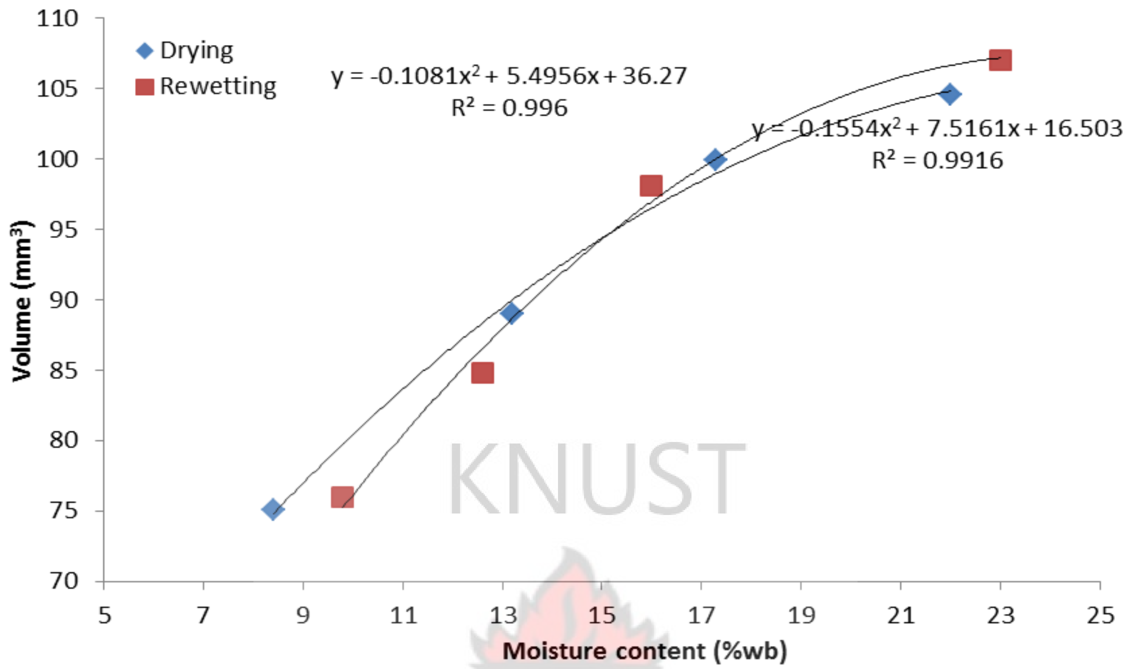

Fig.19. Variation of volume of Songotra with moisture content for drying and rewetting

Razavi and Fathi (2009) found the volume of grape seed to decrease with reduction in moisture content. Ozturk *et al*, (2009) found the volume of new common bean variety '*Elkoca 05*' to increase with increasing moisture content from 317.54mm^3 at 7.50% d.b. to 401.30mm^3 at 19.85% d.b. Altuntas and Demirtola (2007), found the volume of kidney bean to increase linearly from 0.616cm^3 at 8.21%w.b. to 0.658cm^{3}18.01%w.b.

The following equations describe the relationship between volume and moisture for drying and rewetting respectively.

Drying $V = -0.1081x2 + 5.4956x + 36.27$ $R^2 = 0.996$ (47)

Rewetting $V=-0.1554x2 + 7.5161x + 16.503$ $R^2 = 0.9916$ (48)

Where M represents the moisture content (%wb)

4.2.6 Bulk Density

During drying, there was a non-linear increase in bulk density. The bulk density increased from 727.98kgm^{-3} at 22.0%wb to 801.55%wb at 8.4%wb during drying. Rewetting showed a decrease in bulk density with increase in moisture content. It decreased from 807.91kgm^{-3} at 9.8%wb to 728.06kgm^{-3} at 23.0%wb. Significant differences were recorded across all the means at 5%. Estefania *et al.*, (2013) found the bulk density of *chia (Salvia hispanica* L.*)* seeds to decrease from 0.713 to 0.644gcm^{-3} as a function of the increase of moisture content.

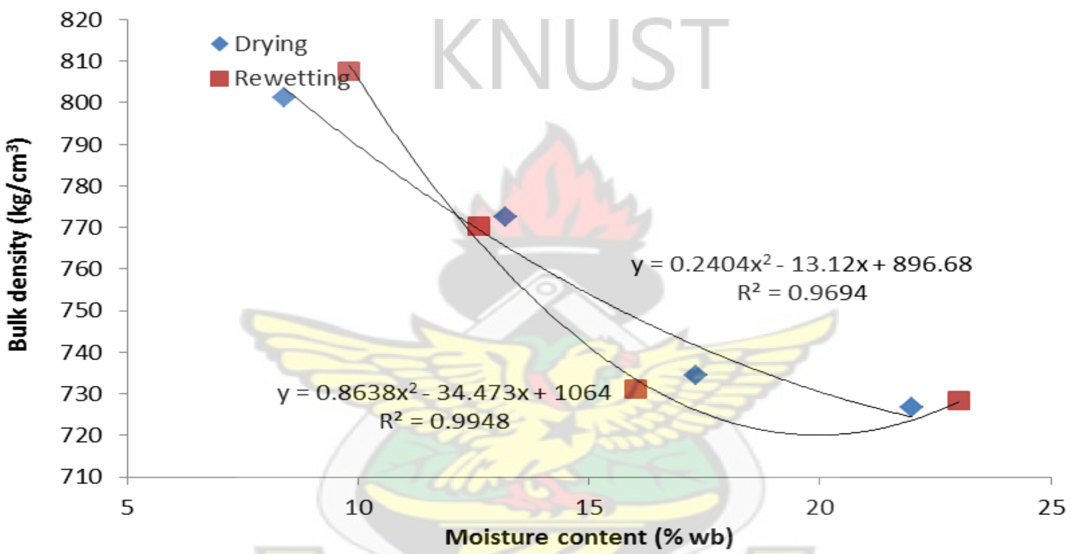

Fig.20. Variation of bulk density of Songotra with moisture content for drying and rewetting

Other researchers have found similar results for soybean (Deshpande *et al.*, 1993), green gram (Nimkar and Chattopadhyay, 2001) and *Asontem* cowpea variety (Ampah *et al.*, 2012). The decrease in bulk density during rewetting may be attributed to an increase in the sizes of the beans resulting in more voids between grains compared to an increase in mass; hence there are fewer grains occupying the same volume and vice versa for drying.

The following equations describe the relationship between volume and moisture for drying and rewetting respectively.

Drying $\quad \ell_b = 0.2404M^2 - 13.12M + 896.68 \quad R^2 = 0.9694 \quad (49)$

Rewetting $\ell_b = 0.8638M^2 - 34.473M + 1064$ $R^2 = 0.9948$ (50)

where M represents the moisture content (%wb)

4.2.7 True Density

True density decreased non-linearly with increasing moisture content during rewetting from 1217.61kgm^{-3} at 9.8%wb to 1206.54 at 23%wb. Drying showed a non-linear increase in true density with decreasing moisture content from 1201.63kgm^{-3} at 22.0%wb to 1222.00kgm^{-3} at 8.4%wb. Significant differences were recorded across all means for both rewetting and drying at 5%.

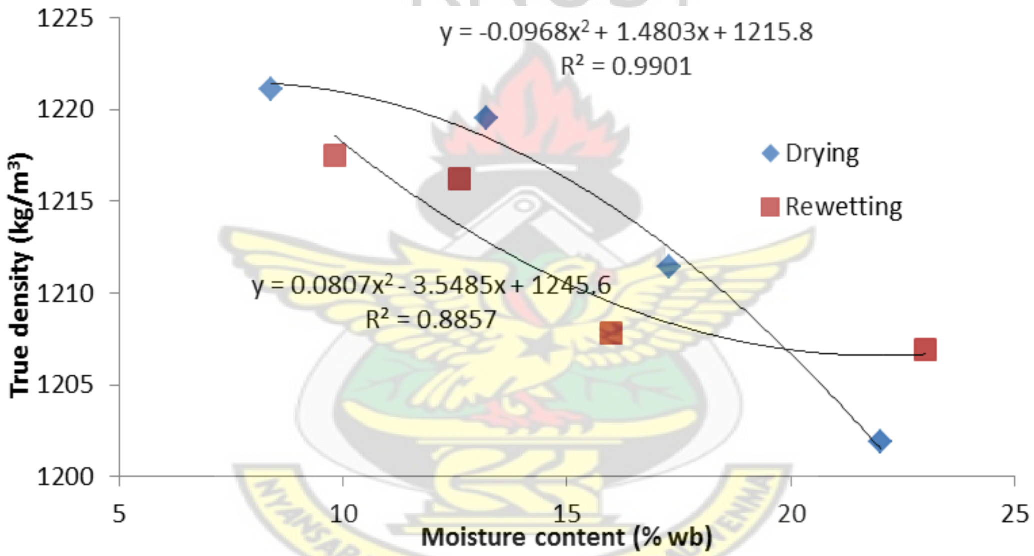

Fig.21. Variation of true density of Songotra with moisture content for drying and rewetting

Shoughy and Amer (2006) reported that the effect of moisture content on kernel density of faba bean seed showed a linear decrease with moisture content ranging from 9.8%db to 26.5%db. The decrease in true density values with increase in moisture content might be attributed to the relatively higher kernel volume as compared to the corresponding mass of the seed attained due to absorption of water. Ampah *et al.* (2012) also found the true density of *Asontem* variety to decrease with increasing moisture for both rewetting and drying. Similar results have been recorded by researchers like Karimi *et al.* (2009) for wheat and

Firouzi and Alizadeh (2012) for *Mashhad* cowpea variety. Kiani et al. (2008) however found the true density of red bean (*Phaseolus vulgaris* L.) to increase with increase in moisture. The following equations describe the relationship between volume and moisture for drying and rewetting respectively;

Drying $\ell_t = -0.0968x^2 + 1.4803x + 1215.8$ $R^2 = 0.9901$ (51)

Rewetting $\ell_t = 0.0807x2 - 3.5485x + 1245.6$ $R^2 = 0.8857$ (52)

where M represents the moisture content(% wb)

4.2.8 Porosity

Porosity increased non-linearly from 33.65% at 9.8%wb to 39.657% at 23%wb during rewetting. During drying, porosity decreased from 56.63% at 22.0%wb to 52.01% at 8.4%wb. There were significant differences across all means at 5%.

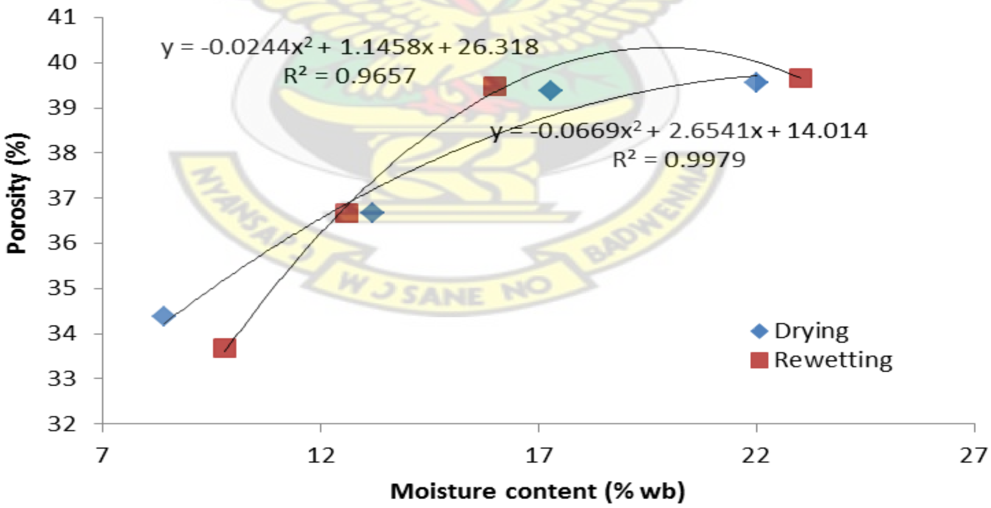

Fig. 22. Variation of porosity of Songotra with moisture content for drying and rewetting

Shoughy and Amer (2006), found the porosity of three different varieties of faba bean to increase with increasing moisture content. Balakrishnan *et al.*, (2011) found the porosity of cardamom to increase with increase in moisture content. Soliman *et al.*, (2009) found in a study on three varieties of wheat that porosity for on variety *Sakha-93* decreased with increase in moisture content but two other varieties *Giza-168* and *Banisuif-1* were related to moisture content in a direct proportion. Firouzi and Alizadeh (2012) also found the porosity of *Mashhad* cowpea variety to decrease with increase in moisture content.

Resistance of bulk seed to airflow is, in part, a function of the porosity and the kernel size.

The following equations describe the relationship between porosity and moisture for drying and rewetting respectively;

Drying $\varepsilon = -0.0244x^2 + 1.1458x + 26.318$ $R^2 = 0.9657$ (53)

Rewetting $\varepsilon = -0.0669x^2 + 2.6541x + 14.014$ $R^2 = 0.9979$ (54)

Where M represents the moisture content (%wb)

4.2.9 1000 Grain Mass

During rewetting and drying, 1000 grain mass increased non-linearly with increasing moisture content. Rewetting from 9.8%wb to 23%wb caused an increase in mass from 140.21g to 150.63g whiles drying recorded a reduction in mass from 151.08g to 138.69g. An increase in mass of 7.43% was recorded during rewetting whiles a reduction in mass of 8.2% was recorded during drying. Significant differences were recorded across all means at 5% for both drying and rewetting.

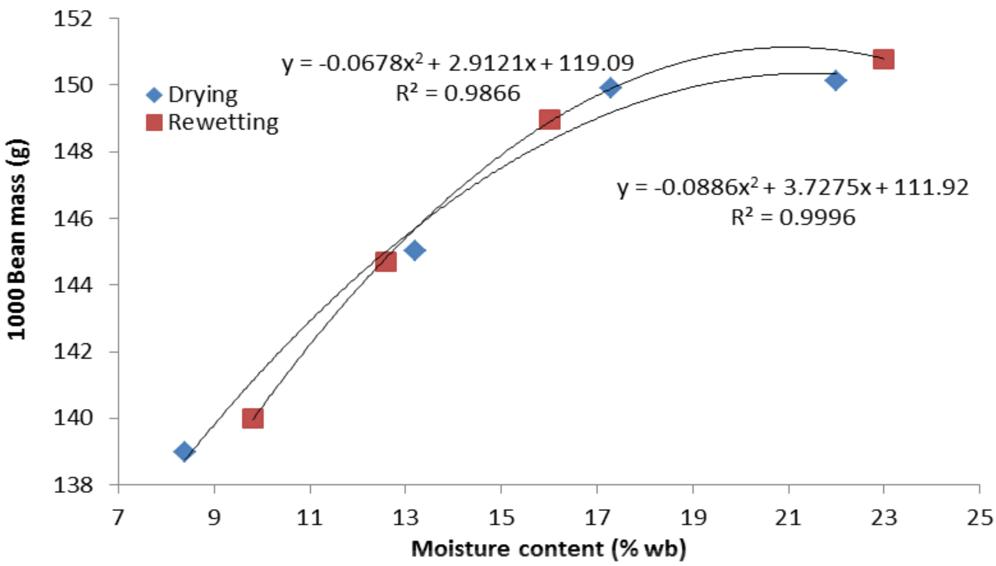

Fig. 23. Variation of 1000 Grain mass of Songotra with moisture content for drying and rewetting

Ampah *et al.* (2012) also found the 1000 seed mass of *Asontem* cowpea variety to increase non-linearly with increase in moisture and they observed a non-linear decrease during drying. Singh *et al.* (2010) and Shirkole *et al.* (2011) however, found the 1000 seed weight of barnyard millet and soybean respectively to increase linearly with increase in moisture content. The following equations describe the relationship between 1000 bean mass and moisture for drying and rewetting respectively;

Drying $1000_m = -0.0678x^2 + 2.9121x + 119.09$ $R^2 = 0.9866$ (55)

Rewetting $1000_m = -0.0886x^2 + 3.7275x + 111.92$ $R^2 = 0.9996$ (56)

where M represents the moisture content (%wb)

4.2.10 Filling Angle of repose

The filling angle of repose for both rewetting and drying increased non-linearly with increasing moisture content. The values for rewetting increased from 22.54^0 at 9.8%wb to 28.86^0 at 23%wb and that for drying decreased from 28.4^0 at 22%wb to 21.48^0 at 8.4%wb. Significant differences were recorded across all means for both rewetting and drying at 5%.

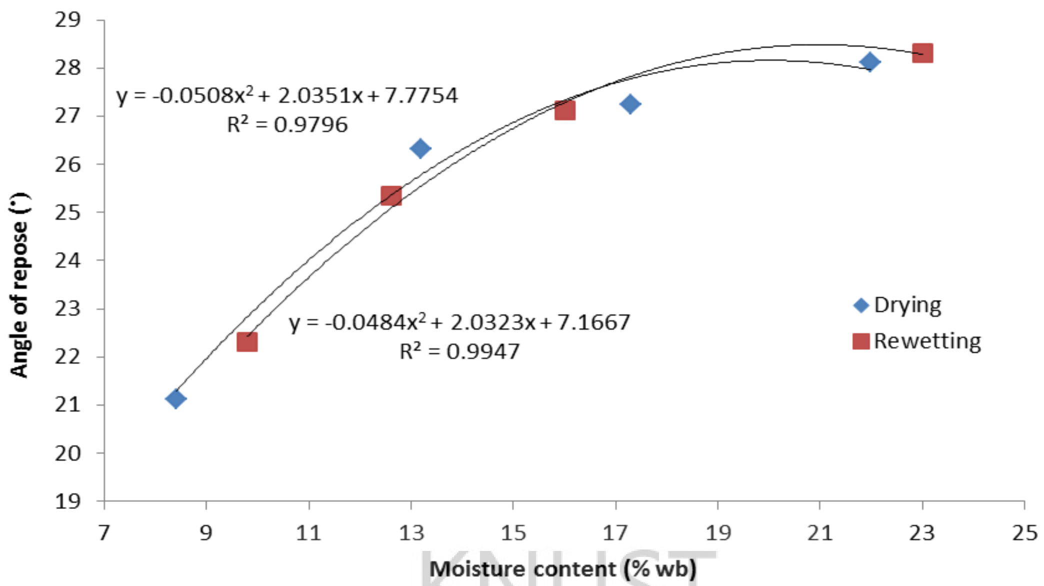

Fig. 24. Variation of filling angle of repose of Songotra with moisture content for drying and rewetting

The increase in filling angle may be due to an increase in surface roughness as well as size of individual grains which affect their ability to form a heap. Davies and Zibokere (2011), found the angle of repose to increase with increase in moisture content for three different cowpea varieties viz- *IAR-339-1, IT86D-1010 and Ife Brown.* Barnwal *et al.*, (2012) also found the angle of repose maize to increase with increase in moisture content. The following equations describe the relationship between filling angle of repose and moisture for drying and rewetting respectively;

Drying $\Theta_f = -0.0508M^2 + 2.0351M + 7.7754$ $R^2 = 0.9796$ (57)

Rewetting $\Theta_f = -0.0484M^2 + 2.0323M + 7.1667$ $R^2 = 0.9947$ (58)

where M represents the moisture content (% wb)

4.2.11 Static Coefficient of Friction

4.2.11.1 Mild Steel

The coefficient of static friction with moisture content during rewetting on mild steel was found to increase non-linearly during rewetting from 0.38 at 9.8% wb to 0.46 at 23% wb. Drying also showed a non-linear decrease with reduction in moisture content; from 0.46 at 22.0% wb to 0.37 at 8.4%wb. Rewetting values showed a high level of significant difference at 5% among all the levels of moisture content.

The variation with moisture content for drying and rewetting can be expressed respectively as follows:

Drying $\mu_m = -0.0006M^2 + 0.0243M + 0.2079$ $R^2 = 0.9955$ (59)

Rewetting $\mu_m = -0.0006M^2 + 0.0246M + 0.1958$ $R^2 = 0.9889$ (60)

where M is moisture content

4.2.11.2 Plywood

The coefficient of friction for plywood increased non-linearly with increasing moisture content during rewetting from 0.31 at 9.8%wb to 0.39 at 23.0%wb. Drying showed a decrease from 0.39 at 22.0%wb to 0.31 at 8.4%wb. Results obtained for rewetting and drying showed significant difference at 5% across all means.

The variation with moisture content for drying and rewetting can be expressed respectively as follows:

Drying $\mu_p = -0.0003M^2 + 0.0166M + 0.1942$ $R^2 = 0.9957$ (61)

Rewetting $\mu_p = -0.0003M^2 + 0.015M + 0.1961$ $R^2 = 0.9505$ (62)

where M is the moisture content

4.2.11.3 Rubber

For rubber, the coefficient of static friction during rewetting increased non-linearly from 0.39 at 9.8%wb to 0.47 at 23.0wb. Drying on the other hand, recorded a decrease in static coefficient of friction with decreasing moisture content from 0.45 at 22.0%wb to 0.31 at 8.4%wb. The variation with moisture content for drying and rewetting can be expressed respectively as follows:

Drying $\mu_r = -0.0005M^2 + 0.0214M + 0.2147$ $R^2=0.9919$ (63)

Rewetting $\mu_r = -7E\text{-}05M^2 + 0.0082M + 0.3166$ $R^2=0.9997$ (64)

where M is moisture content.

4.2.11.4 Review of Coefficient of Static Friction

The static coefficient of friction increased with increase in moisture content on all surfaces. The coefficient of static friction for rubber recorded the highest values followed by mild steel and then plywood. This may be due to the fact that some adhesion is generated between the surface of the rubber and that of the wet seeds. The increase in static coefficient of friction with increasing moisture content may be due to the increase in weight of grains from moisture absorption which reduces its ability to slide. The grains also possibly become rougher on the surface as the moisture content increases making the coefficient of friction increase.

Design of the dimensions of hoppers, bunker silos and other bulk solid storage and handling structures should ensure non-arching phenomena. The higher the coefficient of friction is, the lower the mobility coefficient is, hence requiring larger hopper opening, larger hopper sidewall slope and steeper angle of inclination in inclined grain transporting equipment like chutes (Irtwange and Igbeka,2002).

Altuntas *et al.*, (2004) found the static and dynamic coefficients of friction on various surfaces, namely, plywood, mild steel and galvanized metal also increased linearly with increase in moisture content. The plywood surface offered the maximum friction followed by mild metal and galvanized metal.

Singh *et al.*, (2010) also observed that static coefficient of barnyard millet grain and kernels on sun-mica, iron and canvas surfaces show a linear increase with increase of the moisture content.

Bart-Plange *et al.* (2005); Bart-Plange *et al*. (2006); Tavakoli *et al*. (2009) and Gharib-Zahedi *et al*. (2010) also found increasing linear relationships for cowpeas, maize, barley and black cumin grains respectively on plywood, rubber, glass and galvanized iron sheet.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The investigation of selected physical properties of *Padi-Tuya* and *Songotra* cowpea varieties within the moisture content range of 8.0% wb to 23% wb revealed the following:

1. All linear dimensions, geometric mean diameter, surface area, volume and 1000 grain mass increased non-linearly with increasing moisture content for the two varieties.
2. Padi-Tuya had geometric mean diameter, surface area and volume decreasing from 7.38mm to 7.01mm, 171.27mm^2 to 154.28mm^2 and 210.71mm^3 to 180.15mm^3 respectively under drying conditions. Padi-Tuya also recorded non-linear increases for geometric mean diameter (7.05mm to 7.41mm), surface area (156.32mm^2 to 172.49mm^2) and volume (183.78mm^3 to 213.02mm^3) during rewetting.
3. Geometric mean diameter, surface area and volume for Songotra increased non-linearly from 5.27mm to 5.90mm, 87.29mm^2 to 109.23mm^2 and 76.69mm^3 to 107.35mm^{3}respectively during rewetting and decreased non-linearly from 5.85mm to 5.24mm, 107.66mm^{2}to 86.39mm^2 and 105.04mm^3 to 75.51mm^{3}respectively under drying conditions.
4. Bulk density of Padi-Tuya increased non-linearly with reduction in moisture content during drying from 759.52kgm^{-3} to 799.79kgm^{-3}. Under rewetting conditions it non-linearly decreased from 796.33kgm^{-3}to 751.56kgm^{-3}.
5. Bulk density for Songotra increased non-linearly with reduction in moisture from 727.98kgm^{-3} to 801.55kgm^{-3}under drying conditions and there was a non-linear

decrease in bulk density from 807.91kgm^{-3} to 728.06kgm^{-3} as moisture content increased during rewetting.

6. Padi-Tuya had true density increase non-linearly under drying conditions from 1189.67kgm^{-3} to 1216.78kgm^{-3} while rewetting conditions showed a non-linear decrease from 1216.00kgm^{-3} to 1186.28kgm^{-3}.
7. True density increased non-linearly for Songotra as moisture content decreased under drying conditions from 1201.63kgm^{-3} to 1222.00kgm^{-3} and there was also a non-linear decrease in true density as moisture increased from 1217.61kgm^{-3} to 1206.54kgm^{-3}.
8. Porosity for Padi-Tuya increased from 51.95% at 9.8%wb to 57.98% at 23.0%wb. Under drying conditions however, there was a non-linear increase from 42.18% at 22%wb to 42.47% at 8.4%wb.
9. Songotra had porosity decreasing with the reduction of moisture from39.42% to 34.41% during drying and increasing from 33.65% to 39.66% under rewetting conditions.
10. Padi-Tuya had 1000 Grain mass decreasing from 234.28g to 221.63g under drying conditions and increasing non-linearly from 225.03g to 236.05g during rewetting.
11. 1000 Grain mass for Songotra increased from 140.21g to 150.63g as moisture increased under rewetting conditions whiles there was a non-linear decrease during drying from 151.08g to 138.69g.
12. Padi-Tuya had filling angle of repose increase non-linearly from 18.77^0 to 30.82^0 during rewetting and decrease non-linearly from29.9^0 to 17.25^0 under drying conditions.
13. Filling angle of repose for Songotra increased from 22.54^0 to 28.86^0 as moisture increased during rewetting and under drying conditions it decreased from 28.4^0 to

21.48^0.

14. Padi-Tuya had static coefficient of friction increasing non-linearly on all three surfaces namely plywood (0.29 to 0.35), mild steel (0.37 to 0.59) and rubber (0.35 to 0.48) as moisture increased under rewetting conditions. Drying conditions showed a non-linear decrease in static coefficient of friction on all three surfaces. There was a reduction on plywood from 0.35 to 0.28, 0.54 to 0.37 for mild steel and 0.48 to 0.34 for rubber. Highest coefficients were recorded for mild steel followed by rubber and then plywood.

15. The static coefficient of friction for Songotra during rewetting increased non-linearly with increasing moisture content on all the three surfaces namely plywood (0.31 to 0.39), mild steel (0.38 to 0.46) and rubber (0.39to0.47). There was also a non- linear decrease with reduction in moisture content on all three surfaces namely, plywood (0.39 to 0.31), mild steel (0.46 to 0.37) and rubber (0.46 to 0.36) during drying. For both conditions, rubber offered the maximum friction followed by mild steel and then plywood.

5.2 RECOMMENDATIONS

1. New varieties of cowpea and other seeds and pulses are constantly being churned out from our breeding stations in Ghana and in consequence, it is recommended that research should be conducted on these and other varieties in order to provide data on their physical properties.
2. Other surfaces such as aluminium, glass and different rubber thicknesses should be used in testing for the static coefficient of friction.
3. Methodologies for various physical properties should be tested for reliability.

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APPENDICES

APPENDIX 1.SUMMARY OF AVERAGES FOR VARIOUS PHYSICAL PROPERTIES

Table 6. Summary of averages and least significant differences for Padi-Tuya variety (drying)

PHYSICAL PROPERTIES	MEANS				LSD (5%)
	8.4%wb	13.2%wb	17.3%wb	22%wb	
Length(mm)	9.69	10.01	10.45	10.53	0.0634
Width (mm)	6.79	6.96	7.01	7.12	0.0722
Thickness (mm)	5.26	5.32	5.36	5.43	0.1346
Geometric Diameter(mm)	7.01	7.17	7.31	7.38	0.001797
Volume (mm^3)	180.15	192.92	204.36	210.71	1.27
Sphericity(%)	0.723	0.716	0.699	0.701	0.000702
Surface Area(mm^2)	154.28	161.48	167.81	171.27	1.001
Bulk Density	799.79	789.62	776.29	759.52	1.099
True Density	1215.78	1206.67	1199.87	1189.67	1.339
Porosity	52.01	52.82	54.56	56.63	0.01625
1000 Grain Mass	221.63	225.53	229.60	234.28	1.311
Filling Angle of repose	17.25	23.2	26.4	29.8	0.5027
Mild steel	0.37	0.41	0.48	0.54	0.01951
Plywood	0.28	0.32	0.33	0.35	0.01708
Rubber	0.35	0.39	0.42	0.46	0.01316

Table 7. Summary of averages and least significant differences for Songotra variety (rewetting)

PHYSICAL PROPERTIES	MEANS				LSD (5%)
	9.8%wb	12.6%wb	16%wb	23%wb	
Length	6.98	7.11	7.34	7.68	0.01371
Width	5.21	5.44	5.87	5.99	0.01679
Thickness	4.03	4.21	4.37	4.45	0.04088
Geometric Diameter	5.27	5.46	5.73	5.89	0.01614
Volume	76.69	85.28	98.65	107.35	0.726
Sphericity	0.755	0.768	0.781	0.767	0.00308
Surface Area	87.29	93.69	103.25	109.23	0.5419
Bulk Density	807.91	770.49	731.06	728.06	2.702
True Density	1217.61	1216.05	1207.75	1206.54	0.962
Porosity	33.65	36.64	39.47	39.66	0.225
1000 Grain Mass	140.21	144.62	148.47	150.63	1.282
Filling Angle of repose	22.54	25.02	27.18	28.86	0.763
Mild steel	0.38	0.42	0.44	0.46	0.01258
Plywood	0.31	0.33	0.37	0.39	0.01316
Rubber	0.39	0.41	0.44	0.47	0.01177

APPENDIX 2 OUTPUT FROM GENSTAT 12.1 FOR REWETTING AND DRYING CONDITIONS (ANOVA)

Anova single factor 1000 Grain mass (Songotra rewetting)

Analysis of variance

Variate: %1000_GRAIN_MASS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
M_C_%	3	251.9308	83.9769	121.34	<.001
Residual	12	8.3053	0.6921		
Total	15	260.2361			

Tables of means

Variate: %1000_GRAIN_MASS

Grand mean 145.98

M_C_%	9.8	13.2	16.0	23.0
	140.21	144.62	148.47	150.63

Standard errors of means

Table	M_C_%
rep.	4
d.f.	12
e.s.e.	0.416

Standard errors of differences of means

Table	M_C_%
rep.	4
d.f.	12
s.e.d.	0.588

Least significant differences of means (5% level)

Table	M_C_%
rep.	4
d.f.	12
l.s.d.	1.282

Stratum standard errors and coefficients of variation

Variate: %1000_GRAIN_MASS

d.f.	s.e.	cv%
12	0.832	0.6

Anova Single factor

Angle of repose Padi-Tuya (drying)

Analysis of variance

Variate: repose

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
M_C_%	3	343.1169	114.3723	1074.34	<.001
Residual	12	1.2775	0.1065		
Total	15	344.3944			

Message: the following units have large residuals.

units 3	0.675	s.e.	0.283

Tables of means

Variate: repose

Grand mean 24.169

M_C_%	8.4	13.2	17.3	22.0
	17.250	23.200	26.400	29.825

Standard errors of means

Table	M_C_%
rep.	4
d.f.	12
e.s.e.	0.1631

Standard errors of differences of means

Table	M_C_%
rep.	4
d.f.	12
s.e.d.	0.2307

Least significant differences of means (5% level)

Table	M_C_%
rep.	4
d.f.	12
l.s.d.	0.5027

Stratum standard errors and coefficients of variation

Variate: repose

d.f.	s.e.	cv%
12	0.3263	1.4

APPENDIX 3. CHARTS FOR LINEAR DIMENSIONS AND STATIC COEFFIENT OF FRICTION

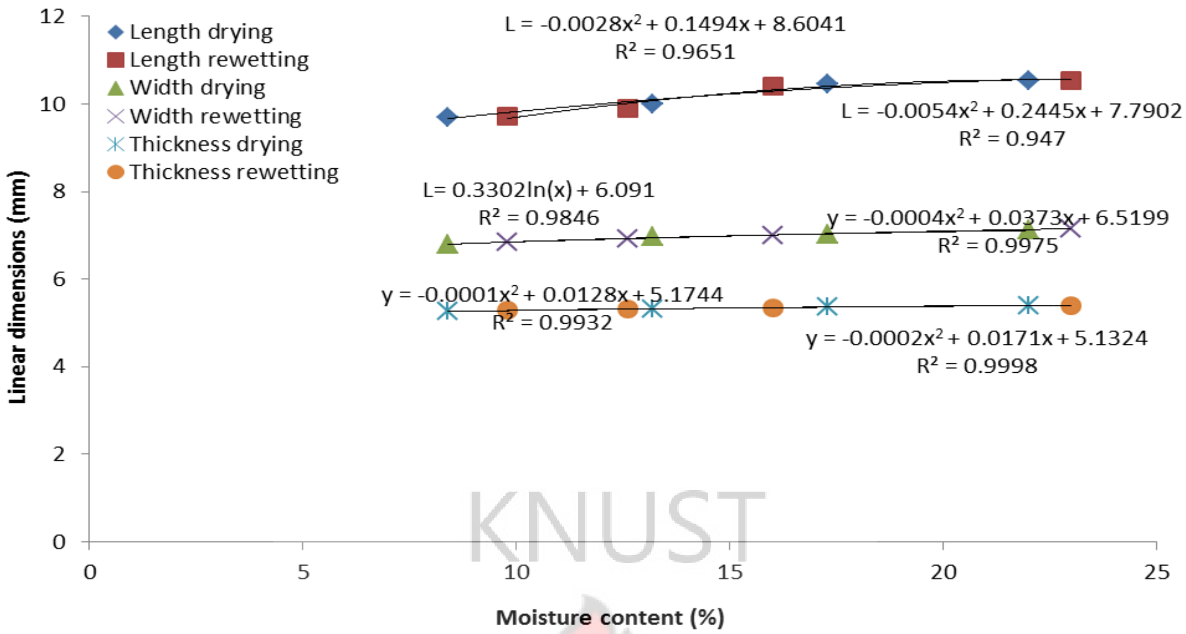

Fig. 25. Variation of linear dimensions of Padi-Tuya with moisture content for drying and rewetting

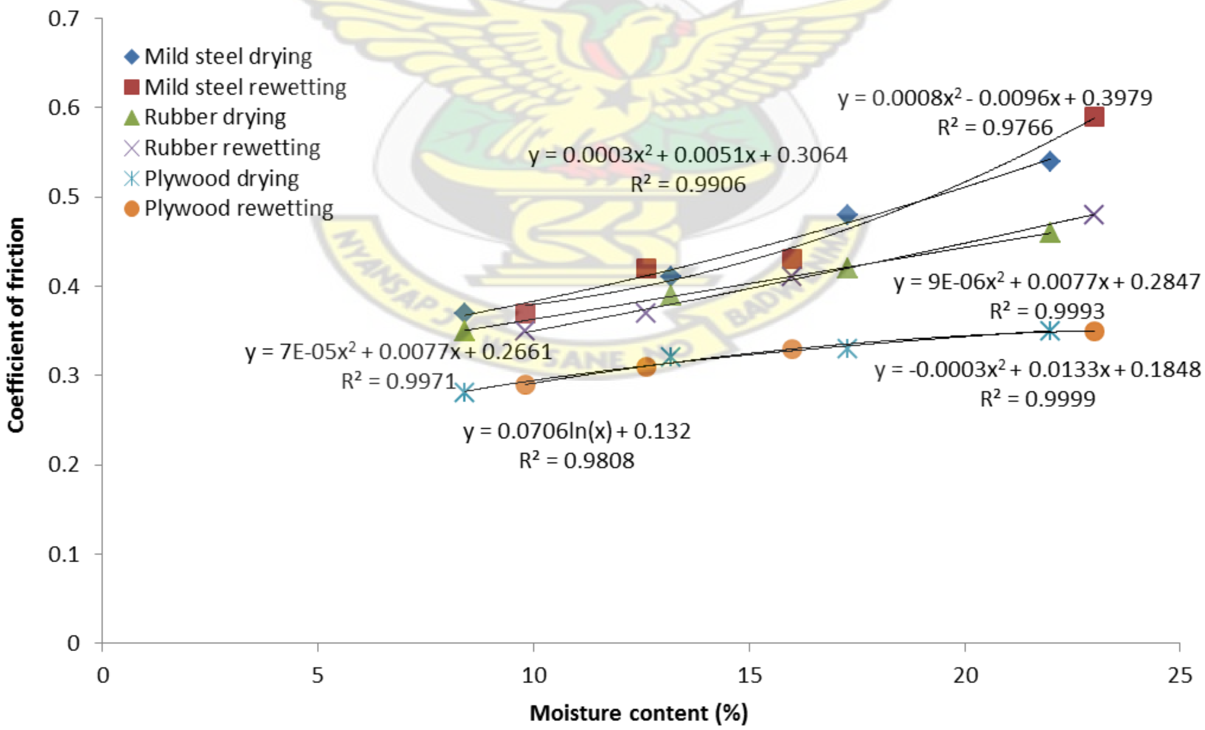

Fig. 26. Variation of static coefficient of friction of Padi-Tuya with moisture content for drying and rewetting

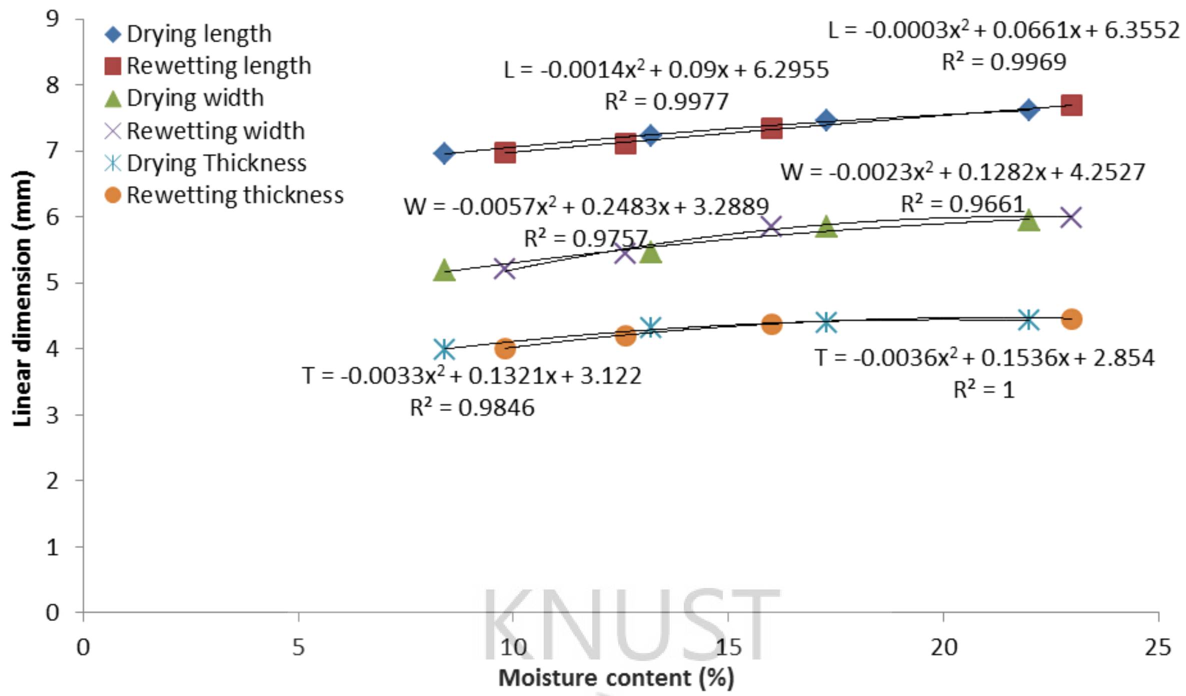

Fig. 27. Variation of linear dimensions of Songotra with moisture content for drying and rewetting

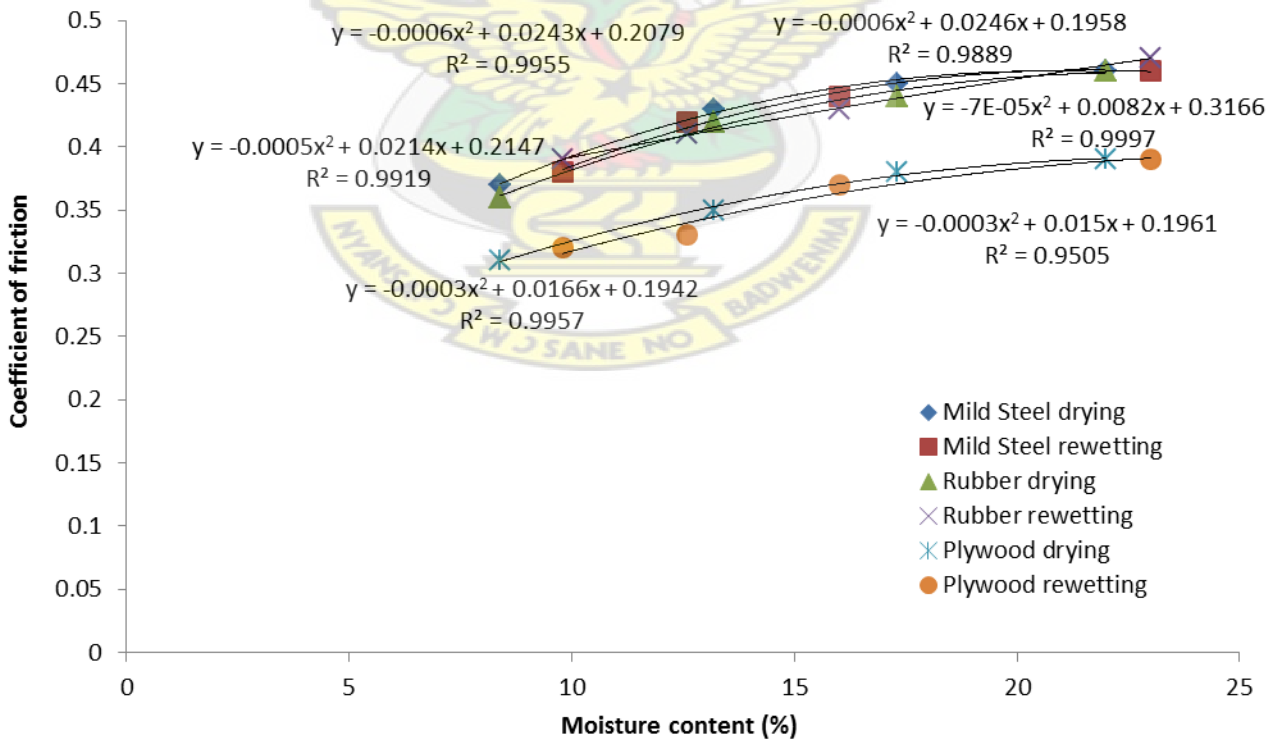

Fig. 28. Variation of static coefficient of friction of Songotra with moisture content for drying and rewetting

APPENDIX 4 EQUATIONS DESCRIBING DRYING AND REWETTING TRENDS OF PHYSICAL PROPERTIES.

Table 8. Equations describing rewetting trends for Padi-Tuya

Physical Property	Equation	R^2
Length	$-0.0054x^2 + 0.2445x + 7.7902$	0.947
Width	$-0.0004x^2 + 0.0373x + 6.5199$	0.9975
Thickness	$-0.0001x^2 + 0.0128x + 5.1744$	0.9932
Geometric Diameter	$-0.0015x^2 + 0.0768x + 6.4241$	0.9825
Volume	-0.1152x2 + 6.0513x + 133.83	0.982
Sphericity	$0.0002x^2 - 0.0098x + 0.8004$	0.8847
Surface Area	$-0.0658x^2 + 3.417x + 128.22$	0.9822
Bulk Density	$0.0822x^2 -0.4863x + 809.83$	0.9993
True Density	$0.0855M^2 – 4.5179M + 1246$	0.9999
Porosity	$-0.0155M^2 - 0.1244M + 51.916$	0.9956
1000 Grain Mass	$-0.0583x^2 + 2.7197x + 204.25$	0.9894
Filling Angle of repose	$14.057\ln(x) - 13.313$	0.9999
Mild steel	$0.0008x^2 - 0.0096x + 0.3979$	0.9766
Plywood	$-0.0003x^2 + 0.0133x + 0.1848$	0.9999
Rubber	$7E\text{-}05x^2 + 0.0077x + 0.2661$	0.9971

Table 9. Equations describing drying trends for Padi-Tuya

Physical Property	Equation	R^2
Length	$-0.0028x^2 + 0.1494x + 8.6041$	0.9651
Width	$0.3302\ln(x) + 6.091$	0.9846
Thickness	$-0.0002x^2 + 0.0171x + 5.1324$	0.9998
Geometric Diameter	$-0.001x^2 + 0.0585x + 6.5825$	0.9962
Volume	-0.0734x2 + 4.5248x + 147.02	0.9957
Sphericity	$0.0001x^2 - 0.0049x + 0.7584$	0.8793
Surface Area	$-0.043x^2 + 2.5797x + 135.47$	0.9959
Bulk Density	$0.2648M^2 – 11.904M + 1059.8$	0.9711
True Density	$-0.0151M^2 – 1.4387M + 1228.8$	0.9985
Porosity	$-0.04M^2 + 1.7355M + 39.133$	0.9424
1000 Grain Mass	$0.0104x^2 + 0.6186x + 215.66$	0.9997
Filling Angle of repose	$12.875\ln(x) - 10.105$	0.9993
Mild steel	$0.0003x^2 + 0.0051x + 0.3064$	0.9906
Plywood	$0.0706\ln(x) + 0.132$	0.9808
Rubber	$9E-06x^2 + 0.0077x + 0.2847$	0.9993

Table 10. Equations describing rewetting trends for Songotra

Physical Property	Equation	R^2
Length	$L = -0.0003x^2 + 0.0661x + 6.3552$	$R^2 = 0.9969$
Width	$W = -0.0057x^2 + 0.2483x + 3.2889$	$R^2 = 0.9757$
Thickness	$T = -0.0036x^2 + 0.1536x + 2.854$	1
Geometric Diameter	$-0.0035x^2 + 0.1658x + 3.9569$	0.9932
Volume	$-0.1554x^2 + 7.5161x + 16.503$	0.9916
Sphericity	$-0.0005x^2 + 0.0162x + 0.6376$	0.9865
Surface Area	$-0.1179x^2 + 5.5987x + 42.71$	0.9924
Bulk Density	$0.8638x^2 - 34.473x + 1064$	0.9948
True Density	$0.0807x^2 - 3.5485x + 1245.6$	0.8857
Porosity	$-0.0669x^2 + 2.6541x + 14.014$	0.9979
1000 Grain Mass	$-0.0886x^2 + 3.7275x + 111.92$	0.9996
Filling Angle of repose	$-0.0484x^2 + 2.0323x + 7.1667$	0.9947
Mild steel	$-0.0006x^2 + 0.0246x + 0.1958$	0.9889
Plywood	$-0.0003x^2 + 0.015x + 0.1961$	0.9505
Rubber	$-7E-05x^2 + 0.0082x + 0.3166$	0.9997

Table 11. Equations describing drying trends for Songotra

Physical Property	Equation	R^2
Length	$-0.0014x^2 + 0.09x + 6.2955$	0.9977
Width	$-0.0023x^2 + 0.1282x + 4.2527$	0.9661
Thickness	$-0.0033x^2 + 0.1321x + 3.122$	0.9846
Geometric Diameter	$-0.0025x^2 + 0.1228x + 4.3772$	0.9974
Volume	$-0.1081x^2 + 5.4956x + 36.27$	0.996
Sphericity	$-0.0002x^2 + 0.0077x + 0.7027$	0.998
Surface Area	$-0.0832x^2 + 4.1207x + 57.157$	0.9967
Bulk Density	$0.2404x^2 - 13.12x + 896.68$	0.9694
True Density	$-0.0968x^2 + 1.4803x + 1215.8$	0.9901
Porosity	$-0.0244x^2 + 1.1458x + 26.318$	0.9657
1000 Grain Mass	$-0.0678x^2 + 2.9121x + 119.09$	0.9866
Filling Angle of repose	$-0.0508x^2 + 2.0351x + 7.7754$	0.9796
Mild steel	$-0.0006x^2 + 0.0243x + 0.2079$	0.9955
Plywood	$-0.0003x^2 + 0.0166x + 0.1942$	0.9957
Rubber	$-0.0005x^2 + 0.0214x + 0.2147$	0.9919