Post-production handling of Mangoes (*Mangifera indica L.*) using *Luffa aegyptiaca* Mill.

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June 2011

A thesis submitted to McGill University in partial fulfillment of the requirements for the degree of Master of Science

ABSTRACT

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POST–PRODUCTION HANDLING OF MANGOES (*Mangifera indica L.*) using *Luffa aegyptiaca*.Mill.

Post-production losses of fruits and vegetables are high in many developing economies. Mango (*Mangifera indica L.*) fruit are particularly difficult to handle after harvest. In Senegal, field-to-market transport alone induces sufficient mechanical damage to reduce marketable produce by 30%. This mechanical damage to fruit is attributable to a number of causes, including but are not limited to: poor packaging, inadequate boxes, crates or baskets, stressful transport conditions, poor road conditions and long traffic delays which prevent the produce reaching markets within a reasonable time.

In investigating a solution for the post-harvest losses of mango due to mechanical damage, this study took into account the different causes in order to minimize losses during both transport and packaging steps. Mechanical properties of Luffa (*Luffa aegyptiaca* Mill.), a vegetable sponge that grows naturally in Senegal was examined and a luffa sponge box was designed. Box height took into account the dimensions of the fruit of three mango cultivars (cvs. ‘Kent,’ ‘Keitt’ and ‘Haden’), while the other dimensions followed the ISO 3394 standard for rigid rectangular boxes. The luffa sponge box was tested in the laboratory for compression and stacking strength and produced results for practical use.

A box-making-tool was also designed to both reduce the time needed to make the box and increase its quality and appeal. The supply of luffa sponge in Senegal was examined during a field research trip and an estimate of the cost of producing a luffa sponge box in the Senegalese context was established.

RÉSUMÉ

MANUTENTION POST-RÉCOLTE DE LA MANGUE (*Mangifera indica L.*) AVEC LE *Luffa aegyptiaca* Mill.

Dans plusieurs pays en voie de développement, les pertes post-récoltes en fruits et légumes sont plutôt élevées. La mange (*Mangifera indica L.*) en particulier est un fruit difficile à transporter après la récolte. Au Sénégal, à eux seuls les dommages mécaniques aux fruits causés par un transport inadéquat entre champ et marché, produisent une perte allant jusqu'à 30% des mangues récoltées. Les divers dommages mécaniques sont attribuables à: un mauvais emballage, des boites, cajos ou paniers non adaptées, des conditions de transports engendrant un stress supplémentaire aux fruits, la condition des routes, et même d'énormes embouteillages retardant à outrance la livraison des produits au marché.

En tentant de trouver une solution aux pertes post-récoltes de la mangue causé par les dommages mécaniques, cette étude prit compte des différentes causes énumérées ci-haut, afin de minimiser les pertes en transport et à l'emballage. Les propriétés mécaniques du luffa (*Luffa aegyptiaca* Mill.), une éponge végétale poussant à l'état sauvage au Sénégal, furent étudiées et une boite en luffa fut conçue. Trois variétés de mangue (cvs. Kent, Keitt and Haden) servirent de guide quant à la hauteur de la boite, tandis que les autres dimensions suivirent le standard ISO 3394 pour les boites rectangulaires rigides. La boite en luffa fut ensuite testée en laboratoire pour vérifier sa force de compression ainsi que sa capacité à l'empilage, avec des résultats convaincants.

Un outil pour fabriquer les boites fut conçu dans le but de réduire le temps nécessaire pour réaliser une boite attrayante et de haute qualité. La possibilité d'approvisionnement en luffa au Sénégal fut examiné lors d'un voyage de recherche sur le terrain et le coût de revient d'une boite en luffa dans le contexte sénégalais fut estimé.

ACKNOWLEDGMENTS

I first want to thank the creator Jehovah (God) who created the wonderful cucurbit; luffa.

I am very fortunate to have worked under the supervision of Dr. G.S.V. Raghavan. I am indebted to his willingness to explore new avenues, his vision and openness in the quest of bioresource engineering solutions to agricultural challenges faced today.

I am very grateful to my brothers, Mr. Noé Adjanohoun and Jonas Adjanohoun, for their help and assistance at every step of the way, in Canada as well as in Senegal. They contributed to making my endeavours and efforts a real pleasure, and above all a success. Great appreciation is also expressed to those who assisted in the field research trip in Senegal and the design and manufacture of the box-making tool.

I further wish to express my special thanks to Mr. Yvan Gariépy for all his technical assistance and guidance and for his patient work with me to develop a clear, methodical and scientific approach to this yet unexplored use of luffa sponge.

From the very beginning I particularly appreciated the diligent help and availability of Dr. Darwin Lyew, who was always ready to point me in the right direction or to the appropriate resources. His help represented an invaluable time-saving component of my thesis work.

I cannot forget my ever so supportive wife Aline for her input and patience that allowed me to accomplish so much.

I want to thank Dr. Georges T Dodds for his assistance in completing this work. I also want to acknowledge the financial support provided by McGill University that helped greatly to carry this work to its conclusion.

Finally, I wish to thank my Executive Director at McGill University, Dr. Pierre Moreau of the Planning and Institutional Analysis department, who allowed me to have flexible working hours during my studies, enabling me to pursue my personal academic interests while working under his supervision.

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CHAPTER I

INTRODUCTION

1.1 Mango

Mango (*Mangifera indica*. L) is a delicious subtropical fruit consumed throughout the world. It is one of the most important tropical fruits. The taste, color and nutritive value of mango make it a fruit of choice. Mango is highly considered in tropical regions as an important source of revenue.

Mango is thought to have originated in the Indian/Burmese monsoon region and belongs to family Anacardiaceae. Ripe fruits are yellow, orange-yellow, red or red-green in color. The mango tree can reach up to 40 m in height and in a mixed cultivation system can be planted with a variety of cultures.

Mangoes can grow from sea level to 1200m in tropical latitudes and can sustain a rainfall of 400-3600 mm. Varieties differ in taste, size, shape and texture. Many local varieties exist in various countries and a diversity of cultivars developed for the trade are increasingly available in many northern countries where mangoes do not grow.

1.2 Luffa

Luffa aegyptiaca Mill. [formerly *Luffa cylindrica* (L.) M. Roem] is known as sponge gourd, towel gourd, vegetable sponge or commonly loofa. It is an annual climbing plant of the cucurbitaceous family which produces cucumber-like fruit containing many seeds and a fibrous vascular system which is a vegetable sponge. It is monœcious, having separate male and female flowers on the same plant. The male flowers occur in clusters while the female flowers are solitary and have a tiny slender ovary. When ripe, the endocarp of *L.aegyptiaca* is used in many parts of the world as scrubbing and exfoliating sponge. In Ghana for instance, until recently every student in a boarding school was required to have a luffa sponge (Mensah and Kudom, 2010). The luffa sponge investigated here, *L.aegyptiaca* is different from the species *Luffa acutangula* (L.) Roxb. also known as ridge gourd. Luffa fruit may be consumed fresh as a vegetable when young and is eaten in various countries in Asia and Africa as a vegetable. Studies have also shown that the seeds of luffa fruit are a good source of oil, certain amino acids, phosphorus, iron and magnesium (Kamel and Blackman, 1982; Grondin *et al.*, 2002).The two species can be easily differentiated by their appearance: *L. aegyptiaca* has a smooth appearance and is of cylindrical shape, while *L. acutangula* has ridges. Figure 1 shows the difference between the two types of luffa. Both species are found in Senegal

Figure 1- *Luffa aegyptiaca* (green and unripe) and *Luffa acutangula* (brown and ripe) (photo by author).

CHAPTER II

PROBLEM STATEMENT

2.1 Problem Statement

Mango is a vulnerable and difficult crop to transport (Sawant and Shinde, 2000). In Senegal, as in many other developing countries production and distribution of mangoes leads to losses; part of post-harvest losses are a result of mechanical injuries due to poor handling and inadequate packaging of the crop from the field to the customer. In Senegal this step alone accounts for 15 to 30% of post-harvest losses, and increases as the distance between the field and the sorting or packing station increases (Ternoy *et al.*, 2006). Mechanical damage also encourages the development of pathogens in the fruits, which further increases crop losses, which is accounted further down the supply chain (Mascarenhas *et al.*, 1996). Farmers, traders, exporters and ultimately customers are all concerned by this problem. On many occasions the poor condition of some rural roads, as well as traffic congestion to considerable amount of stress in fruits before they reach a sorting or packing station, a market, or the final customer.

2.2 Proposed Solutions (Hypothesis)

The proposed solution is to make light, shock-absorbent boxes for transport of mango using *L. aegyptiaca* or luffa. Luffa sponge does not sustain plastic deformation and could be classified in the elastic-plastic behaviour category when subjected to loading. Luffa sponge allows fruits to breathe and could be an interesting low-cost material for boxes. It is a natural product that is resistant and could be used repeatedly due to the presence of lignin, which makes up a significant portion of its fibres and wall components (Onelli *et al.*, 2001). Appropriate packing of mangoes during transport from the field to the customer using luffa sponge would reduce bruising and crushing, as well as subsequent losses driven by mechanical damage. It would also improve produce respiration. Suitable packaging would also prevent contamination, and ultimately provide increased revenue to the farmers and better quality of fruits to the customers.

CHAPTER III

OBJECTIVES

The objectives of this work were to: (i) investigate relevant mechanical properties of luffa sponge, (ii) design a secondary product packaging or box for mango transport with luffa and (iii) study the potential supply of the sponge gourd in Senegal. It is expected that this work will provide much needed information on the mechanical properties of luffa sponge and set the basis to determine whether using it as a material to make boxes for shipping mangoes from the field is a suitable solution to the problem of transport of mangoes in the Senegalese context.

Given that luffa plant grows naturally in Senegal and is only used in a limited scope as a scrubbing agent or dish cloth, further investigation of the use of luffa sponge as a raw material to make shipping boxes is needed; this would be an attractive solution to the problem of post harvest losses of mangoes.

The final chapter (chapter VIII) focuses on the supply of luffa sponge and its associated economics in the local context.

CHAPTER IV

LITERATURE REVIEW

4.1 Mango in Senegal

Senegal was the site of the first mango trees reported to exist in West-Africa. Mango trees appear for the first time in the *Catalogue of nursery plants of the Government of Senegal,* written in 1824 by the French botanist Jean Michel Claude Richard, the "head nursery gardener", who later gave his name to the northern Senegalese city of Richard-Toll (Rey *et al.*, 2006). Mango trees were grown in various part of Senegal in the latter part of the 19th century, and today they can be found all over the country in city streets, gardens, private houses and public places. They are used for their fruits as well as for their shade due to their thick foliage. Figure 2 shows a village in Senegal with mango trees planted near houses.

Figure 2 - Mango trees in village houses in Senegal, 2010 (photo by author).

Agriculture is the main economic activity in Senegal. It employs over 70% of the national workforce and contributes to close to 10% of the nation's Gross Domestic Product (GDP). According to the Food and Agriculture Organization of the United Nations (FAO) mango production in Senegal has enjoyed a steady growth from 73 Mg in 2000, to 105 Mg in 2009, representing an increase of 43% in 9 years. This production corresponds to an area of 16,000 ha. Even though the production data are only available on an aggregate level [*i.e*., including mangosteens (*Garcinia* × *mangostana* L.) and guavas (*Psidium guajava* L.)] the large share of mangoes in this group gives a good indication of their production. These are estimates that do not take into account all cultivated areas. The precarious situation resulting from insecurity in the south of the country, particularly in Casamance, restricts accurate evaluation of the production.

Despite some noticeable progress on the export trade, most of the production is consumed in the national market. An unknown amount of imports from neighboring countries, namely Mali and Guinea contributes to the supply in local markets due to the natural transfer of goods near borders. These mangoes tend to be imported before the mango season in Senegal which lasts from early May to late October.

Mangoes are commercially produced across Senegal mainly in the Niayes region of Dakar, Thiès, Louga, and Saint-Louis administrative districts (Diedhiou *et al.*, 2007). In these regions many people depend on the proceeds of their harvest and are directly impacted by the variation in revenues generated from the sale of mangoes. The isolation of the southern Casamance region, separated from the rest of the country by the nation of Gambia, makes it difficult to integrate the crops cultivated in that region into the distribution system. The transport and logistics needed to bring the production from fields to markets located in the rest of the country is confronted with numerous hurdles, including, but not limited to, poor road conditions, abundant check points and vast traffic jams.

The principal region of mango production destined to the export market, the Niayes, is a fertile strip of land stretching 180 km in length, by 5-40 km across, which produces 70% of all vegetables consumed in Senegal. A recent study conducted by the United States Agency for International Development (USAID) (2006) estimated that over 40,000 people were employed in the mango sector in Senegal and that the number is increasing monthly as more acreage is devoted to cultivating mangoes (Ternoy *et al.*, 2006). Most orchards are 2-10 ha in extent, with only a few large plantations exceeding 30 ha.

4.1.1 Cultivation of mango

According to FAO estimates, mango cultivation in Senegal has progressed from 11,000 ha in 2005 to 16,000 ha in 2009. Several mango varieties are cultivated in Senegal. Local varieties include ‘Sierra Leone’, or ‘Greffeul’, ‘Sewal’, ‘Djibelor’ &c. It is difficult to evaluate the number of such mango trees as they are present in squares, house yards, along road sides etc. They are mainly for on-location consumption or are sold in nearby markets (Rey *et al.*, 2007). An increasing number of Floridian cultivars used for the export market are now cultivated in Senegal, including the ‘Kent,’ ‘Keitt,’ ‘Valencia’, etc. Table 1 shows the progression in acreage devoted to mango production and yield increases between 2005 and 2009. The combination of increase in acreage and yield signals the importance of mango cultivation in recent years in Senegal. This increase has been driven by the development of the export market and has helped attaining higher returns on investment over the same period. Parallel to production increase the export has also increased steadily. Table 2 shows the relationship between the growth in production of mango and in export during the same period.

Table 1 - Area harvested and yield of mango in Senegal, (FAOSTAT, 2011)

Year	2005	2006	2007	2008
area (ha)*	11000	13335	14000	16000
Yield (Mg ha^{-1})*	5.6	6.16	6.79	6.25

* Numbers are FAO estimates and includes mangosteens and guava

Table 2 - Production and export of mango in Senegal (FAOSTAT, 2011)

Year	2005	2006	2007	2008
Production (Mg)	61646	82194	95000	100000
Export (Mg)	4260	7041	8846	6648

The gap between mango production and exports from 2005 to 2008 shows that the increase in production was not necessarily linked to an increase in quantities exported. It was nevertheless reported by the FAO that, within that period, Senegal exported mangoes to 25 different countries, including France, the United Kingdom, The Netherlands, Austria, Germany, Italy, Saudi Arabia, and South Africa. However the increase in mango production in Senegal was hampered by important post-harvest losses due to inadequate handling and fungal diseases arising during ripening (*e.g*., anthracnose, alternariose and stem end rot) (Diedhiou *et al.*, 2007). Moreover, some cultural practices, like inversion of fruits in soil to avoid sap burn in some orchards, increases contamination and crop losses.

One of the biggest issues in present day mango production in Senegal is the fruit fly *Bactrocera invadens* (Diptera: Tephritidae). These insects cause enormous losses in orchards and have proved to be a big obstacle to mango production in recent years. In 2007, a Member States of the Economic Community of West African States-commissioned study on the extent of the damage inflicted on fruit production by fruit flies, conducted by the consultancy firm Italtrend, estimated losses due to *B. invadens* at 20-60% in the Niayes, 50-75% in Casamance, and 85%-100% in the Saloum region of Senegal (Italtrend, 2007).

Different types of orchards are found in Senegal depending on the region where mango is cultivated and the owners or operators of the fields. Orchards can be classified in four different groups: industrial, semi-industrial, controlled, and village level. Industrial and semi-industrial plantations have a high planting density (400 trees per hectare on average), are well maintained and use irrigation systems. Yields can reach 30 Mg ha^{-1}. Plantations over 50 ha in extent are usually exploited for the export trade. The European market is the prime destination of Senegalese mangoes. Varieties in these types of orchards are the ones primarily sold in the European market (*e.g*., 'Kent,' 'Keitt,' 'Valencia,' 'Tommy Atkins,' 'Palmer,' 'Zill' and 'Haden'). In recent years, increasingly large areas have been planted to cvs. 'Kent' and 'Keitt' for exports as well as the national market (Rey *et al.*, 2007). The additional care needed to produce crops of good quality that are fit for export leads to higher production costs and higher prices in the urban markets.

Controlled orchards are improved traditional orchards. The traditional and local varieties are grafted or enhanced with the introduction of new cultivars, mostly 'Kent' and 'Keitt.' They are also well maintained but not always irrigated. They are of larger in extent than the industrial and semi-industrial orchards described above. They cover several thousands of hectares and supply the various cities in Senegal.

Orchards at the village level represent the greatest acreage and are mainly found in the south of the country. These are not maintained and produce delicious but fibrous mangoes of local varieties. The ‘Mango’ also called ‘Sierra Léonaise’, the ‘Balante’, the ‘Dioroul’, the ‘Bouko Diekhal’ are, among others, the local varieties found throughout the country. The production from these farms is mainly consumed locally in villages and in nearby towns.

4.1.2 Mango Harvesting and Transport

In developing countries, the most common causes of postharvest losses of mature vegetables and fruits, including mangoes, is rough handling causing bruises (Kitinoja and Kader, 2002). In Senegal, the conditions under which mangoes are harvested depend heavily on the type of mango orchards being harvested, the mango cultivars and the target consumer. Different practices are carried out for produce destined to the local, urban or export markets. Appropriate handling of harvested fruits from the field to the customer is a major challenge in the Senegalese context. The quality standard needed for the export as well as the local market is heavily dependent on proper harvesting practices and adequate transportation of harvested fruits.

Production intended for village level consumption does not follow a specific standard for harvest and whenever possible are immediately sold, near the field or in small village markets. Harvest is conducted primarily by the owners. The fruits are collected from the trees and placed in a basket or polystyrene bag with no particular care. The transport of mango from the field to the markets in this context is done by donkey-drawn and horse-drawn carts, or vans and trucks depending on the quantity to carry and the financial means of the farmers or owner of the crops. The poor transport conditions leads to post harvest losses due to mechanical damage, which, in turn, result in the low economic value of the harvest. Figure 3 illustrates the harvest of mangoes in some orchards in Senegal. Nevertheless, increasing demand for quality fruits in urban centers, mainly in Dakar, has lead to rising standards in harvesting practices in orchards producing mangoes destined to city markets. Even greater care is taken when mangoes from industrial, semi-industrial or controlled orchards are collected for export (Ternoy *et al.*, 2006).

Figure 3 – Left: Woman preparing baskets filled with harvested mangoes Right: Men loading a van with freshly harvested mangoes (Still from USAID Video: 'Tout est à Terre')

Practices are directly in line with the indented end-customer. International standards for mango that can be exported have dictated a post-harvest approach adopted by the biggest producers and traders in the industry. Cultivars selected for the international market, mostly 'Kent' and 'Keitt,' are harvested following strict procedures in order to assure the highest possible quality of the product. Harvesters are trained and fruits are sorted at the packing stations according to their size, physical conditions and degree of maturity, as well as other physiological factors, in order to meet the requirements of the European and other markets where the Senegalese mango is exported. In the Niayes and Thies regions which produce 70% of the mangoes exported from Senegal, harvesting requires on average 20 people per hectare and great care is taken in the fields to avoid collecting fruits that will be later discarded as unfit for export (Ternoy *et al.*, 2006). Fruit maturity, disease, coloration, mechanical damage and other similar factors are all taken into account right in the field during harvesting. Transport of mangoes that will be exported are well taken care of during the supply chain from the field to the sorting and packing station. Mangoes are usually carried in plastic crates and corrugated fiberboard boxes loaded in vans or trucks. Mechanical damages of fruits still occur due to mishandling of boxes, crates and overloading in trucks, as well as poor road conditions and traffic congestion. Other factors creating post harvest losses by fruit injury is the remoteness and lack of roads in certain production areas like Tambacounda and Casamance (Ternoy *et al.*, 2006). Fruits that do not meet the quality standards for export are sold in the local market.

An added difficulty in the case of Senegal`s mango production is the geographic location of Casamance, a soil-rich region producing large quantities of mango but partially disconnected from the rest of the country by the nation of Gambia. The long transit period, the cost of transport and frequently cumbersome procedures needed to bring the produce from Casamance in the South, through Gambia to Dakar is a major obstacle. Dakar, the capital city of Senegal, is the main consumption and distribution hub for fruits and vegetables. One inhabitant in of four in Senegal lives in Dakar and the international port and airport assure a constant flow of goods to and from countries around the world. Figure 4 shows the path of mangoes shipped from the field to the first packing or sorting station or directly to the markets.

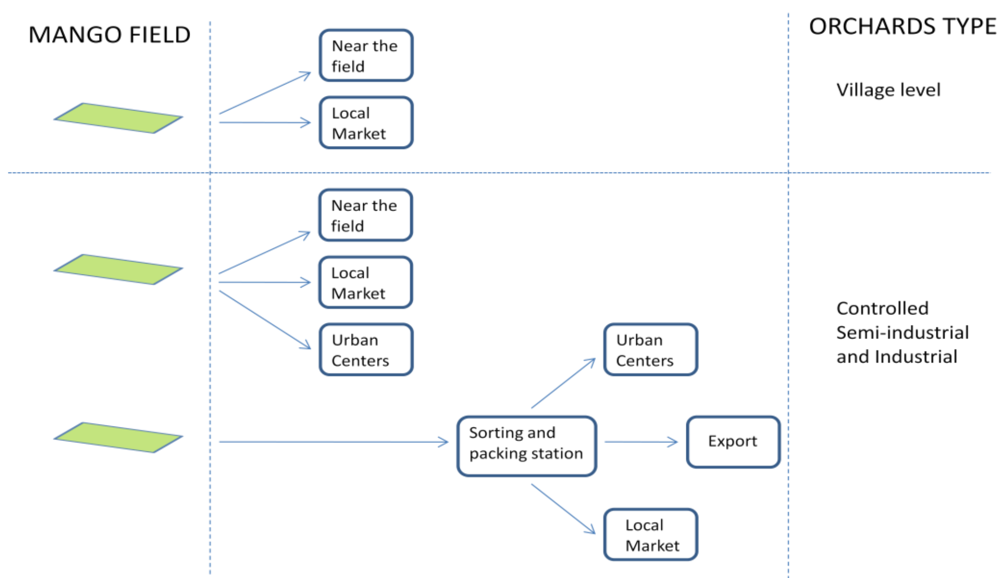

Figure 4 - Path of transport for mango harvested in Senegal from the field to the first distribution point

4.1.3 Organization of the Mango industry

The Mango industry in Senegal is composed of many different sub-sectors. These are the mango producers, the plant producers, the local traders, the processors, the exporters, the association of producers and finally the institutions supporting the mango sector.

There are many mango producers in Senegal. Up to 5000 producers were in the list of traders in 2006 and many more are expected to be producing mangoes today. Along with the four main producing areas (Dakar, Thies, Kolda and Ziguinchor), orchards can now be found in various places in Senegal due to the commercial potential of mango and the recent support from the government for this particular crop.

The mango seedling (plant) producers have built their trade on the need expressed by producers. From a secondary activity geared towards obtaining mango trees for their own future consumption, plant producers have turned to producing dwarf varieties of mango as the advantage became more and more obvious. This has been sustained by various government and NGO (Non-Governmental Organizations) support programs. The training provided by the programs has resulted in a number of nurseries being developed by well-trained technicians. It is therefore possible to have quality plants without difficulty and grafting is also well mastered by many plant producers.

Mangoes are collected by traders and sold in urban centers or in nearby markets. These traders are fruit wholesalers mainly from Guinea. Also some women buy directly from farmers and later sell their produce in nearby markets along city roads. More and more Senegalese are now entering the trade and negotiate various terms with producers. Also, there are a number of harvesters who are also traders. These brokers harvest mainly for the export market and follow specific guidelines required by the future exporters. Their produce is sent to the sorting and packaging stations in preparation for shipment abroad.

A limited number of small food processing businesses exist in the industry. They are mainly women's groups helped by NGOs and some private individuals. Drying of mangoes is the most common processing practice carried out here. Other avenues are being explored to process the mango into juices or marmalade, but most of these efforts are still in their early stages.

A growing numbers of producers and producers' associations are now turning to the export market. Two main associations are present in Senegal : the Organisation Nationale des Producteurs Exportateurs de Fruits et Légumes du Sénégal (ONAPES) and Sénégalaise des Exportations des Produits Agricoles et Services (SEPAS). Each of the organizations is composed of a numbers of producers. ONAPES has six member organizations while SEPAS is composed of 15 different organizations. Both associations strive to increase export revenues of their members by providing support at different levels. Training of producers and support for logistics by air or by sea are among the help provided by the groups.

Important efforts are being made to meet the quality requirements of the European market that represent the main importers of mangoes from Senegal. The Netherlands, Belgium, France and the UK are among the biggest buyers. The proximity by air and sea to Europe is an interesting parameter to be used by the Senegalese.

A number of institutions are also supporting the mango industry by carrying on research or making the necessary changes and adjustments in order to promote an increase in the national production both for the local and/or international markets. Some of these institutions are:

- Centre de Coopération International en Recherche Agronomique pour le Développement (CIRAD). CIRAD is a French institute that promotes agricultural research for development. The institute assists in the introduction and development on new mango cultivars in partnership with local researchers and producers.

- 'La Station Fruitière de Recherche et de Vulgarisation' in Mboro helps in promoting new varieties and provides needed support to farmers.

- The ‘Programme de Promotion des Exportations Agricoles’ (PPEA) is a World Bank project that helped in the construction of a Feltiplex. The Feltiplex is a group of four refrigerated warehouses specifically designed for producers wanting to export and are located near production zones in Noflaye, about 30 km from the capital, Dakar. The PPEA has also enabled the construction of a similar facility at Leopold Sédar Senghor airport in Dakar.

- The ‘Agence Sénégalaise de Promotion des Exportations’ (ASEPEX) created in 2005 by the Senegalese Ministry of Commerce also promotes the export of mangoes, among other products, by providing insight on opportunities and technical and financial assistance.

- The ‘Programme de Développement de Marchés Agricoles du Sénégal’ (PDMAS) is a follow up to the PPEA with a more focused and strategic approach to help boost production and export of agricultural products regionally and internationally.

4.2 Luffa

4.2.1 Luffa Gourd

Luffa (*L. aegyptiaca* Mill), commonly known as loofa or luffa sponge, is a member of the family Cucurbitaceae. The number of species in the genus Luffa varies from five to seven. Only the two species *L. aegyptiaca* and *L. acutangula* (L.) Roxb are domesticated (Bal *et al.*, 2004b).

The luffa plant is not cultivated in Senegal. It grows naturally as a wild plant without particular care and adapts to different soil types. No studies or papers on luffa sponge production in Senegal were found. Nevertheless, various articles on luffa sponge production, growing habits, intercropping, use and applications have been found for studies done in Nigeria, India, Pakistan, Uganda, Turkey and even the United States (Davis, 1994; Demir *et al.*, 2008; Okusanya, 1983a; Chaturvedi and Yadav, 1983; Kamatenesi-Mugisha *et al.*, 2007).

Luffa plant is an annual climber of 6 m or more, which grows naturally in all kind of vegetation and is also cultivated in different parts of the world. It is found naturally in tropical countries where rainfall is high enough but not overly abundant. The gourd when ripe has a fiber like vascular system that creates a vegetable sponge. The sponge is commercialized in countries like Japan, Malaysia, India, and China and is much appreciated as a skin exfoliating agent in many parts of the world. It is often used to make hats, shoes, and various hotels amenities. Although no standards exist for luffa sponge, commercial grade luffa used in the skin care industry tends to be uniform in size, light in color, free from seeds and long enough to obtain several pieces of sponge of 10 cm or more from each specimen.

According to Porterfield (1955), one of the first researchers to have conducted studies on luffa, and widely quoted in the literature, "the initial justification for the culture of sponge gourds on a commercial scale is based on the particular fitness of their skeletal network for many practical uses, and the special emphasis on their increased production is due to their successful employment as filters in marine steam engines and also in diesel engines" (Porterfield, 1955). Figure 5 shows a female Japanese-American WW II internee at the Rohwer War Relocation Center (Rohwer, Arkansas), standing on barracks porch steps holding a long luffa fruit hanging from a vine overhead. Substantial growth of flowering vine covers the roof with eight luffa, each several feet long (Museum, 1942).

Figure 5 - Female Japanese-American WW II internee at the Rohwer War Relocation Center (Rohwer, Arkansas). Picture from the Gift of the Walter Muramoto Family, Japanese American National Museum
(97.292.6CG)

4.2.2 Luffa Production

Luffa is a sub-tropical plant, which requires warm summer temperatures and a long frost-free growing season when grown in temperate regions. It is an annual climbing plant with tendrils. Luffa plants' growth habits are similar to those of cucumbers *(Cucumis sativus* L.). Yield increases when the plant is trained on a vertical trellis or allowed to climb. This avoids fruits being in contact with the ground and prevents rotting and the distortion of fruits. Figure 6 shows luffa vines on supports that produce luffa fruits hanging from the vine.

Figure 6 - Luffa production in Paraguay (with permission of Elza Zaldivar, Rolex Awards Laureate in 2008)

Soil, climate, frost, disease and insects are all factors that can affect the yield of a luffa plant. In good conditions, a plant can produce 25 fruits after a growing season of six months. Attempts have been made to produce luffa sponge on a commercial scale in different part of the world with various levels of success. Back in the early 1900's an attempt to commercially produce luffa sponge in the island of Java yielded disappointing results. Out of an estimated 80,000 luffa fruits, only 3,000 were harvested (Howes, 1931). The failure was attributed to the damp tropical climate that was not suitable for producing luffa fruits on a large scale. Similar experiments in India were not convincing compared to results obtained in Japan (Porterfield, 1955).

Propagation of luffa plant is by seed. Luffa seeds resemble those of watermelon (Figure 7) and come from the holes in the core of the luffa fruit. The average number of seeds produced by a luffa fruit is not known but it has been observed to vary from 30 to over 250 per fruit (Ogunsina *et al.*, 2010). Variation in fruit length seems to affect the number of seeds the fruit will contain. Warm temperatures improve germination. A high seeding density, followed by thinning out of excess seedlings, or germination in trays under controlled conditions before transplantation into the field can help overcome poor luffa seeds germination rates. Luffa plants need a well-drained soil with moderately high organic content and pH values between 5.5 to 6.5 to thrive. Field and laboratory studies on the ecology of luffa plants have shown that it grows best in nonsaline soils with high humus, nutrient, and soil moisture contents, and that nitrogen is a major element limiting its growth (Okusanya, 1983c). Extensive germination and growth experiments have also demonstrated that high temperatures and high light intensity are required for good growth of luffa plants, with the ideal temperatures ranging between 21°C and 31°C (Okusanya, 1978) . Consequently the growth of luffa plant is likely to be relatively poor in shaded areas and in uncleared bush when grown in the wild.

Figure 7- Luffa seeds (photo by author)

In cooler climates, plants need to be started indoors in order allow full maturity of the fruit before the frost starts. For instance in Japan seeds are sown between the months of March and April and transplanted in ridges three to four feet apart. "The explanation of the apparent paradox that the best luffa fruits, which normally would be expected from naturalized tropical plants, are obtained from temperate Japan is thought to be connected possibly not only with the volcanic nature of the soil but also with proper attention to fruit pruning, careful processing and strict observation of soil needs" (Porterfield, 1955).

Luffa fruit has to be harvested at the right stage of maturity. This is indicated by the fruits turning brown and also becoming much lighter to the touch than the unripe ones. To keep the sponge as white as possible it is important not to harvest the fruits too late, to avoid the staining of the brown skin on the sponge. Some producers bleach their luffa sponge after harvest with a 10% bleach solution, while others will pick them at an earlier stage to avoid the use of chemicals. The main commercial production countries and regions are China, Korea, India, Japan and Central America(Bal *et al.*, 2004b). Luffa plant is also grown in home gardens out of interest or for domestic use by an increasing number of people in various countries. Luffa sponge is being commercially produced by only a small number of African countries, mainly Egypt, Tunisia and South Africa. Despite the adequate weather for the crop, its presence in numerous countries in sub-Saharan Africa is only in the wild.

4.2.3 Luffa fiber characteristics

As early as the 1940s, Sinnott and Bloch (1943) had analyzed the development and histology of the fibrous networks of different types of *L. aegyptiaca*. They found that the strands began to differentiate when the ovary primordium was about one millimeter wide, and new ones continue to form until cell division ceased. Most strands were modified vascular bundles which became fibers. They also reported that fibers length ranged from very short to about 3800 μm, and were, on average, 1500-2000 μm long. Many fibers had irregular shapes and were difficult to separate by maceration. They have noticed that different races of luffa fruits differed considerably in the development of their fibrous net, both in terms of the diameter and spacing of their strands, and in the length and character of their fibers. More recent studies demonstrated that almost all the strand cells show lignin deposition on the middle lamella, attributable to the fact that both the middle lamella and primary cell wall are rich in matrix polymers providing plenty of holes in which lignin easily penetrates and incrusts the wall (Boudet *et al.*, 1995; Onelli *et al.*, 2001). The difference in the quantity of lignin found in luffa fibres varies based on different metabolic factors including light intensity and photoperiod. Luffa seedlings grown under appropriate light conditions later containing a greater amount of lignin in their fruit. Lignin reinforces and waterproofs the walls of specialized cells and plays a fundamental role in their mechanical support (Boudet *et al.*, 1995). The highly complex macroscopic architectural template of luffa sponge is broadly composed of 60% cellulose, 30% hemicelluloses, and 10% lignin (Mazali and Alves, 2005). Scanning

Electron Microscopy (SEM) analysis revealed that the luffa fruit microspongy fibrous network offers fast and good accessibility to fluids. The absorbent capacity of the fibers for deionized water was found to be 13.6 g g^{-1} (Bal et al. 2004). This specific characteristic of luffa sponge suggests its efficiency in absorbing liquids. A close-up picture of luffa sponge fiber is shown in Figure 8.

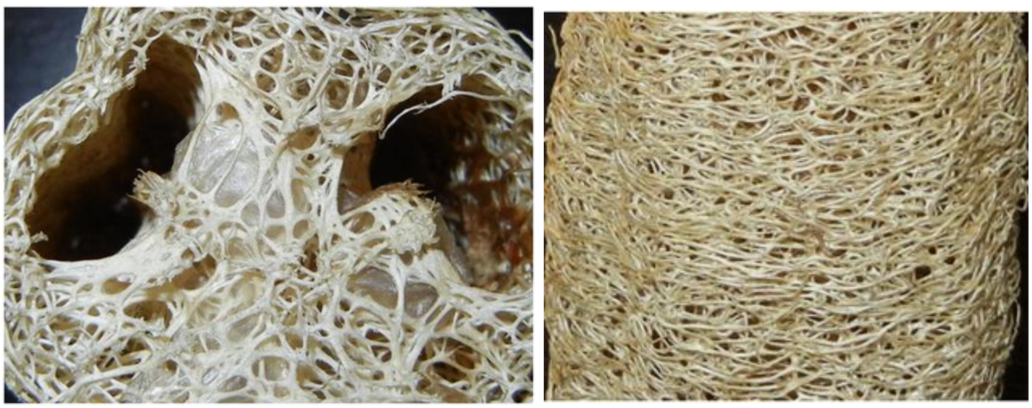

Figure 8 - Close-up on *L. aegyptiaca* endocarp and fibrous network (photo by author)

4.2.4 Luffa applications

Luffa sponge is well known today in the cosmetics and skin care industry. On an artisanal level it is used to make hats, shoes, gloves and a variety of hotel amenities. It is sold in various forms, including, but not limited to, a natural sponge or soap for exfoliation of the skin, a body or facial pad, &c. In the early 1900`s in the United Kingdom the demand for luffa sponge was greatest in mining and industrial areas, where its body cleansing powers were well appreciated by the workers and where it was used as an oil-filtering material (Howes, 1931).

In recent years, research into the possible uses of luffa sponge has offered glimpses of different potential yet-to-be-developed applications for the sponge as well as the seeds in areas such as agriculture, medicine, environmental engineering, and biotechnology (Oboh and Aluyor, 2009). Luffa sponge can be used by industry for many purposes including packaging, insulating, or filling materials. More applications of luffa sponge fiber exist.

Altinisik *et al.* (2010) found that *L. aegyptiaca* can be used as an efficient adsorbent for the removal of malachite green from aqueous solution. Similarly, Demir *et al.* (2008) demonstrated that luffa sponge could be used as an adsorbent for removing methylene blue from aqueous solution since it was renewable and sustainable and shows higher adsorption capacity and BET (Brunauer, Emmett, Teller) surface area than other cellulose wastes such as orange and banana peel. Moreover, the dye adsorption capacity of luffa sponge fibers was found to be closer to the dye adsorption capacity of activated carbon than that of inorganic (flyash, Pyrophyllite and Kaolin) and cellulosic-based adsorbents.

The feasibility of using *L. aegyptiaca* sponge as a carrier for cell immobilization was investigated by Ogbonna *et al.* (1994), who found luffa sponge to be an excellent carrier for immobilization of flocculating cells. Luffa's low density and very high porosity and specific pore volume in comparison with other carriers used for immobilization by cell adhesion contributes to this attribute. Furthermore, luffa sponge was found to be stable over the whole range of pH and could be autoclaved many times without any noticeable change in its shape, structure and texture. The immobilized cells grew within the void volume, reaching a high cell concentration of over 4.4 g-cells/g-sponge.

Boynard and D'Almeida (1999) reported on the water absorption behaviour of luffa sponge polyester composites in a study of the engineering applications of natural fibres in resin matrix composite materials. They found that luffa sponge could be used to advantage in resin matrix composite materials, if an inorganic barrier layer such as glass fibres, was used as the external layer, to avoid a close contact between the fibre and the external environment, and avoid the water absorption behaviour of the luffa-polyester composite. In a separate study (Boynard and D'Almeida, 2000), they suggested that luffa sponge has some potential practical advantages over some of the more usual natural fibres used as reinforcement in composite materials due both to the reduction in fibre preparation as luffa sponge occurs naturally as a mat, and the change in the failure mode of composites when luffa is introduced.

Chen and Lin (2005) used *L. aegyptiaca* as a three-dimensional scaffold for the culture of rat hepatocytes. They found that hepatocytes attached well to the surface of luffa fibres and that their metabolic activities were comparable to or better than those in monolayer culture on tissue culture polystyrene control surfaces. Previous experimental results suggested that luffa sponge is a suitable scaffold for high-density culture of human hepatocyte cell lines and that the immobilized cells could express high levels of liver-specific functions(Chen *et al.*, 2003).

Studies conducted in Japan in the mid 90's and early 2000's by Ogbonna *et al.* (1994, 2001) showed that luffa sponge is a very good carrier for immobilization of flocculating cells. The physical properties of luffa sponge made it particularly good for immobilization of aerobic microorganisms and due to its high porosity (79-93%) and high specific pore volume (21-29 cm^3 g^{-1}), luffa sponge facilitated mass transfer within the bed. They also showed that efficient large scale ethanol production from sugar beet juice was possible by using luffa sponge for cell immobilization in a bioreactor containing the luffa sponge bed. They further noted that since luffa sponge was economical and that the cell immobilization was achieved by simply adding the cell suspension to the bioreactor, the economic viability of the system depended only on the cost of the substrate. In the Japanese context where the study was carried out, sugar beet juice costs prohibited the production of ethanol, but the authors concluded that using luffa sponge for cell immobilization in a bioreactor was well-suited for the production of ethanol from low cost substrates such as molasses.

The evaporative cooling capacity of luffa sponge has also been studied and compared to that of date palm fibres (stem), and jute. Work conducted by Al-Saliman (2002) showed that the average cooling efficiency for luffa fibres was 55.1% compared to 49.9% for a widely used commercial pad, and that cooling efficiency degradation indicated that luffa sponge has an overall advantage over other fibres (palm and jute). Luffa also showed the greatest resistance to bio-degradation and especially to the proliferation of moulds.

In the context of the morphosynthesis, the chemical construction and patterning of inorganic materials with unusual and complex architecture, the microspongy fibrous system of luffa sponge offers good accessibility to fluid and high retention capacity for aqueous solutions. High fidelity calcium carbonate and hydroxyapatite replicas of the fibrous network were achieved by Mazali and Alves (2005) utilizing a facile synthetic route, suggesting the possibility of using biodiversity in generating new materials.

Onelli *et al.(2001)* studied the arrangement and composition of luffa sponge fibres in order to explain their functional properties. Their results suggested that the use of mature luffa sponge in packing devices was justified because of the organisation of the fibres and localisation of wall components in each fibre strand. They also found that the low biodegradability linked to the presence of lignin allowed recycling and repeated use of the material. Some interesting physical properties of the luffa sponge were flexibility, strength, elasticity, tensegrity and shape memory.

A recent study conducted in Nigeria, showed *L. aegyptiaca* seeds to contain protein and fat, the fat being largely made up of linoleic and stearic acids (Ogunsina *et al.*, 2010). The oil was found to be stable at ambient temperatures and when refrigerated. The study provided essential baseline information on handling and processing luffa seeds and prompted the development of value added and protein-fortified food products for humans or livestock.

In 2008, Elsa Zaldívar an innovative social activist from Paraguay won a Rolex Award for her ecological initiative to combine luffa sponge waste material from craft-making and plastic waste to make lightweight panels for low-cost housing, in a bid to tackle the acute housing problem in Paraguay. This was an attempt to replace wood, an overly exploited resource in Paraguay, with a new and versatile luffa composite material.

CHAPTER V

DESIGN CONSIDERATIONS FOR A LUFFA SPONGE SHIPPING BOX

Proper packaging and transport of fruits and vegetable is essential to maintaining product quality. As pointed out by (McGregor, 1989), 'it makes no sense to ship high quality, high value, perishable products in poor quality packaging which leads to damage, decay, low prices, or outright rejection from the buyer.' In line with maintaining the quality of harvested mangoes from the field to the distribution centre and ultimately to the customer, a number of considerations were taken into account in the design of the luffa sponge box. These factors included the optimal protection of the fruits throughout the transport chain, as well as addressing economic, environmental and socials objectives in the context of the box to be adopted in Senegal. The focus was towards designing a bulk package to ship the fruits after they were harvested for processors and wholesale buyers rather than a smaller box for consumers (Boyette *et al.*, 1996). In addition of being lightweight, hygienic and durable, the following considerations guided the design process.

5.1. Low cost

Luffa plant grows naturally in Senegal and is available in rural and peri-urban areas where mango is produced. It is therefore expected to be available at little to no cost to farmers. Producers would have the option to pick them up in the bushes or to grow them. For the latter option luffa plants could be used as green fences around production fields or cultivated in parts of the field.

5.2 Fruit respiration

The fibrous texture of luffa sponge and the unique natural holes found in the core of the fruit allows for an adequate aeration and respiration of mangoes without additional perforation requirement.

5.3 Shock absorbent

Mango boxes will have to withstand rough handling during loading and unloading, compression from the overhead weight of other containers, impact and vibration during transport as well as high humidity (McGregor, 1989). Luffa sponge allows the absorption of shocks hence preventing bruising, which is an important characteristic in order to maintain fruit quality. Due to poor road conditions and trucks carrying mangoes from field to packing and distribution centers often being overloaded it is paramount to have adequate padding for the mangoes. Luffa sponge is therefore a material of importance in its ability to absorb shocks, thus helping to protect the mangoes from mechanical damage.

Double-faced corrugated fiberboard is the predominant form used for produce containers and heavy-duty shipping containers, such as corrugated bulk bins that are required to have high stacking strength. These may have double or even triple-wall construction (Boyette *et al.*, 1996). The natural structure of luffa sponge allows the making of boxes that would give similar padding properties to corrugated fiberboard and provide many different configurations. Figure 9 and Figure **10** show the configuration of corrugated fiberboard and the inner core and external side of luffa sponge respectively.

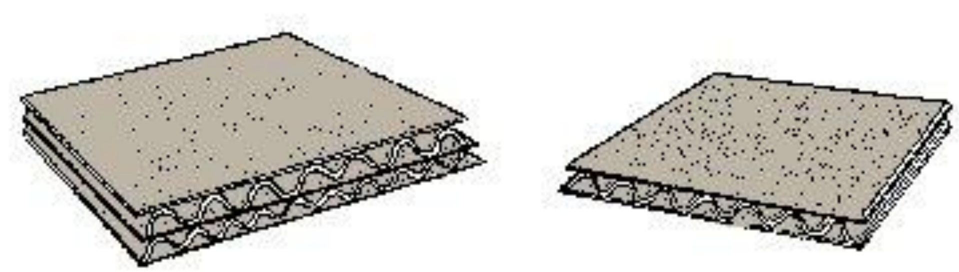

Figure 9 – Left: Configurations of triple-wall corrugated fiberboard. Right: Configurations of double-wall corrugated fiberboard (Boyette et al., 1996)

Figure 10 – Left: Inner core of *L. aegyptiaca* and. Right: External side of luffa *L. aegyptiaca* (photo by author)

5.4 Minimal transformation and job creation

Minimal transformation of the material used to make the box was also a concern to keep costs low and increase the chances of adoption of the luffa sponge box. Inexpensive labor is plentiful in Senegal and designing a box that can be fabricated without special skills would create a new activity in the sector of mango production.

5.5 Ability of the box to withstand moisture

The box's ability to withstand moisture was considered in the design of the luffa sponge box, as it would be exposed to rain during the mango harvesting season as the harvest of mango in Senegal takes place over the dry and 'wet' or humid season of April to November (Diedhiou *et al.*, 2007). The design of the box needed to address this factor and the appropriateness of such a box in wet or moist conditions must be assessed.

5.6 Transport and staking

It was assumed that luffa sponge boxes would not only serve for transportation of mangoes but also for storage in warehouses. Therefore the ability of the boxes to be stacked without fruit damage resulting was taken into account. This aspect is important as luffa is a 'sponge' that is compressible under load.

5.7 Adoption by stakeholders

Adoption of luffa sponge boxes by mango supply chain participants (farmers, traders, exporters, wholesalers, distribution centre operators, retailers and transporters) is central to the success of the design. Luffa sponge is known and used in Senegal but only as a scrubbing agent. The acceptance by the different stakeholders is assumed to be possible with little hesitation from the group. The immediate results in loss reduction and increased revenues are reasons that should allow acceptance of the luffa sponge boxes.

5.8 Recyclability and Biodegradability

The life of the luffa sponge box in relation to its use was also considered. Its reusability, durability and possibility to be recycled for other uses were considered in line with environmental and waste disposal issues. The design would also consider a full life-cycle for the box.

5.9 Ease of repair

A modular approach in building the box would allow the possibility of easy repair when damaged. Damage to the box would come from damage to a number of luffa units in the box, allowing their replacement without too much difficulty. This would promote an optimal life to the boxes while reinforcing the solidity by the addition of new luffa pieces.

5.10 Pre-compression of luffa sponge

It was decided to use the luffa sponges in their cylindrical shape as this would increase the stability of the box (Amino *et al.*, 1971). The reduction of the surface-to-volume ratio of the sponge was achieved by simple pre-compression of specimens used to make the box. The ‘flattened’ cylindrical shape would reduce the surface-to-volume ratio while keeping the padding and shock-absorbent properties of luffa. Unlike pre-compressed luffa, uncompressed luffa would occupy more space thus reducing volume needed for fruits (Figure 11).

Figure 11 – Left: High surface-to-volume. Right: uncompressed versus compressed luffa (photo by author)

5.11 A single layered fruit box

A single layered fruit box would be designed with luffa sponges for mango transport from the field to the market or packing station. This approach is already used in the mango industry which avoids direct mechanical damage to fruits from staking (Kitinoja and Kader, 2002). The mango cultivars to be used for the design of the box are: Kent, Keitt, and Haden. It would also be possible to adapt the design to other mango cultivars by changing the box`s dimensions as required. The initial concept for the luffa sponge box is shown in Figure 12.

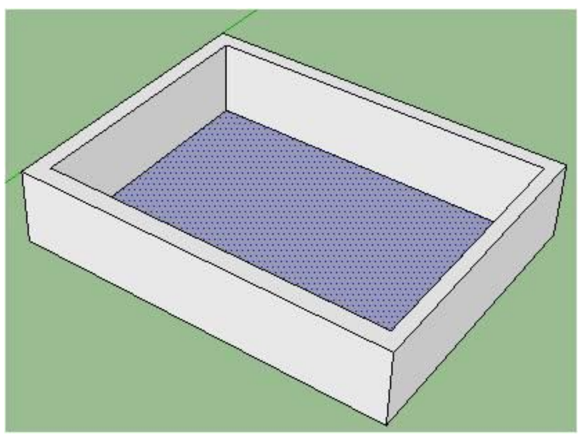

Figure 12 - Single layer box

5.12 International standards ISO 3394 dimensions for the box

Even though the luffa box would be semi-rigid rather than rigid, ISO 3394 seemed the most appropriate standard to follow in the absence of standards for boxes made of luffa sponges. ISO 3394 is the ISO standard for 'Dimensions of rigid rectangular packages – Transport packages'. It sets forth a series of dimensions for rigid rectangular packages based on the standard dimension of 600 mm × 400 mm (23.62 in ×15.75 in).

This standard seemed to have the best fit the needs of the design and was therefore adopted. The basic module dimension (600 mm × 400 mm), rather than a derived dimension of smaller size (*i.e.*, 300 mm × 400 mm) was chosen, considering the optimal space needed to carry mangoes in bulk packages. The use of such a standard would also allow easy stacking and interlocking in warehouses or on standard shipment pallets.

5.13 Number of mangoes per box

The average dimensions and weight of the mango cultivars for which the luffa box was designed are given in Table 3.

Table 3 - Mango cultivar linear dimensions (Source: www.cglrc.cgiar.org)

Mango Cultivar	Average Mass (g)	Average Length (mm)	Average Width (mm)
Haden	431	100	80
Keitt	456	117	92
Kent	545	124	97

Mango dimensions and weight justified the use of ISO 3394 as a guideline in order to optimize the holding capacity of the box, while keeping the filled mango box at a reasonable weight. The choice of this size is also justified by the fact that very wide and heavier boxes encourage rougher handling, product damage and container failure (McGregor, 1989). The luffa box would hold 20 to 24 mangoes of any given cultivar considered in this study, either vertically or horizontally.

5.14 Compression Force (in N) for testing stackability

Mango cannot carry much vertical load without some damage. Therefore, it is vital that the box protects the fruits from crushing. The rectangular geometry of corrugated containers that is paralleled with the luffa box implies that most of the stacking strength is carried by the corners (Boyette *et al.*, 1996). In the design configuration there are no ventilation slots or holes to weaken the sides. These are not needed due to the natural aeration provided by the luffa sponge fiber.

The mean dimensions and weight of the mango cultivars gives an indication of the weight of a filled box being between 10 and 12 kg, including the empty box weight. The determination of what amount of compression force the luffa box would have to endure in the warehouse and shipping environment is important for the design process and will be investigated.

CHAPTER VI

MATERIALS AND METHODS

The material used in the water absorption and compression tests, as well as in the design the protoptype box were brought from Senegal, West Africa, to Montreal (QC, Canada) in a corrugated fiberboard box. The skin was already removed and the luffa sponges were emptied of their seeds. The specimens were 250 mm long and had a mean diameter of 45 mm. They were cylindrical and uniform in shape. The edges of each specimen were removed to allow a more uniform sample set. Six luffa sponges were cut across in half to yield 12 test samples. The samples were tagged, weighed and measured to record their exact length and diameter. All the corresponding values were documented in a personal computer using Microsoft Excel. Additional luffa sponges, used in making additional boxes, were collected in the field in Senegal in different geographic location and presented a greater variability in shape, length and diameter. Figure 13 shows a luffa sponge used in the lab.

Figure 13 - Luffa sponge used in the lab with skin already removed (photo by author)

6.1 Water absorption tests

As natural fibres readily absorb humidity (Boynard and D'Almeida, 1999), water absorption tests were conducted to reveal the kinetics of luffa sponge water absorption over a specific time period. For these experiments, six luffa samples from three sponges were used. The initial mass and final mass of the samples as well as the immersion times were recorded, and weight gain *vs.* time of immersion curves were plotted and analyzed.

6.2 Compression tests

Twelve luffa samples from six sponges were used for the compression tests. The force in Newtons (N) corresponding to a displacement in millimeter as well as the energy at break point in Joules (J) were recorded in a computer connected to the *Instron* machine. Force to displacement curves for each test were automatically plotted. Compression tests helped in determining various properties of luffa sponge. The dynamic nature of the material under compression and its core made of three elliptical holes (sometimes four and exceptionally two) running the full length of the cucurbits led to establishing best fit parameters during the analysis of the kinetics of luffa sponge under compression. Figure 14 illustrates the approach used to calculate the cross section and longitudinal areas under which a force, *F*, was applied.

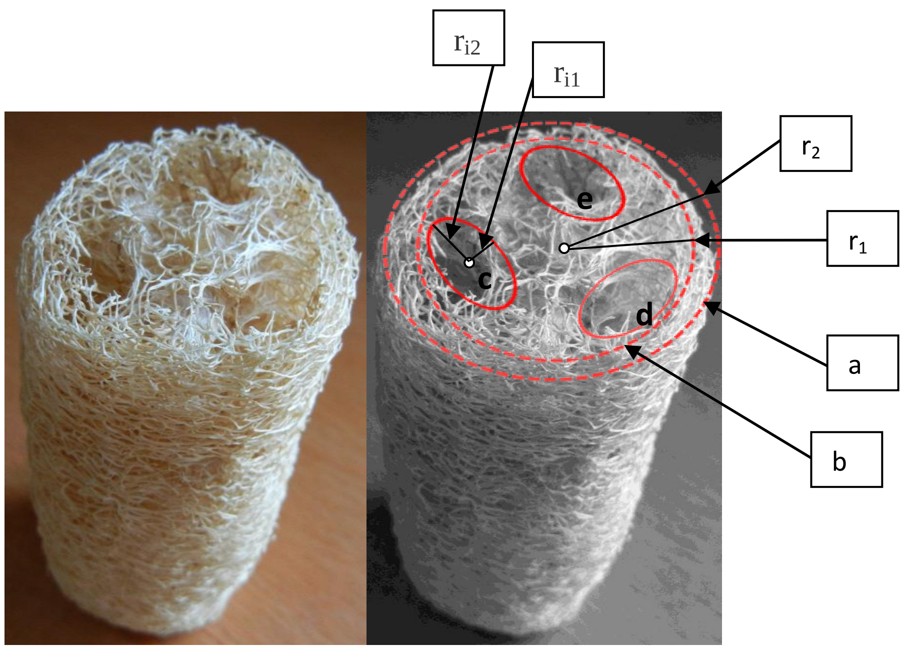

Figure 14 – Luffa sample cut from luffa sponges used in the lab for compression tests and cross section area representation (photo by author)

The area '*a*' of the cross section of a luffa sample could be calculated as follow:

$$a = \pi r_2^2 - [\pi r_{c1} r_{c2} + \pi r_{d1} r_{d2} + \pi r_{e1} r_{e2}] \quad [1]$$

where,

r_2 is the cross-sectional radius on the luffa sample, and

r_{c1} and r_{c2}, r_{d1} and r_{d2}, r_{e1} and r_{e2}, are the 2 semi-major axes of the ellipses c, d, and e (Figure 14).

Experimental data gathered during the study showed that the three elliptical holes in the core of the sample could be considered identical in size allowing eq. 1 to be rewritten as:

$$a = \pi(r_2^2 - 3r_{i1}r_{i2}) \qquad [2]$$

where,

r_{i1} and r_{i2} are the length of the 2 semi-major axes of any hole in the luffa sample.

As luffa samples in this experiment were to be used intrinsically they were no added values to subtract the area of the core ellipses in the calculation. Therefore Eq. 2 was approximated to the following formula for a circle's area equivalent to the cross-section of a sample:

$$a = \pi r^2 \qquad [3]$$

where,

r was the radius of a given luffa sample.

Consequently, the luffa samples were considered as homogeneous cylinders of volume V rather than cylindrical shells with a porous core. The mass density could then be calculated as:

$$\rho = \frac{m}{V} \qquad [4]$$

where,

m is the mass of the sample (kg), and

V is the total volume of the luffa sample (m^3).

The area a' (Figure 15), where a force F is being applied along the sample positioned horizontally, was evaluated assuming $d_1 \approx d_2$ and $L1 = L2$, resulting in:

$$a' = L \times d \quad [5]$$

where,

L is the length of the sample, and

d is its diameter.

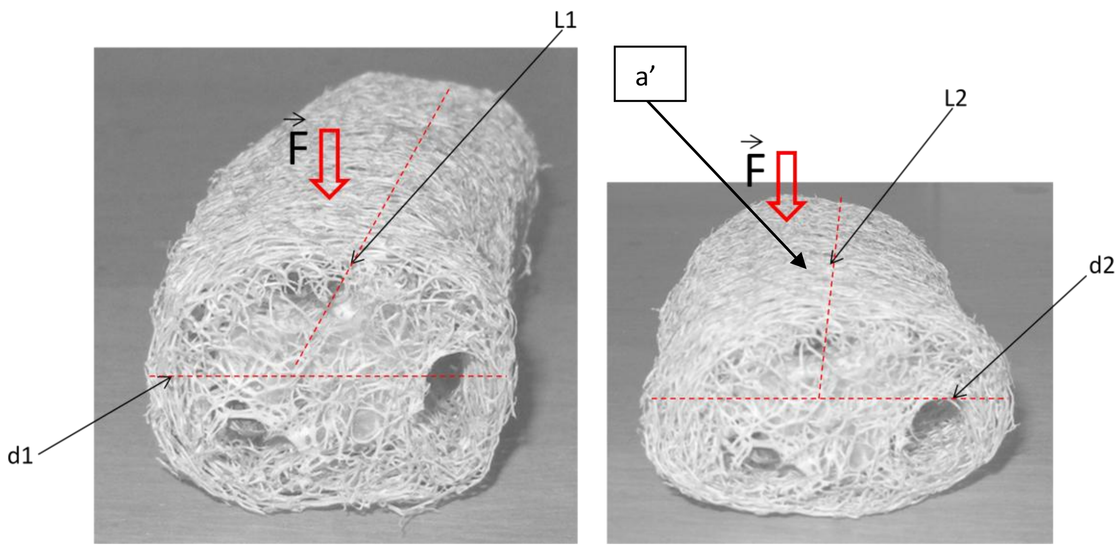

Figure 15 –Representation of horizontal surface of a luffa sponge under compression (photo by author)

6.3 Luffa sponge box design trials

The luffa sponges employed in making boxes differed in length and diameter according to their origin. The mean length and diameter of the specimens or 'modules' that constituted the boxes ranged from 182 mm and 49 mm, respectively, for those collected in Dakar, 144 mm and 47 mm for those collected in Ziguinchor, and 263 mm and 74 mm for those collected in the Fatick region. The ends of each luffa sponge were removed to generate a more uniform piece by reducing the variability in diameter that occurs towards the ends of each specimen.

The first step of the design process was to find a way to keep the luffa pieces attached to one another. Three options were explored; tying, sewing and gluing. The second step was to employ one method to make a small box. The third and final step consisted in picking the best option found for luffa sponge binding and make a bigger rectangular semi-rigid box following ISO 3394 guidelines with dimensions of 600 mm × 400 mm, and of desired height.

An attempt was made to tie the samples together by inserting binding ropes through the natural holes found in the core of the sponge. This avoided tearing the specimens thereby maintaining the integrity of the samples assembled and solidity of the fiber architecture. A second attempt using the tying method was undertaken, using the ropes to tie the samples externally to each other.

The sewing method used the natural voids of the fibrous matrix of the luffa sponge rather than the internal holes in the core. This method prevented damaging the fibers and each piece was sewn one at a time in an increasingly large pattern to form a surface to be used for each side of the box. The luffa sponges that seemed more resistant to tearing by their texture and feel were selected for the purpose.

The gluing method used luffa samples that were pre-compressed. The compression prior to gluing was aimed at reducing the volume and increasing the compactness of the luffa sponges. The reduced volume with the constant mass of the sample increased the mass density of the specimens. This process enhances the adhesion surface between luffa modules and provided the necessary strength.

6.4 Luffa sponge box compression and load testing

The completed luffa boxes, made in the laboratory using the gluing method were tested to evaluate their compressive strength. A box was considered as a collection of individual modules made by luffa sponge pieces. It was tested in its natural dry state and later in a humid state. The elastic-plastic behavior of luffa sponge was measured and the force of compression assimilated to static load. Analyses of the results were conducted in order to compare the findings with the tests carried out on single luffa sponge samples.

6.5 Equipments

A flexible stainless steel ruler, a metal saw, six beakers of different sizes, a scale, a timer and distilled water were used for the absorption tests.

An *Instron* material testing machine, Series 4500 model 4502, was used to quantify the force of compression applied on the different luffa samples as well as on the completed luffa box. A wooden board of 889 mm long, 635 mm wide and 19 mm thick was used to complement the plates of the *Instron* machine when carrying out tests on the box.

A number of materials were purchased to make the boxes. Braided polystyrene rope, fishing line, clear glue sticks, a glue gun, and 160 mm upholstery needles were purchased from a local hardware store in Montreal, QC, Canada. A polystyrene cord used for a strap was also bought from a local sewing store in Montreal. In addition two glue types were purchased in Dakar, Senegal and tested for gluing the luffa pieces together: 'Exposy Stell resin and hardener' by Eaglestar and 'Ponal' wood glue by Henkel, Dusseldorf. A pair of scissors and a lath of wood were also used as accessories to make the boxes.

A complete tool made of wood was designed and later constructed in the field in Dakar, Senegal. This was done with the purpose of reducing the time needed to complete a luffa box as well as to increase the appeal of the finished boxes. The tool was first drawn in 'Google Sketchup,' a software from Google Corporation. The draft drawing was then designed in 2D and then in 3D using CATIA V5, release 18 software from Dassault Systèmes. The instrument was later fabricated by a local carpenter in Senegal and used to make two boxes.

Mango fruits purchased in a local supermarket as well as water filled 'zip lock' plastic bags (Johnson and Sons Inc.) were used to test the holding capacity of the luffa box and simulate a box full of mangoes. A label was attached to the box's strap to mimic a finished mango box.

6.6 Experimental design and procedure

For the water absorption tests, immersion in distilled water was carried out successively for 5, 10 and 15 minutes on the same three randomly-selected samples . Three samples were immersed in water for a full 30 minutes. The initial mass of the samples was recorded and after each period of immersion the final mass was also recorded after removal of excess water. The samples were not squeezed and no specific tool or material was used to remove the excess water; only the water that could be removed by gently shaking the samples in a sink was removed.

For the compression tests, 12 samples were used. Six samples were tested in the horizontal position; three dry and three wet. The other six were tested in the vertical position; three dry and three wet. Some 21 days later, wet samples that had been left to thoroughly dry in at ambient temperatures were tested again to see the variations in compressive strength from the first set of tests. The tests consisted of placing the samples under vertical compression in the *Instron* Universal test machine, one at a time. A target displacement of 25 mm was used and the corresponding force applied and displacement were recorded in a computer connected to the *Instron*. Measurements were performed with a crosshead speed of 50 mm min^{-1} under the ambient conditions of 23°C and 50% relative humidity. Each test was repeated 5 times on each sample. The mean values and standard deviations for the five replications were calculated and used as final results for the tests.

The luffa box was put under compression using an *Instron* Universal test machine. A compression force of 500 N was applied on the box with a wooden board used as contact surface. The box was tested in its natural dry state, and then after humidification to with 25% of its initial. Compression was repeated five times with a load of 500 N, equivalent to a wooden board applying a force of 50 N on the box coupled with loading cells of 450 N. The box was later loaded with a weight similar to a full mango box of equal size, and its behavior observed. The initial height of the box was 225 mm, and it was composed of six rows of pre-compressed luffa arranged horizontally on each side. The experimental approach used in the experiments is shown in a schematic diagram (Figure 16).

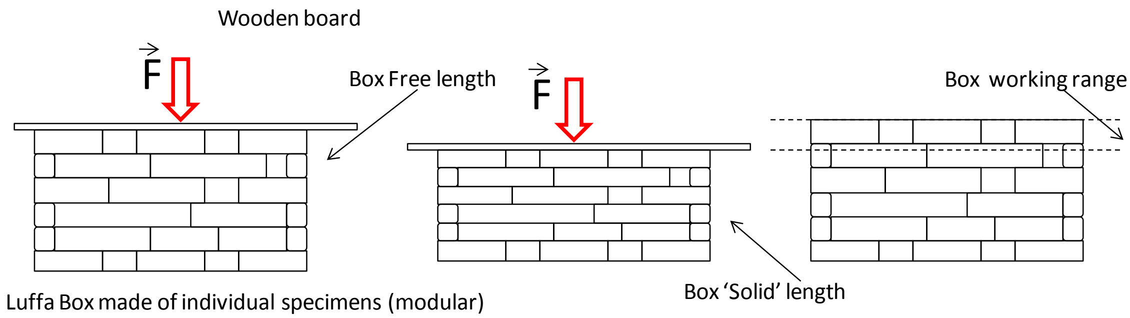

Figure 16 – Schematic diagram of the luffa sponge box kinetics under load

The previously designed and fabricated box-making tool was used to make boxes. The luffa pieces were progressively put on the 'base-maker' part of the tool and pre-compressed with the 'base-maker handle'. Glue was then added between the luffa pieces and compressed again with the tool handle to promote adhesion. The tool needed to be against a vertical surface (i.e. a wall) for increased compression strength. When the bottom part of the luffa box was completed, it was removed from the base-maker and put in the 'finisher' to build the sides. The sides of the luffa box were built by gluing pieces of luffa one in top of the other following the four edges of the box bottom pad until the desired height of the box was reached. In the experiment the sides were built 180 mm hieght. Compression was applied as the luffa sponges were being glued vertically with a simple plank of wood.

The box-making tool was inspired by the principle of a fabric-weaver. The tool comprised three parts: the 'base-maker', the 'base-maker handle' and the 'box-finisher' (Figure 17, 18). The 'base maker' and its handle are used to make the bottom or base of the luffa box, and the 'finisher' is to erect the sides. The 'base-maker' module including its handle allows the pre-compression of the luffa pieces while they are being glued to each other, thus avoiding an initial step necessitating the pre-compressing of the luffa modules. The 'box-finisher' guarantees that the sides of the box will be built straight. The dimensions of the box-making tool were as follow:

- Base-maker: 650 mm (length) × 460 mm (width) × 70 mm (height)
- Base-maker handle: 425 mm (length) × 30 mm (width) × 60 mm (height)

- Box-Finisher: 600 mm (length) × 400 mm (width) ×160 mm (height)

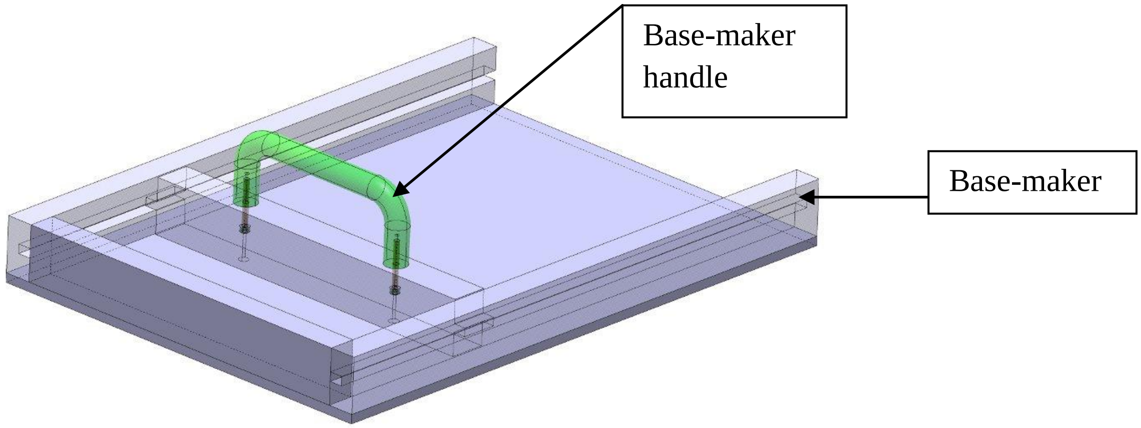

Figure 17 - ‘Base-maker and base-maker handle of luffa sponge box tool

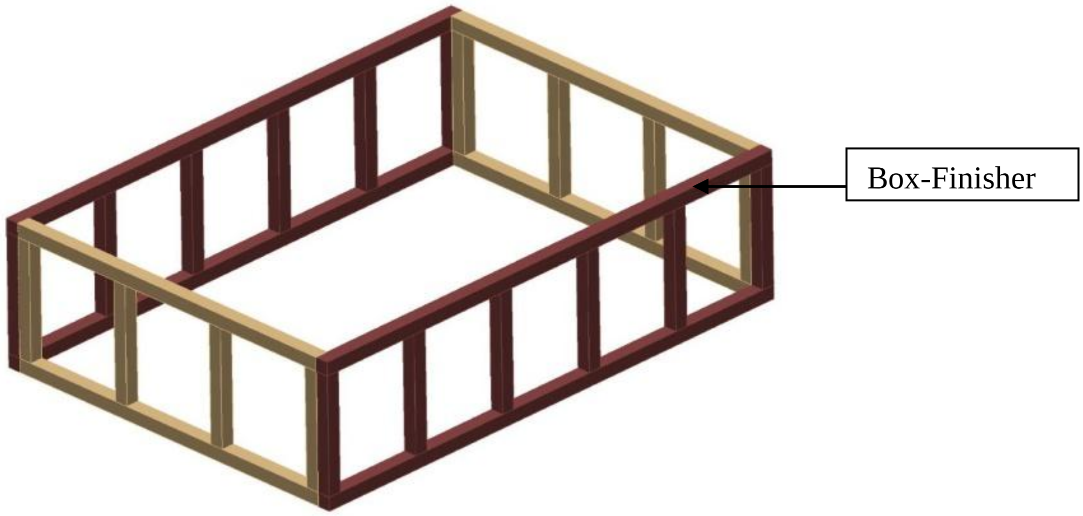

Figure 18 - ‘Box-Finisher’ of luffa sponge box tool

During the luffa box-making process a method which included gluing each luffa piece to at least three to six other luffa pieces was followed in order to provide greater bonding strength between the luffa pieces that made up the box. Figure 19 shows the pattern employed, including sides and corners, when gluing the luffa pieces together, based on design drawings elaborated during the initial stages of the research.

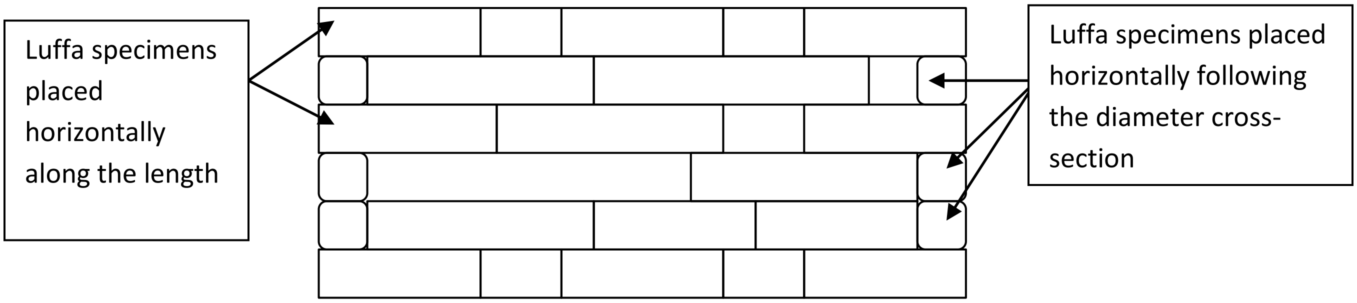

Figure 19 - Schematic diagram of a luffa box sides arrangement

The first completed box in the laboratory was tested in dry and in moist states to simulate the strain and creep of the luffa box under compression and in the field. The box previously in a dry state was sprayed with 25% of its weight (approx. 250g) in water, using an ordinary spray bottle containing tap water. After humidification the box was wrapped in a 'Fisherbrand' polypropylene biohazard autoclave bag **(**635 mm × 889 mm) and left for 24 hours before testing. The tests were carried out in an identical manner for the two states: dry and then moist. In the first step the luffa box was placed under vertical compression in order to quantify the displacement induced by a load of 500 N. A wooden board that exercised a force equivalent to 50N at the top of the box was used as a contact surface with the *Instron* machine plates. In this series of tests, five measurements were taken and the mean and standard deviation were calculated and recorded.

In a second step, the luffa box was placed under vertical compression in the *Instron* machine for close to 27 hours. The *Instron* machine plates were adjusted repeatedly for each test in order to be continually in contact with the box. The corresponding displacement was recorded at various intervals with the computer connected to the *Instron* machine. All measurements were performed with a cross head speed of 50 mm min^{-1} under the ambient conditions of 23°C and 50% relative humidity.

6.6 Data Analysis

Instron Series IX Automated Materials Tester Version 8.25.00, Excel version 2007 from Microsoft Corporation and SAS version 9.2 from SAS Institute Inc. software packages were used to analyze the collected data.

CHAPTER VII

RESULTS AND DISCUSSION

7.1 Results

7.1.1 Water absorption

After 5 minutes of water absorption the luffa samples gained between 190 to about 230% of their original weight. After the initial stage of absorption there was a negligible mass changes between 5 min immersion and a 10 or 15 min immersion.. Figure 20 shows the relatively little weight gain following the 5 minutes immersion stage.

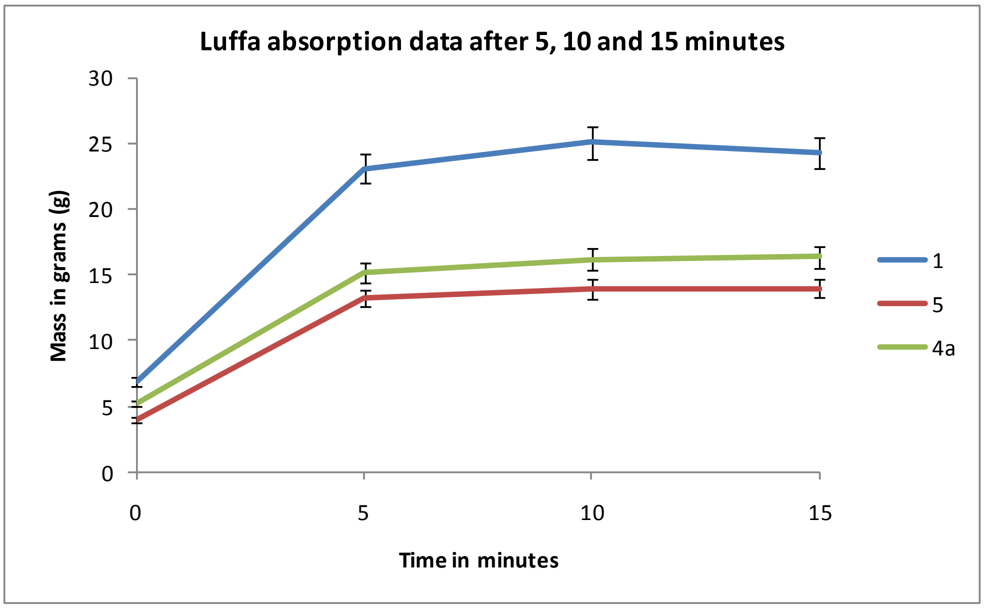

Figure 20 – Moisture absorption of luffa at different time intervals

The mass change after an immersion in distilled water for 30 min was between 194 to 248% and is in the same range of the ones obtained after only 5 min (Table 4), suggesting that luffa sponge reaches saturation after only a short period of time when immersed in water. The implication of this behavior must be considered in the design or its use as a natural fiber or within a composite material. This finding is in line with previous literature showing that the vegetal material of luffa sponge is structured in a microspongy fibrous system that offers quick, good accessibility to fluid, thus suggesting the efficient use of the material in liquid absorbency (Bal *et al.*, 2004a).

Table 4 - Luffa sponge absorption experiment data after 30 minutes

	Luffa sample Mass		Weight gain(%)
Luffa Sample	initial Mass	m30	after 30 minutes
2	7.44	21.9	194%
3	5.64	19.1	238%
4	5.00	17.4	248%

7 .1.2 Vertical compression on horizontally positioned samples

Three luffa samples tagged 2a, 3a and 6a were kept dry in their natural state and put under compression in a horizontal position. Three other samples tagged 2, 3 and 4 were soaked in distilled water for 30 minutes and excess water removed before testing. The mass, length, diameter and surface of the six samples used for compression in this experiment are shown in Table 5. Five successive compression tests were conducted on each sample (Figure 21). The force in Newton (N) needed to create a target displacement of 25 mm on each attempt as well as the mean and standard deviation are shown in Table 6.

Figure 21 – Compression of a horizontally positioned luffa sample (photo by author).

Table 5 – Luffa sponge samples characteristics used for vertical compression in a horizontal position

Sample	Mass (g)	Length (mm)	Diameter (mm)	area Lxd (m^2)10^{-3}
2a	7.54	101	46.3	4.67
3a	4.65	95.0	43.2	4.10
6a	3.11	93.0	41.9	3.90
2	7.44	101	46.5	4.69
3	5.64	95.0	48.8	4.64
4	5.00	95.0	42.0	3.99

Table 6 – Force of compression on six luffa samples (three dry and three wet) with a displacement target of 25 mm positioned horizontally

	Luffa sample (dry)			Luffa sample (wet)		
	2a	3a	6a	2	3	4
Test nb.	Force (N)	Force (N)	Force (N)	Force (N)	Force (N)	Force (N)
1	421	477	140	120	74.9	136
2	405	450	134	112	70.4	128
3	390	431	129	110	68.1	124
4	381	421	126	106	66.7	122
5	375	412	124	104	65.7	120
Mean	394	438	131	110	69.1	126
S.D.	18.8	25.6	6.60	5.95	3.67	6.00

It can be noticed that both in dry and wet samples the force needed to create the target displacement of 25 millimeters decreases steadily from one test to another until the fifth compression. There is a drop in compression force needed to create the same effect as the compressions are repeated. This is due to the fact that each compression creates a double effect of plastic and elastic deformation of the material. The luffa sponge fibers sustain some deformation after compression but remain elastic.

There is an important variation in the material strength from sample to sample both in dry and wet states as shown by the large range of force (438 N versus 131 N for dry samples and 126 N versus 69.1 N for wet samples) needed to produce a similar displacement. This is in accordance with literature showing the variability in luffa fruits and plants based on factors like soil types and mineral nutrients (Okusanya *et al.*, 1981; Okusanya, 1983b). Table 7 shows the position (mm) where each test starts for the six luffa samples. It is worth mentioning that the first test does not exactly start at the value zero (0) due to the slight contact between the compressing plate and the fiber of the luffa sample. The mean and standard deviation of the plastic displacements during the test are calculated from the second test's starting position.

Table 7 – Starting position from origin of each test

	Position from origin in mm					
	Luffa sample (dry)			Luffa sample (wet)		
Test nb.	2a	3a	6a	2	3	4
1	0.31	0.34	0.14	0.69	1.39	0.38
2	10.2	11.5	8.08	3.96	4.25	4.14
3	11.3	12.5	9.16	3.79	5.02	4.97
4	11.8	13.0	9.50	4.74	5.42	4.79
5	12.0	13.4	9.85	5.24	5.69	5.46
Mean	11.3	12.6	9.1	4.4	5.1	4.8
S.D.	0.81	0.81	0.76	0.68	0.63	0.55

From the Table 7, the exact permanent (or cumulative) displacement from original size from test number 2 to test number 5 can be calculated as p_2-p_1, p_3-p_1, p_4-p_1, and p_5-p_1 with p_1, p_2, p_3, p_4 *and* p_5 being the initial position of the compressing plate at the beginning of succeeding tests. Table 8 shows the cumulative displacement.

Table 8 – Calculated displacement from original size of each luffa sample tested horizontally

	Calculated displacement from origin in mm at the beginning of test 2 to test 5					
	Luffa sample (dry)			Luffa sample (wet)		
Test nb.	2a	3a	6a	2	3	4
2	9.8	11.2	7.9	3.3	2.9	3.8
3	11.0	12.2	9.0	3.1	3.6	4.6
4	11.4	12.6	9.4	4.1	4.0	4.4
5	11.7	13.1	9.7	4.6	4.3	5.1
Mean	11.0	12.3	9.01	3.75	3.71	4.46
S.D.	0.81	0.81	0.76	0.68	0.63	0.55

Figure 22 shows a typical graph of the force needed for compression of a luffa sample; forces applied on sample 3a are shown. The graph illustrates with small vertical lines the starting point of each compression test, from the first to the fifth. The permanent displacement of the luffa sample occurs with the contact between the compression plate and the sample happening at 0.34, 11.5, 12.5, 13.0, 13.4, mm respectively from the original compressing plate's position.

Plastic deformation of luffa sponge fiber under compression is more acute in the dry state than it is in the wet state (Figure 22). Between 9 mm and 12 mm of permanent displacement occurred in the dry state, whereas values fell in the range of 3.7 mm to 4.5 mm in the wet state, indicating that luffa sponge is more elastic when wet. This is an important consideration when planning to use the material, as it suggests two essential characteristics of luffa sponge: (i) luffa sponge is more resistant to elastic deformation when dry, and (ii) it is more resistant to plastic deformation when wet.

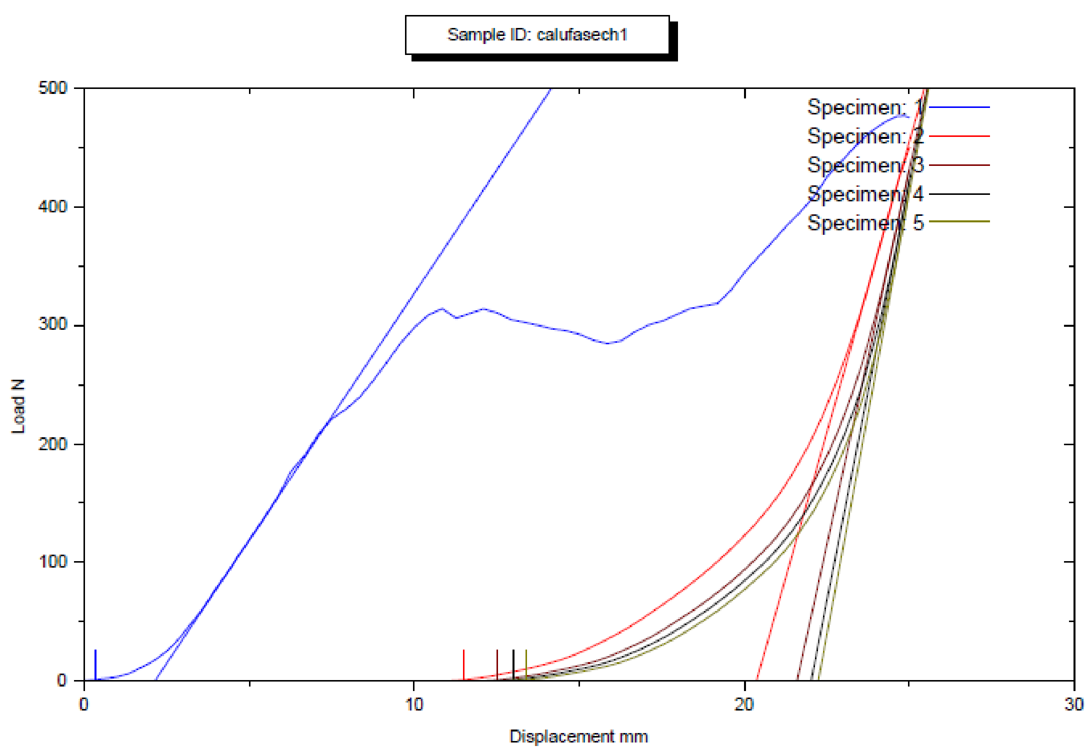

Figure 22 – Compression data of luffa sample 3a

In a second phase of analysis of luffa sponge compression the wet samples tagged 2, 3, and 4 were left to dry for seven days at ambient temperatures and then tested again following the previous method. The luffa sponges gained 3.5 to 4 times their compressive strength after becoming dry from a humid state (Table 9). This also suggests that it loses much of its strength when it becomes wet: under the test conditions only 27% of the force was needed on the wet sample compared to the dry one to create a displacement of 25mm. The compressive strength of the dried luffa sponge were comparable to those of samples 2a, 3a, and 6a that were tested in their natural dry state, without any prior wetting. This implies a recovery in strength equal or close to the original after the luffa sponge has regained its dry state. Figure 23 and Figure 24 demonstrate the gain in strength of sample number 3 after two weeks of drying.

Table 9 – Force needed for compression of previously wet samples

	Luffa sample (dry after wet)		
	2	3	4
Test nb.	Force (N)	Force (N)	Force (N)
1	438	264	500
2	413	249	500
3	401	242	500
4	393	240	500
5	389	236	500
Mean	407	246	500
S.D.	19.5	11.1	0.16

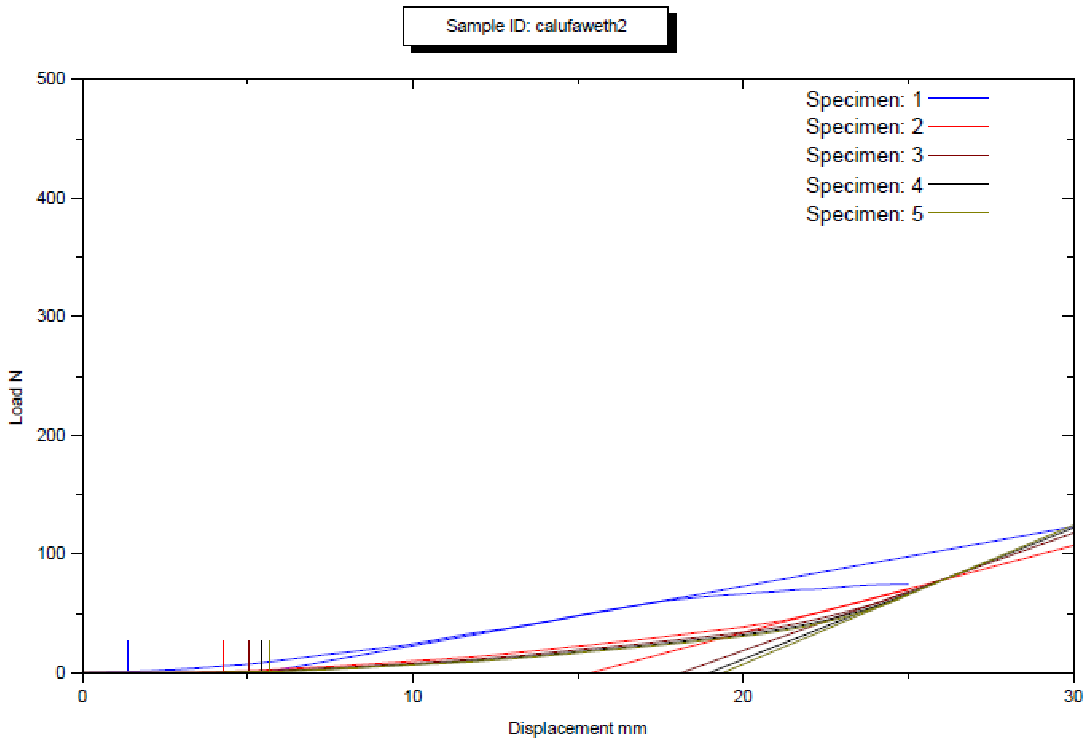

Figure 23 - Compression data of luffa sample 3 in a wet state

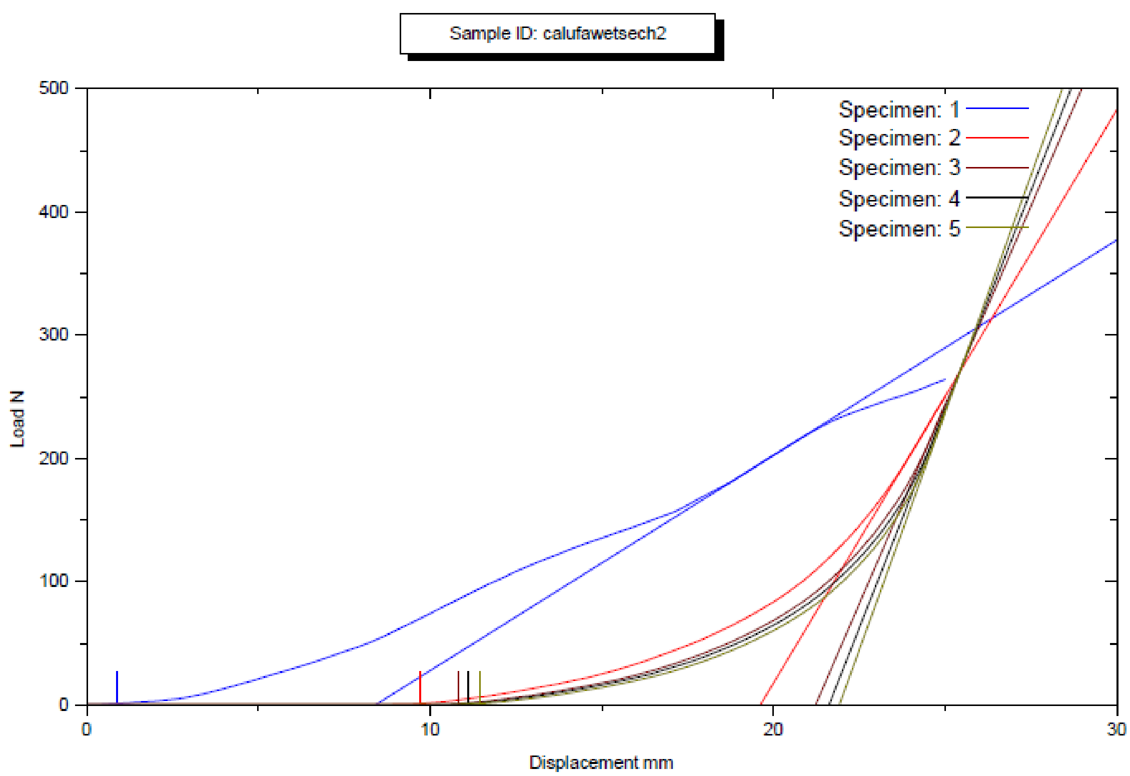

Figure 24 - Compression data of luffa sample 3 in a dry state after having been wet

The stress (σ), linear strain (ε_L) and stiffness (k) of the luffa sample were, respectively:

$$\sigma = \frac{F}{a'} \quad [6]$$

$$\varepsilon_{\mathrm{L}} = \frac{\Delta L}{L_0} \quad [7]$$

$$k = \frac{F}{\Delta L} \quad [8]$$

Table 10 illustrates the substantial contrast in σ, ε_L, and *k* between the dry and wet states of the luffa samples, suggesting the need for a careful and different approach to using the material whether for dry or wet conditions.

Table 10 – Stress, Strain and Stiffness of horizontally-positioned luffa samples

	Luffa sample (dry)			Luffa sample (wet)		
Stress	2a	3a	6a	2	3	4
F (mean)	394	438	131	8.7	6.11	9.55
a' (m2)*10^{-3}	4.67	4.10	3.90	4.69	4.64	3.99
σ (Mpa)	0.0844	0.107	0.0335	0.0235	0.0149	0.0317
σ (psi)	12.2	15.5	4.86	3.41	2.17	4.59
Strain						
ΔL (mm)	11.0	12.3	9.01	3.75	3.71	4.46
L_0(mm)	46.3	43.2	41.9	46.5	48.8	42.0
ε_L	0.237	0.284	0.215	0.0807	0.0759	0.106
$\varepsilon_{L\ (\%)}$	0.892	1.07	0.808	0.303	0.285	0.399
Stiffness						
k (N/m)	35,899	35,733	14,499	2,321	1,648	2,141

7.1.3 Vertical compression on vertically-positioned samples

In a manner similar to the compression test for horizontally-positioned samples, three luffa samples tagged 1a, 5a and 6 were kept dry in their natural state and put under compression in a vertical position. Three other three samples tagged 1, 4a and 5 were soaked in distilled water for 30 minutes and their excess water removed before testing. The mass, length, diameter and surface of the six samples used for compression in this experiment are given in Table 11. Five successive compression tests were conducted on each sample (Figure 25). The force (N) needed to create a target displacement of 25 mm on each attempt as well as the mean and standard deviation are shown in Table 12.

Figure 25 - Compressed luffa sample in a vertical position (photo by author).

Table 11 – Linear dimension, mass and area of vertically-tested samples

Sample	Mass (g)	Length (mm)	Diameter (mm)	area pi * r2 $(m^2)10^{-3}$
1a	4.88	105	48.8	1.87
5a	3.78	95.0	46.1	1.67
6	3.08	93.0	39.5	1.22
1	6.95	105	47.1	1.74
4a	5.24	95.0	45.2	1.60
5	4.02	95.0	44.2	1.53

Table 12 - Force of compression on six luffa samples in the vertical position (three dry and three wet) required to achieve a displacement of 25 mm

	Luffa sample (dry)			Luffa sample (wet)		
	1a	5a	6	1	4a	5
Test nb.	Force (N)	Force (N)	Force (N)	Force (N)	Force (N)	Force (N)
1	252	80.2	64.6	60.9	24.3	14.9
2	225	77.5	55.6	56.8	22.8	13.9
3	217	74.9	53.0	55.4	22.1	13.4
4	213	74.2	52.1	54.5	21.8	13.2
5	210	73.0	51.3	54.0	21.5	13.1
Mean	223	76.0	55.3	56.3	22.5	13.7
S.D.	17.2	2.89	5.42	2.80	1.12	0.73

As with the compression tests in the horizontal position, the vertically tested samples show the same pattern in decreasing force needed for a 25 mm displacement from test to test. The same large drop in force needed for the target displacement under wet *vs.* dry conditions was also apparent.

Displacement from the original size (Table 13) and permanent cumulative displacement (Table 14) of vertically-tested luffa samples from tests 2 to 5, show a much lower plastic deformation of samples for a similar temporary displacement when compared to samples in the horizontal position. There is an average plastic deformation of 9 mm to 12 mm for a diameter range of 42 mm to 46 mm with the horizontal dry samples whereas there was only a plastic deformation of 7 mm to 12 mm for vertically-tested samples with a length ranging from 93 mm to 105 mm.

Table 13 - Starting position from origin of each test

	Position from origin in mm					
	Luffa sample (dry)			Luffa sample (wet)		
Test nb.	1a	5a	6	1	4a	5
1	0.82	2.02	0.37	0.36	0.35	1.62
2	12.2	7.79	7.99	3.91	3.55	4.99
3	13.1	8.88	8.79	4.83	4.40	5.92
4	13.6	8.93	9.09	5.35	4.92	6.47
5	13.9	9.07	9.38	5.66	5.08	6.63
Mean	13.2	8.7	8.8	4.9	4.5	6.0
S.D.	0.72	0.59	0.60	0.77	0.69	0.74

Table 14 - Calculated cumulative displacement from original size of each vertically-tested luffa sample

	Calculated displacement from origin in mm at the beginning of test 2 to test 5					
	Luffa sample (dry)			Luffa sample (wet)		
Test nb.	1a	5a	6	1	4a	5
2	11.4	5.77	7.62	3.55	3.20	3.37
3	12.3	6.86	8.42	4.47	4.05	4.31
4	12.8	6.91	8.72	4.99	4.57	4.85
5	13.1	7.06	9.01	5.30	4.73	5.01
Mean	12.4	6.65	8.44	4.58	4.14	4.38
S.D.	0.72	0.59	0.60	0.77	0.69	0.74

Compression of wet luffa samples (no. 1, 4a, and 5) left to dry under ambient temperature for seven days and then tested vertically showed little difference from initially dry samples (Table 12) with respect to the compression force required to achieve a 25 mm displacement (Table 15). The force required for wet samples was roughly 4-fold less than for initially dry, or wetted and dried samples (Table 15).

Table 15 - Force of compression on the same three vertical samples under wet and re-dried conditions

	Luffa sample (wet)			Luffa sample (dry after wet)		
	1	4a	5	1	4a	5
Test nb.	Force (N)	Force (N)	Force (N)	Force (N)	Force (N)	Force (N)
1	60.9	24.3	14.9	214	84.8	63.7
2	56.8	22.8	13.9	207	81.6	61.1
3	55.4	22.1	13.4	203	79.8	59.6
4	54.5	21.8	13.2	200	78.7	58.9
5	54.0	21.5	13.1	198	78.0	58.3
Mean	56.3	22.5	13.7	204	80.6	60.3
S.D.	2.80	1.12	0.73	6.41	2.73	2.18

Thus, as in the horizontally tested luffa samples, wetted samples recovered their strength after having dried naturally. The compression experiments indicate that luffa sponge sustains only partially plastic deformation and could be considered an elasto-plastic material. The luffa samples regained some of their lost diameter or height after the load was removed. The results also show that luffa sponges can sustain a bigger stress and are stiffer when used in their horizontal position.

Table 16 shows the σ, ε_L, and *k* between the dry and wet states of the luffa samples tested vertically.

Table 16 - Stress, Strain and Stiffness of vertically tested samples

	Luffa sample (dry)			Luffa sample (wet)		
Stress	1a	5a	6	1	4a	5
F (mean)	223	76.0	55.3	56.3	22.5	13.7
a' (m2)*10^{-3}	1.87	1.67	1.22	1.74	1.60	1.53
σ (Mpa)	0.0437	0.017	0.0151	0.0114	0.00	0.00
σ (psi)	6.33	2.47	2.19	1.65	0.0102	0.0062
Strain						
ΔL (mm)	12.4	6.65	8.44	4.58	4.14	4.38
L_0(mm)	105	95.0	93.0	105	95.0	95.0
ε_L	0.118	0.07	0.0908	0.0436	0.0435	0.0461
$\varepsilon_{L\ (\%)}$	11.8	7.00	9.08	4.36	4.35	4.61
Stiffness						
k (N/m)	18,039	11,424	6,552	12,303	5,435	3,123

In order to determine how to hold the luffa 'modules' together the first method attempted was to tie them with a braided polystyrene rope to form a sturdy surface. This method proved to be inefficient due to the excessive use of rope needed to maintain the specimens in the form of a solid surface. Besides the added costs for the rope, this method would not be suitable for a box made to carry mangoes.

A second method used was to sew the luffa sponges using an upholstery needle and fish wire, using the natural voids of the luffa fiber matrix and thus avoiding the need to create holes in the structure of the luffa pieces. Many problems were accounted with this second method. The irregularities of the shape and surface made it difficult to sew the luffa samples close enough to each other. There was a sharp contrast in stability between the luffa samples tied with ropes and the luffa samples sewn with fishing wire. Additionally there was constant pressure build-up on wires when vertical loads were applied to the surface formed. This pressure negatively affected the luffa samples by tearing the fiber matrix and weakening the assembled pieces.

A third method tested was to assemble the luffa pieces with glue. After compression with a plank of wood to increase their density, the luffa pieces were glued together using different types of glue: (i) a clear glue stick used with a hot glue-gun, (ii) Exposy Stell resin and hardener' (Eaglestar), or (iii) 'Ponal' glue (Henkel, Dusseldorf). The trials conducted with the clear glue stick and the 'Ponal' glue seemed appropriate with positive result. The luffa modules could be solidly bonded together with minimal volumetric interference and the assembled unit was visually attractive. It was noted though that the 'Ponal' glue was less resistant to water and took more time to dry than the clear glue. Figure 26 shows two pieces of luffa glued together.

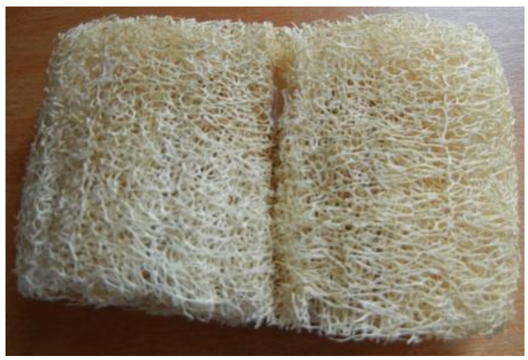

Figure 26 –Glued luffa with clear glue stick applied with a glue-gun (photo by author).

7.1.4 Completed Luffa box

The most appropriate method for keeping the luffa pieces together as determined earlier was used for the construction of the mango shipping box. The fiber nature of luffa sponge comprises a significant amount of void. A way to reduce the void and increase the surface of adhesion was to compress the luffa sponge before gluing them. The pre-compression produced a denser surface to glue. After pre-compression with a plank of wood, a number of specimens were glued sequentially with clear glue sticks and a glue gun to form a box. The box dimensions were 600 mm long × 400 mm wide × 225 mm tall. These dimensions were chosen to match the ISO 3394 standard for 'Dimensions of rigid rectangular packages – Transport packages'. The standard only sets the length and width of the box leaving the height at the discretion of builder. The height of 225 mm was chosen arbitrarily, in line with the luffa samples on hand.

Twenty-four ‘Zip lock’ bags filled with water and totaling 10 kg were placed in the box to simulate a box full of mangoes. The pressure exercised on the floor of the box when filled showed that the box would need support at the base to prevent it from being damaged. A strap was added along the length of the box, as illustrated in Figure 27. The strap served as a handle and provided the needed support to the base. The strap used helped transfer the pressure from the bottom of the box to the strap avoiding damage due to excess fruit weight in the box. Six hours were needed to complete the first box in the lab.

Figure 27 - Luffa sponge box made in the lab with mangoes and with a strap (photo by author).

A second and a third box were made during a field research trip in Senegal. The box-making tool was used. The primary goal of the tool was to reduce the time needed to make the box. A secondary goal was to produce more standard-sized boxes. The dimensions of the two boxes were 600 mm (length) × 400mm (width) ×180 mm (height). The ‘base-maker’ and ‘finisher’ considerably reduced the time needed to make the boxes; from six hours for the first box made in the lab to about one and a half hours. The time could be reduced even more if the glue used would dry faster. Figure 28 shows one of the completed boxes with mangoes.

Figure 28 – Box completed in the field with mangoes (photo by author).

The use of the 'Ponal' glue was adequate in the field. It enabled a strong bond between luffa pieces, needed no electricity and could be found easily in local hardware stores.

In recent years there has been a great push for sustainable solutions to environmental problems, as well as a special emphasis on food security in the countries of the developing world. In this context the reduction of post-harvest losses due to mechanical damage during transportation is pivotal to increasing food availability and quality. A sharp drop in post harvest losses will also contributes towards a higher income to farmers and different stakeholders acting in the agriculture sector. The use of luffa sponge boxes to carry mangoes and ultimately other fruits and vegetables represents an attractive avenue in Senegal where up to 30% of mangoes are lost during the transit from the field to the costumers (Ternoy *et al.*, 2006).

7.1.5 Luffa box compression

Compression on luffa samples prior to making the shipping box highlighted the kinetics of luffa sponge under load. The initial plastic deformation followed by the elastic stage suggested the pre-compression of specimens prior to gluing them together. This process was expected to make each luffa module behave like an individual spring within the elastic range of the collection of luffa sponges that made up the luffa box.

Compression rendered the working length of luffa modules slightly smaller than the free length, and ensured a good contact between specimens making up a box. Furthermore the fibre matrix of luffa sponge helps minimizing the distance between two glued luffa while creating a strong bond. The ensuing box made of luffa samples arranged horizontally was tested for compression under a static load. This approach was chosen as the individual luffa pieces making up the box were not to be submitted to high loading cycles under normal shipping circumstances. The box under compression first in its dry state then wrapped in plastic in its humid state is shown in Figure 29.

Figure 29 – Left: Dry box under compression. Right: Humid box under compression (photo by author).

The box height and change in dimension, the compressive force, the displacement, and slopes under compression for the tested box under ambient conditions are shown in Table 17. The change in height was calculated from the beginning of the second test when the compressive plate of the testing machine was adjusted to the new height of the box.

Figure 29 below shows the graphs and slopes as drawn by the analysis software connected to the *Instron* testing machine. Despite the displacement under the 500 N load applied to the box at each test, the box is elasto-plastic and regains much of its original size after compression. The relatively small standard deviation in the slope of the graphs indicates the stability of the box after the first compression. The box changes in height by less than two millimeter to a fraction of a millimeter per compression after the first compression. It can be said that this phenomenon is helped by the use of pre-compressed luffa samples with considerably reduced free length, and reduced the box's working range that acts like a spring under static load.

Table 17 – Displacement, slope of graph and change in height of the luffa box under a 500 N compression load under dry conditions

	Luffa box (dry)under 500 N compressive Force				
Test nb.	Box height* (mm)	Force (N)	Displacement at max load (mm)	Slope N/mm	Change in height at the beginning of test (mm)
1	225	500	44.1	16.3	0.00
2	218	500	37.6	20.5	6.70
3	217	500	36.2	21.9	1.70
4	216	500	35.5	22.8	0.80
5	215	500	34.9	22.5	0.70
Mean	218	500	37.7	20.8	2.48
S.D.	4.01	0.00	3.73	2.66	2.85
* final height was	215				

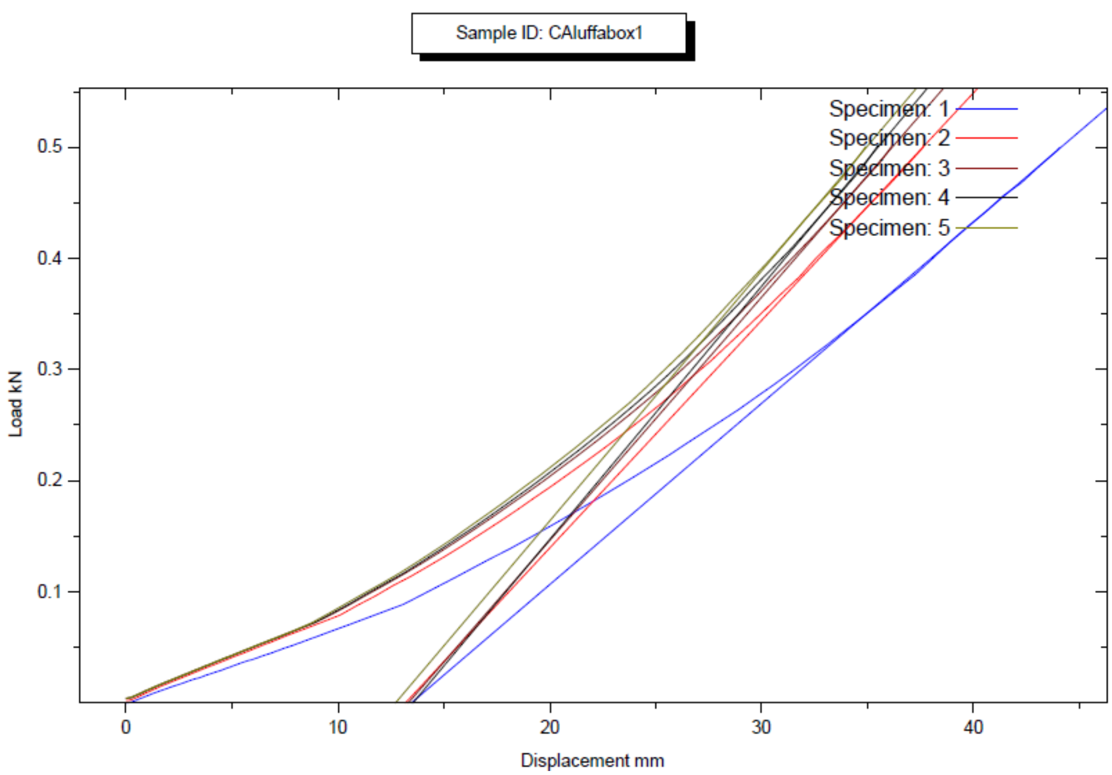

Figure 29 – Graph of luffa box displacement under loads of up to 500 N

The force applied on the box is:

$$F = m \times G \qquad [9]$$

where,

m is the mass resting atop the box (kg), and

G is the acceleration due to gravity, or 9.81 m s^{-2}. The equivalent mass to the 500 N force used in testing can be derived from Eq. 9 as:

$$m = \frac{F}{G} \qquad [10]$$

Thus the applied force of 500 N would be equivalent to a load on the luffa box of $m = 500 / 9.81 \approx 51$ kg. The dead weight of the box measured before the test was 1 kg. This implies that the testing conditions in the lab simulate a box under the compressive load of five other boxes full of mangoes, each with an average mass of 10 kg. The average temporary displacement of 37 mm by the luffa box could be theoretically distributed among the luffa samples making up the box's walls. In the tested box, six rows of horizontally positioned luffa sponges accounted for the box's height of 225 mm. Therefore one sixth of the elastic deformation during compression could be attributed to each luffa sample. This approach shows that up to 6 mm of temporary displacement is attributable to each luffa sample within its elastic range. This is in line with previously found results in tests conducted on samples at the beginning of the experiment, showing that they could be compressed in their dry state for up to 16 mm after initial plastic deformation.

The pronounced displacement registered at the first compression attempt (6.5 mm) and the following stabilization in deformation (2.7 mm in the four successive tests) show that reduced displacement for the box under load can be achieved with increased pre-compression of luffa samples. The principles of clash allowance of 10% of the maximum working deflection in springs could also be applied to the case of a luffa box. A similar clearance between the top of a luffa box and of the fruits might help to prevent bruising from compression.

Fourteen days after the compression tests in the natural dry state, the box was tested again with a compressive force of 500 N under humid conditions. A full 24 hours prior to the tests, the box was sprayed with 250 g of tap water and wrapped in a 'Fisherbrand' polypropylene biohazard autoclave bag. The displacement at max load and resulting slope of the compression exercised on the box are shown in Table 18.

It is to be noted that despite the compression exercised on the box in its dry state that brought the final box height to 215 mm the humid box before the first test had a height of 227mm. This is 2 mm higher than when the box was tested dry for the first time. This elastic 'spring-back' effect of 12 mm is indicative of the elasticity of luffa sponge as a material.

Table 18 - Displacement, slope of graph and change in height of the luffa box under a 500 N compression load under humid conditions (250 g of water)

	Luffa box (humid) under 500 N compressive Force				
Test nb.	Box height* (mm)	Force (N)	Displacement at max load (mm)	Slope N/mm	Change in height at the beginning of test (mm)
1	227	500	100	7.22	0.00
2	183	500	59.2	12.5	44.3
3	174	500	51.7	16.3	8.70
4	169	500	47.7	18.7	4.90
5	166	500	45.2	20.4	3.00
Mean	184	500	60.8	15.0	12.2
S.D.	25.0	0.00	22.6	5.28	18.2
* final height was	164				

The result obtained for the humid box paralleled individual tests carried on wet luffa samples. The large difference in displacement between the dry box's 37.7 mm of displacement, and the humid box's 60.8 mm, shows the important difference in stiffness between the dry and wet states of luffa sponge under load.

The area (A) upon which the force is being applied can be assimilated to a rectangular shell with an external dimension of 600 mm × 400 mm and with a width equal to the average diameter of the luffa sponges used to make the box. The area could then be calculated as follow:

$$A = (L \times l) - (L' \times l') \quad [11]$$

where,

L and *l* are the length and width of the exterior of the box, and

L' and *l'* are the length and width of the interior of the box.

Twelve measurement of the box's wall thickness was taken, three on each side and the average width of the rectangular shell (Table 19) was used in the calculation of the area upon which the force is being applied:

$$A = (600 \times 400) - [(600\text{-}46.6)\times(400\text{-}46.6)] = 44428\ mm^2 = 0.0444\ m^2 \quad [12]$$

Table 19 – Box's wall thickness measurements

	Box's wall thickness Measurement	Diameter (mm)
	1	42.1
	2	53.4
	3	51.0
	4	52.6
	5	44.3
	6	46.1
	7	47.2
	8	45.0
	9	40.2
	10	42.6
	11	40.5
	12	54.1
Average		46.6
S.D.		5.05

The Stress, Strain and Stiffness of the luffa box under dry and in humid conditions are shown in Table 20.

It is to be noticed that a similar stress creates a very different strain on the luffa box depending on whether the box is dry or humid. A temporary deformation of 16.7% is registered for the dry box, compared to 26.8% when the box is humid. It should be noted that the humid box had a slight tendency to bulge inwards. The clear difference in behavior between dry and humid states of luffa sponge needs to be integrated when designing a box. In order to reduce this large elastic range, a bigger pre-compression of luffa samples needs to take place before their use. The permanent deformation of samples tested horizontally and dry suggest a pre-compression of at least 25 percent of the specimens in order to minimize elastic deformation under load. This estimation results from the ratio of plastic deformation to the original sample's length of horizontally positioned samples tested while dry. This feature was not considered when making the box.

Table 20 - Stress, Strain and Stiffness of luffa box under 500 N load and in dry and humid states

	Luffa box (dry)	Luffa box (humid)	Luffa box (dry after humid)
Stress			
F (mean)	500	500	500
A (m^2)	0.0444	0.0444	0.0444
σ (Mpa)	0.0125	0.0125	0.0125
σ (psi)	1.81	1.81	1.81
Strain			
ΔL (mm)	37.7	60.8	41.5
L_0(mm)	225	227	225
ε_L	0.167	0.268	0.185
$\varepsilon_{L\ (\%)}$	16.7	26.8	18.5
Stiffness			
k (N/m)	13,280	8,227	12,038

7.1.6 Luffa box stacking strength

In a second set of compression tests that lasted 27 hours the strain behavior of the luffa box was monitored, with the change in height of the box tested in its natural dry state and when humid measured after different time intervals (Tables 21 and 22). The compression plate was adjusted at each time interval to maintain a 500 N load on the box over the full testing period.

Table 21– Luffa box under sustained compressive force in dry conditions

Compression	Time (hours)	Luffa box (dry) under a sustain compressve force of 500 N		
		Box height* (mm)	Deflexion (mm)	Total change in height at the beginning of test (mm)
1	0.00	219	0.00	0.00
2	0.01	177	42.3	42.3
3	0.08	175	1.60	43.9
4	1.00	174	0.90	44.8
5	3.00	173	1.30	46.1
6	5.00	172	0.70	46.8
7	22.3	168	3.80	50.6
8	22.8	168	0.20	50.8
9	24.3	168	0.40	51.2
10	26.8	167	0.60	51.8
	Mean	176	5.8	47.6
	S.D.	15.4	13.7	3.6
	* height after load removal	187		

Table 22 - Luffa box under sustained compressive force in humid conditions

Compression	Time (hours)	Luffa box (humid) under a sustain compressve force of 500 N		
		Box height* (mm)	Deflexion (mm)	Total change in height at the beginning of test (mm)
1	0.00	187	0	0.00
2	0.01	115	72.3	72.3
3	1.67	111	3.7	76.0
4	4.00	109	2.5	78.5
5	22.5	106	2.8	81.3
6	23.5	104	1.9	83.2
7	24.0	103	0.7	83.9
8	25.5	103	0.5	84.4
9	27.0	102	0.7	85.1
	Mean	115	9.5	80.6
	S.D.	27.2	24.9	4.6
	* height after load removal	115		

The first displacement of the box when under load is always by far the most important one. In both dry and humid conditions the first deflections, registered at $t = 0.01$ hr were 42.3 mm and 72.3 mm, respectively, representing about 80% of the box's total change in height over the full 27 hours. The dry and humid luffa boxes lost 24% and 46% of their heights, respectively, under a sustained compression of 500 N over the full test period. The findings highlight the fact that one must have a good knowledge of the conditions under which a luffa box would be used in order to properly design it. For a short cycle use of only a few to 27 hours, for instance while in transit from the field to a packing station or the market, the deflection registered when a load is put on a box is indicative of the deflection during its utilization. Good pre-compression of specimens before making a box would also reduce displacement under load and help preserve the integrity of the box's content from damage due to compression. The sequence under which the test took place could also have an effect on the box's height change. Table 23 shows the sequence of all compression tests conducted on the box. The 27 hours compression tests took place just after the five successive compressions in both states. The succession under which the experiments were conducted show that interest is to be given to the difference in height change ratio as an indication of the box's kinetics under load rather than the amount of deflection during the tests.

Table 23 - Chronological order of tests and changes on luffa box height

Test type	Tests in chronological order	Height (mm)*	
		Starting	Finishing
compression (dry)	1 - (Day 1)	225	215
sustained Load (dry)	2 - (Day 1,2)	219	187
compression (humid)	3- (Day 15)	227	164
sustained Load (dry)	4 - (Day 15,16)	187	115
compression (dry after humid)	5-(Day 21)	225	219

Table 23 shows also the initial and final heights of the luffa box. After each test type the final height of the box did not remain constant until the following test. Under dry conditions it sprang back by four millimeters from 215 to 219 mm. When humidified with 25% of its weight, the box gained 40 millimeters passing from 187 mm to 227 mm; then was compressed to 164 mm at the end of the compression under humid condition; it then recovered 23 mm to 187 mm by the beginning of the last series of compression tests. The final height was 115 mm after the last test in a humid state. The box was then soaked in warm water for 30 minutes and recovered to nearly the double of its final height to reach 225 mm. Seven days later it was tested for compression again after having dried in ambient temperature of 23^{o}C. The elasto-plastic behavior of luffa sponge was well illustrated by this spring back phenomenon during the series of experiment on the box. The apparently plastic deformation during each test is semi-plastic as the box recovers part of its height when the load is removed due to the elastic nature of the luffa sponge fibers. After all the compression tests carried on the box, its final height is 219 mm only 6 mm away from its initial height at the beginning of the series of experiments.

7.2 Discussion

The water absorption behavior of luffa sponge fibers in these experiments has shown that within minutes luffa sponge reaches saturation by absorbing roughly twice as much as its dry weight. This attribute could be put into great use in application where rapid absorption of water is needed. This characteristic does confirm the use of luffa sponge as a material of interest for dye removal in aqueous solutions (Altinisik *et al.*, 2010; Demir *et al.*, 2008) . It is of interest to note the considerable gain of resistance to displacement of previously wet samples that have dried. This suggests that the samples recovered much if not all of their strength after regaining their dry state. In the context of making shipping boxes for mango, luffa sponge absorbency could be put to great use as illustrated by the strength recovery of the box after immersion in warm water. Overly compressed boxes that had lost their required height and fruit-protection attributes could be soaked in an attempt to help them regain their strength. This investigation showed that the a luffa box recovered 91 percent of its stiffness at the end of the series of experiments. A careful design based on operational conditions of the box could limit the inconvenience caused by the greater displacement under the humid *vs.* dry state, as observed in this study. The stress and strain applied on the box totaled 15 compressions under static load and 54 hours under a sustained load of 500 N. The results are indicative of the stress under load a luffa box could handle in the field, during shipment or in a warehouse.

Moreover, the type of glue used would influence the ability of the luffa box to remain intact even after being soaked in water. The clear glue stick was resistant to water while the 'Ponal' glue was not. It is therefore important to choose carefully the type of glue to be used in consequence of the expected use of the boxes. Also in a scale-up production mode it would be beneficial to take into account the longer time period needed for a particular glue type to dry. In this study while the glue gun-applied clear glue dried almost instantly the 'Ponal' glue took several minutes to dry. A consideration that might represent an obstacle to the adoption of the luffa box in Senegal is the price of the glue. It was necessary to purchase CAN $1.5 of 'Ponal' glue for one box in Dakar. In Montreal the clear glue stick cost CAN $3. It is possible to realize an economy of scale in a large production of boxes or alternatively use a less expensive but adequate glue type to manufacture the boxes. Glue that does not require electricity to melt would be more suitable for adoption and reduce costs. It is also worth noting that a considerable amount of luffa sponge is needed for each box. According to the literature reviewed a luffa plant produces on average 20 to 25 luffa fruits (Porterfield, 1955). This means that at least 3 luffa plants are needed to obtain sufficient luffa sponges for one box. Further investigation could address the way to use less luffa sponges per box.

CONNECTING TEXT

So far we have arrived at a suitable design of luffa boxes for transporting mangoes. In the next chapter we focus on the availability of luffa and its associated economics.

CHAPTER VIII

SUPPLY OF *L. AEGYPTIACA* Mill AND COST OF PRODUCING A LUFFA BOX IN THE SENEGALEASE CONTEXT

A field research component was carried out in Senegal, from November 2010 to January 2011 in order to determine if luffa (*L. aegyptiaca* Mill) was in sufficient supply to achieve the perspective of making mango shipping boxes with luffa sponges. Two boxes were made in the field following the procedure established. This helped in evaluating the cost of producing luffa boxes in the Senegalese context. It was found that the supply of luffa was plentiful as luffa plant grows naturally in various parts of the country with no care. Additionally luffa plants could also be grown to supplement the natural supply. The supply and cost would affect the viability of using luffa boxes as an appropriate solution to post-harvest losses of mangoes. The cost of producing a luffa box was relatively low, at less than CAN $2 and could possibly be lowered further. Stakeholders in the mango industry would gain from reducing losses that occur during transport of their produce and using luffa boxes to ship mangoes is an option that they might seriously consider. Besides reduction of post-harvest losses of mangoes an increase of fruit quality is also a strong incentive to adopt luffa boxes in Senegal, especially in the export sector as luffa sponge is still an underutilized and abundant natural resource.

The field research trip conducted in Senegal to study the supply of luffa and analyze the cost of producing a luffa box was instrumental in supporting the case of having mango boxes made with luffa sponge. An appropriate solution to the post-harvest loss of mangoes due to mechanical damages during transport is necessary in Senegal where 15 to 30% of post-harvest losses of mango occurs between the field and the sorting or packing station (Ternoy *et al.*, 2006).

8.1 Objectives

This study attempted to verify whether an adequate supply of luffa was available in Senegal and if a reasonable price for boxes could be achieved in a scenario where mango producers would use luffa boxes to ship their produce from the field to the packing or sorting station or market. The underlying goal of this field research was to find evidence for the possibility of developing a sustainable box made from an underutilized resource that has the desired properties of a fruit packing material.

8.2 Methodology

The field research involved visits to various places in Senegal, in cities as well as in the countryside to assess the presence or absence of luffa plants. The location, the type of site and the date of the visit was recorded (Table 24). Samples were collected from various sites and the growth pattern of the luffa plants noted. The average dimensions of 12 samples from each of three main sites were calculated. An attempt to count the number of luffa fruits per wine was done but proved to be unrealistic in the field due to the growing pattern of the luffa vines. Two luffa boxes were made and the cost of each evaluated. A ‘box-making tool’ designed for this purpose was used to make the boxes.

8.3 Results

Various details were collected during the site surveys to determine luffa plants distribution in Senegal. The sizes small, medium and large refer to a luffa sponge of average size 144 mm, 182 mm and 263 mm respectively (Table 25). The luffa sponges were measured after the skin was peeled.

Table 24 – Survey of luffa plants supply in Senegal

Date	Location	Site particularities	Basic description of luffa fruit and plant	Other notes
21 – Nov-10	Rufisque	In abandoned, half built and disserted houses. Some houses partly transformed to garbage dumps	Medium, still green and growing, climbing fences and buildings. Some flowers on the wines	
22-Nov-10	Dakar	In a water retention area that also have garbage thrown into it	Medium, still green and growing, climbing the water retention wall. Many flowers were still on the wines while luffa fruits were growing on them.	The plants were very lush and vigorous
24-Nov-10	Dakar	On a long fence wall of a military camp. Luffa plant were intertwined in other plants growing along the fence	Medium, some green and some brown (ripe). Also some was growing on the floor next to the wall	Close to no fruits were found on the luffa plant growing on the floor.
26-Nov-10	Dakar	On a fence wall and in a field cleared to build a house	Medium, some green and some brown (ripe). The previous years' luffa wine could be seen dry under the fresh new wine. Some flower were present	The field was completely covered with the luffa plants but most luffa fruits were found on the perimeter wall
2-Dec-10	Ziguinchor	In houses and trees all over the city. Heavily growing on trees and other type of plants and even on abandoned vehicles	Small, some green and some brown (ripe). High concentration of fruits in general	There seem to be much more luffa per wine and more seeds per luffa fruit in Ziguinchor but this could not be confirmed. In the natural state it was hard to determine the number of luffa plants growing
10-Dec-10	Fatick region	On trees and huts. Also on floor of garbage dumps.	Large, some on the floor but sometimes rotten or distorted.	The biggest luffa were found on this region
28-Dec-10	Dakar	On brick, fences and walls	Not measured but of similar size to those found in other places in Dakar (≈180 mm long). Still flowering and producing. Some ripe and other unripe luffa fruits	

Figure 30-33 illustrate some of the elements mentioned in Table 24 above, in various locations where luffa was found in Senegal. Some additional photographs can be seen in the appendices.

Figure 30 – Luffa plant in Dakar near water retention area

Figure 31 – Luffa plant in Ziguinchor, all over a tree

Figure 32 – Luffa plant in Ziguinchor, growing on an abandoned bus along the street

Figure 33 – Luffa plant in Fatick, growing on the ground and in a garbage dump

Even though luffa can be found freely in many different places and regions in Senegal it can also be purchased from local markets where some women keep them in stock. The lack of demand for the sponge contributes in the infrequent supply of luffa in the markets. In some instances women that used to sell them mentioned that they were not carrying them in their stock any more due to a lack of interest from buyers. It is important to note that luffa sponge is only a side article, sold on occasion by these women.

In recently cleared areas for new houses luffa was seen to grow in abundance before the houses were built. Nevertheless with recent urbanization extending cities to previously unoccupied areas, less and less luffa plants are seen in the capital city of Senegal (Dakar), especially because the luffa plant is seen as a weed. Consequently it is getting harder to find luffa growing in densely populated areas of Dakar.

Luffa seems to be growing in very different types of soil and needs support as seen by its growth on long fences and walls. It also grows around rubbish dumps where there is a wall or tree for the luffa plant to climb on; fruits will set well in these cases. The finding here are in agreement with literature (Okusanya, 1983b; Okusanya *et al.*, 1981). Because luffa is an annual crop it is striking to see how new vines grow over the previous year's plant, with green luffa fruits hanging where the old vine had dried off.

In Ziguinchor, in the southern part of Senegal the abundant supply of luffa was particularly striking as close to every other house had luffa plants growing on it. The luffa fruits found in Ziguinchor were generally of shorter length than the one found in Dakar but seemed to be stronger. These differences tend to confirm that luffa fruit quality is directly impacted by soil quality.

The biggest luffa fruits were found in the Fatick region. The growth patterns were similar to the ones found in other locations and sites. Luffa also grew along fences, on trees and anywhere the plants could climb. The fruits were of better quality when they did not touch the ground or in contact with the soil.

Generally, it was hard to determine where a given vine was growing when it was growing in colonies with other plants. Smaller luffa fruits have smaller seeds in them and there seem to be a relationship between the size of the luffa fruit and the size of the seeds. The bigger the fruit, the bigger are its seeds and vice versa. There also appears to be a correlation between the number of seeds and the size of the seeds. The bigger the seeds the fewer they were in the fruit. Smaller luffa fruits appeared to have a greater number of seeds, particularly in Ziguinchor. As suggested in literature despite its vigor and adaptability luffa plants seem to grow only where the ground was reached by the sunlight (Okusanya, 1978).

It can be said that luffa grows in Senegal in many different regions. Despite this abundance of luffa the fruit is rarely used as a bathroom sponge or to scrub dishes. It is not consumed in Senegal and it is mostly seen as an unwanted weed. It should also be noted that even though there is plenty of vegetation in Casamance, the luffa plants seemed to be more prominent in the city of Ziguinchor compared to other places visited in the South, like Oussouye, Mlomp and Djibelor. At the sites visited there was much less cleared bushes and less uncovered ground reached by the sun, conditions needed for luffa vines to thrive.

Table 25 below gives dimension of luffa sponges from the fruits collected in various places in Senegal, particularly Dakar, Ziguinchor and in the Fatick region.

Table 25 - Dimension of some randomly picked luffa specimens collected in the field in Senegal

	Location					
Specimen	Dakar		Ziguinchor		Fatick	
	Lenght (mm)	Diameter (mm)	Lenght (mm)	Diameter (mm)	Lenght (mm)	Diameter (mm)
1	180	50	160	45	220	60
2	240	55	130	45	280	78
3	150	45	132	40	294	80
4	194	55	130	55	224	75
5	270	50	155	55	310	75
6	170	47	125	40	270	78
7	190	50	155	50	258	70
8	195	43	175	45	260	80
9	150	50	165	50	280	90
10	160	45	140	47	255	77
11	130	45	130	53	270	60
12	155	50	125	40	232	70
Average	182	49	144	47	263	74
S.D.	40.0	3.9	17.5	5.6	27.4	8.5

Enough luffa samples were collected in order to make two boxes. Some were also collected close to maturity. It was found that the humidity remaining in a luffa sponge that had not completely dried on the vine led to the fruit rotting when stocked in a polystyrene bag for later use. Moreover the luffa fruits found hanging on walls, fences or similar supports, were of better shape and cleaner than ones found on the ground.

As the luffa fruits collected were not purchased, an estimation of the cost of paying someone to collect the fruits was used to evaluate the price of the luffa sponge. An average of 70 to 80 luffa sponges is needed to make a box depending on the specimens' sizes. This investigation showed that it is reasonable to collect enough luffa fruits for one box and peel them for use in about one hour providing that the luffa plants are close by. Based on an eight-hour day salary of $CAN 4 for someone collecting the luffa fruits it will cost $CAN 0.50 ($CAN4 / 8) to collect enough fruits for a box in Senegal. The glue used was 'Ponal' wood glue by Henkel Dusseldorf. A 1 kg glue pot retailed for $CAN 2.6 and was the most expensive item involved in building the luffa box. Nonetheless only half a pot would be needed per box, representing $CAN 1.30 of glue. There also is a 5 kg glue pot that comes cheaper, $CAN 2.6 per kilogram of glue. The 5 kg glue pot was not available at the local hardware store when the boxes were being made and its price was unknown. When including the salary given to someone making the box and the economy of scale realized when making many boxes it is possible to make a box with variable costs not exceeding $ CAN 2. The fixed cost would include eventually the 'box-making tool' that represented an expenditure of $ CAN 25 and the cost of few pairs of scissors.

8.4 Discussion

This study demonstrated that the supply of luffa is plentiful in Senegal and that the cost of producing a luffa box is reasonable in the Senegalese context. It will be of essence to carry out a real life test by shipping mangoes from field to markets or to distribution centers using luffa boxes. The availability of the resource and the possibility to grow the crop makes this option attractive not only for Senegal but also for other sub-tropical countries producing mangoes where luffa grows naturally. Collection of the luffa fruits should be restricted to the vines with support since the fruits are of better quality.

Also this avoids using luffa sponges that may rot due to higher than normal levels of humidity. Picking luffa fruits from the ground should be avoided since they are normally contaminated with undesirable bacteria. It might be necessary to wash the luffa sponges and dry them before use. For fruits collected in places where garbage has been dumped it would be recommended to add bleach to the water when cleaning the sponges.

Making luffa boxes to ship mango is an interesting avenue and an innovative use of a yet unexploited resource. Although it is closely tied to having a sufficient supply of luffa in Senegal to produce the boxes, it is possible to have boxes made at a reasonable cost. It would also be advantageous to investigate ways to have glue that could cost less and be from a natural source. A complete sector of activity could be added to the mango industry in Senegal with the manufacture of luffa boxes for carrying mangoes from the field to packing stations or customers. The supply of luffa sponge could be supplemented by growing the crop. Skills could be developed in the making and the repairs of the boxes and services created on the commercialization method of the product. The shipping box could be adapted for other fruits and vegetables opening up other commercial opportunities. Product development in order to propose different packaging alternatives could also be another path to promote growth in the sector. Luffa boxes would provide physical protection, be reusable, recyclable, biodegradable and manufactured efficiently with minimal cost, thus grouping many desired attributes for a green packaging material (Bachman, 2009). In a scale-up mode, the luffa sponges used would have to be sorted and washed, especially if collected freely in the bush. Depending on the age of the sponge the cleaning process can be very simple. The luffa sponges can be dried by laying them horizontally for a few hours and then vertically in a container to continue the drying process and to free up space. A container allowing free air flow would accelerate the drying process. Alternatively the sponges could be dried in a net bag in order to save space. The water used will have to be kept clean at all times in order to avoid transmitting bacteria to fruits that will be transported in the boxes. When collected in the bush the luffa fruits are likely to have a high level of non-uniformity. The fruits could be small, long, large or even very small. Other plants could also be present and could cause damages to the luffa fruit and the level of cleanliness of the sponges might vary from one vine to another. As naturally growing luffa vines are not trained they tend to lie on the ground leading to a reduced yield of fruits. The age of the luffa sponge would probably affect its strength. Further experiments could shed light on this aspect. Sponges from new luffa fruits are expected to be stronger than sponges from luffa fruits left on the vine for many months after full maturity. In the sorting process, irregularity in shape and size could be used beneficially by using certain type of thickness and length for specific parts of the box.

Figure 34 below shows how a model could be developed around the activity of making the boxes for mangoes and potentially for other fruits and vegetables vulnerable to mechanical damage during transport. Further studies could compare the ecological impacts of using luffa boxes with plastic crates or corrugated fiberboard used in the trade.

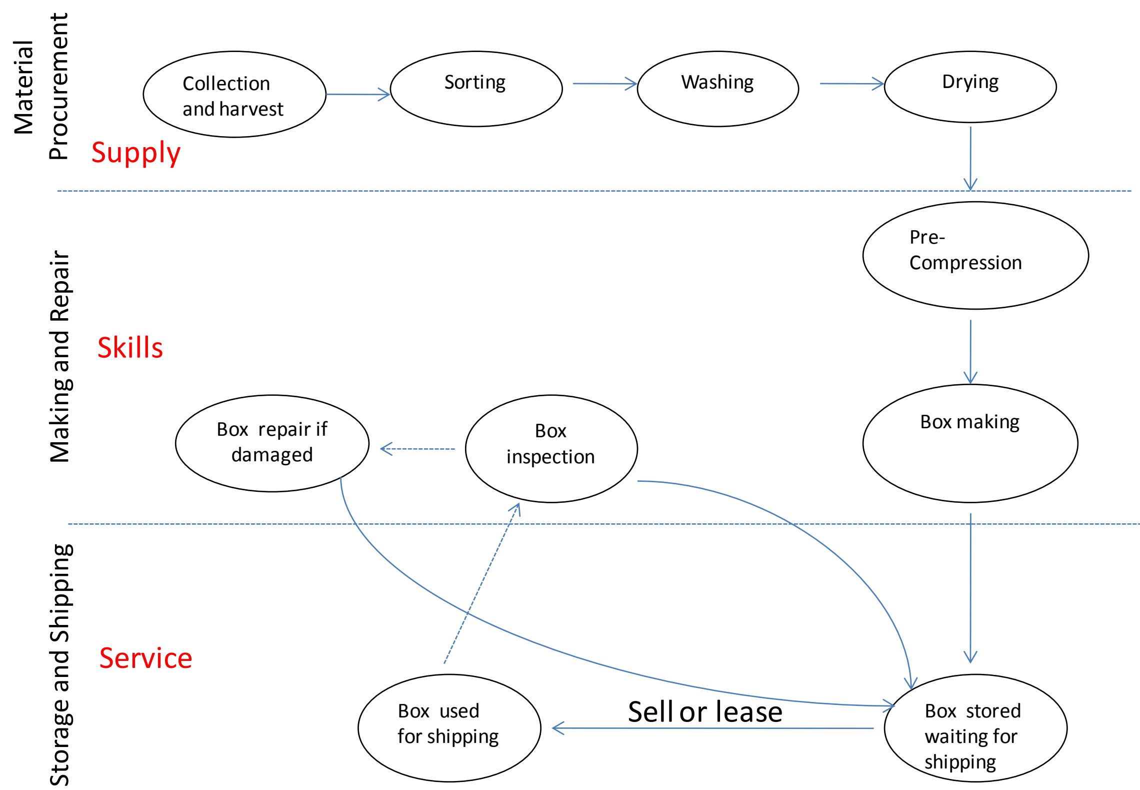

Figure 34 – Schematic diagram of the development of a luffa box production model

Besides local and national transportation, mango exporters could be interested in using the boxes to carry their crops from the field to their packing station as the quality of their fruits is even more strongly correlated to their expected revenue. The different stakeholders operating in this sub-sector need to ensure that their produce already transported brings the highest possible yield and meets the highest standards set in the destined markets. However some producers pack their mangoes to the customer`s requirements directly from the field in boxes that would be sold to the end customers. Those boxes are then transported to treatment stations closer to the shipping port or airport in Dakar. For such producers it would be beneficial to ship their production in luffa boxes and only pack them for the importer in the treatment stations in order to avoid mechanical damages due to the hauling of fruits from the field in corrugated fiberboard boxes.

CHAPTER IX

SUMMARY AND CONCLUSION

This study brought to light a number of desirable mechanical properties of luffa sponge as a packing material. The resistance to compression and strain as well as the elasto-plastic properties of luffa sponge makes it a remarkable biomaterial for shock absorbency. Its fibrous texture promotes fruits respiration and air circulation. The water absorption of the material facilitates the reversal of the plastic deformation allowing it to regain as much as 90% or more of its stiffness, strength and size after repeated compression. The modular assemblage of luffa samples that makes the box proposed in this study provides the flexibility to replace damaged luffa specimens rather than the whole box, prolonging even further its use in the mango and fruit transport channel. The perspective of making luffa boxes for shipping mangoes also adds a range of commercial activities that could be developed for the mango industry and beyond.

The supply of luffa in Senegal is abundant and found in many region visited during the field research component of the study. Luffa was found in Dakar, Ziguinchor, Sokone, Missira, Karang and in many other places. Most of the regions where luffa was found are also mango producing areas. It is therefore feasible to use luffa sponge in those regions to make boxes to ship the harvested fruits. This would not require importing the resource from a different part of the country with supply being close by. Additionally supply of luffa sponge could be provided relatively easily by production of the crop. A careful design of luffa boxes could help making solid packages for fruit transport with an underutilized and unexploited crop in Senegal, and probably in other places.

There is not enough scientific data concerning thermal, mechanical and chemical properties of luffa sponge (Tanobe *et al.*, 2005). With regard to its potential as a packing material luffa sponge remains an interesting material that could be used in many different forms. Further research on luffa sponge would certainly result in an increased and wider use of luffa especially in the industrial sector. Shipping mango in luffa sponge boxes is a plausible approach to reduce post-production losses of mangoes due to mechanical damage during transport in the Senegalese context. Further work towards scaling up the production of the luffa boxes and investigating other packaging applications for fruits and vegetables subject to mechanical damage during transport would be advisable. Luffa sponge can be sourced in the area where the boxes would be produced and used. The boxes made could be manufactured using clean production techniques and technologies based on the principle developed in this research study with the ‘box-making-tool’. Finally, they could be produced at a relatively low cost and optimize the use of energy.

This study has set the framework and preliminary steps towards the development of adequate and sustainable transport boxes for mangoes and also other fruits and vegetables subject to mechanical damage during transport from the field to consumers.

CHAPTER X

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CHAPTER XII

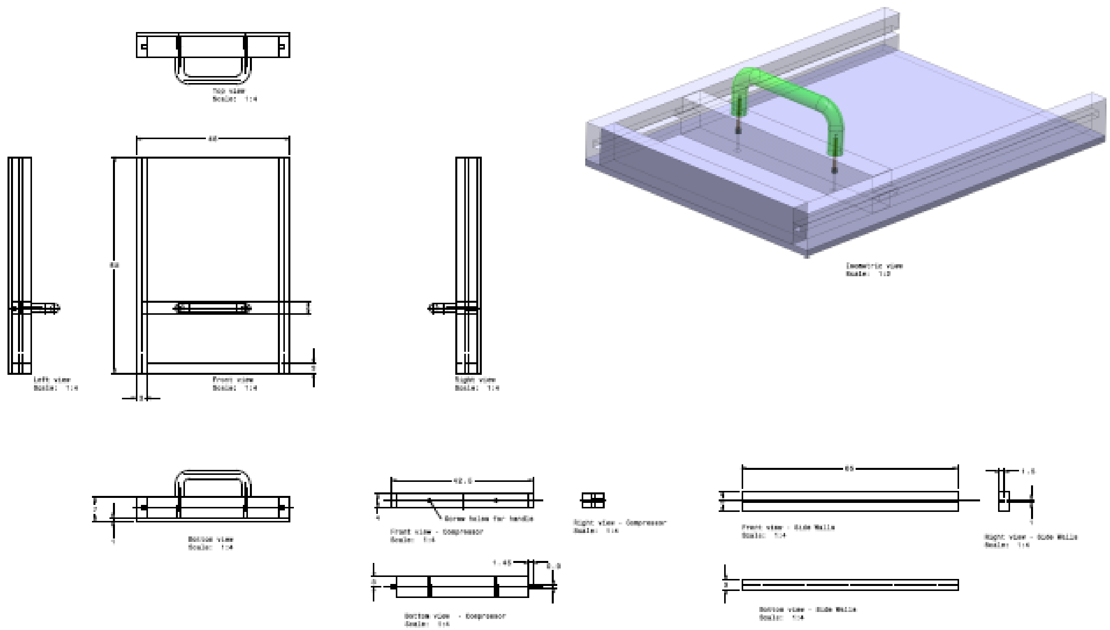
APPENDICES

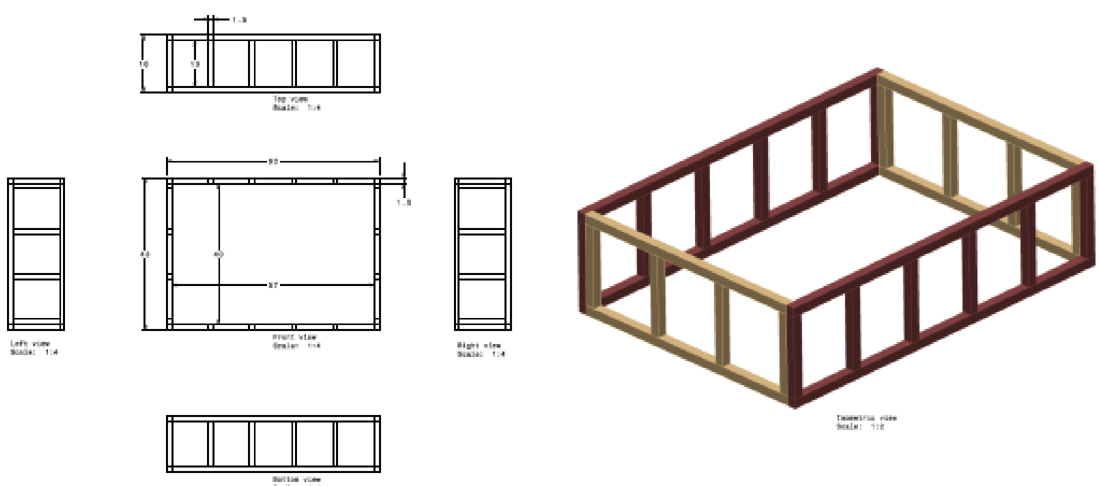
Appendix 1 - Technical drawings of luffa Box-making tool

Appendix 2 - Pictures of luffa growing in Senegal

Appendix 3- Pictures of luffa Box-making tool and luffa boxes made in Senegal

Appendix 1 - Technical drawings of luffa Box-making tool





Appendix 2 - Pictures of luffa growing in Senegal

Luffa growing on piled-up bricks in a neighborhood in the city of Dakar

Luffa growing abundantly in a yet to be built compound in Dakar

Luffa growing along a fence wall in Dakar

Dried up luffa plant on a tree along the street in Ziguinchor

Appendix 3- Pictures of luffa Box-making tool and luffa boxes made in Senegal

Luffa box-making tool showing ‘Base-maker’ and handle

Luffa sponge box

Two luffa boxes made in the field with one in the ‘Finisher’ part of the box-making tool