EVALUATION OF BIODEGRADABLE CONTAINERS FOR SEEDLING PRODUCTION IN TREE NURSERIES

BY
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(2018-17-011)

THESIS

Submitted in partial fulfillment of the requirement for the degree of

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DEPARTMENT OF SILVICULTURE AND AGROFORESTRY
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VELLANIKKARA, THRISSUR- 680656
KERALA, INDIA
2020

DECLARATION

I, hereby declare that the thesis entitled **"Evaluation of biodegradable containers for seedling production in tree nurseries"** is a bonafide record of research done by me during the course of research and this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

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1. INTRODUCTION

Environmental degradation is the biggest concern that impacts all domains of human life. Apart from the perceived climate change, manmade pollutions bring considerable deterioration in the environmental quality. The excessive use of non-biodegradable plastic has started impacting the environment in serious proportions. Plastic based materials are widely used in agriculture and forestry primarily as seedling containers. The conservative estimates suggest that roughly 0.35 million tons of plastic are used in agricultural sector annually (Patel and Tandel, 2017). The economic feasibility, durability, easiness of handling, irrigation and application of plant protection measures make it most popular among the nursery containers. However, such massive use of plastic for plant container production causes serious environmental degradation such as longer periods of non-degradability and consequent soil degradation, blocking sewerage systems, breeding areas for mosquitoes and other vectors, etc. (Sanghi, 2008 and Adane and Muleta, 2011). This calls for alternate strategy to substitute plastic containers.

In Kerala state (India), the Forest Department is the major agency involved in the practice of production forestry which meets the planting material requirements through the central nursery facilities available across the state. In addition, the College of Forestry under the Kerala Agricultural University and large number of private nurseries across the state are involved in production of forest tree seedlings. All these nurseries primarily depend on polythene bag containers for seedling production. In the context of general awareness on the roles of trees in maintaining environmental stability and mitigating climate change and massive tree planting initiatives are made by government agencies and non-governmental organizations. This calls for large scale production of quality planting materials in the forestry sector in the future. Plastic container-based nursery production has been the major approach by virtue of its multitude of managerial and economic benefits. However, considering the possible environmental concerns on the use of plastic in the forest nurseries it is imminent to evolve effective biodegradable containers to replace polythene bags.

The desirable characteristics of good seedling container include its potential to hold potting media, supply water and minerals, physical and mechanical support to planting stock, facilitate healthy root system with balanced root: shoot ratio, cost effectiveness and easiness in nursery and planting practices. Forest trees in general need longer periods of retention in the nursery. Seedlings characteristics and field performance can be strongly influenced by the nursery regimes. Seedling quality has been strongly influenced by size of the containers, growing density and design characteristics of the containers. Larger containers produce large sized seedlings. However, optimum size of the containers varies with species, growing density, environmental condition and length of the growing season (Tsakaldimi *et al*., 2005).

The biodegradable containers owe considerable advantages over the polythene tubes. Some of the potential advantages include, planting of seedlings with entire container, provision of better drainage and aeration promoting root growth, minimize transplanting shock, little disruption to the vigour of the seedlings as the roots grow through the side wall of the pot into the soil thereby reducing the problem of root congestion caused by plastic pots. However, the main disadvantages are that the biodegradable containers are fragile and require careful handling during transportation of seedlings. They also lack a solid wall which prevent in training the roots to the lower part of the container. Being bio-materials, chances of the container being infested with algae and fungi are more which may affect the growth of seedlings and overall hygiene. Yet another factor of concern is the high cost of bio-degradable containers. The quality bio-degradable containers available in the market are costly and hence may not be economical for mass production of seedlings. However, consumer demand for environmentally conscious products and practices is on the rise and consumers are willing to pay more for eco-friendly products, such as plants grown in biodegradable containers (Behe *et al*., 2013).

There are many types of bio-containers available. Composted dairy manure containers made up of composted, compressed cow manure with binding agent, containers made from peat and paper fiber, paper containers, rice straw containers, rice hull containers made up of grounded rice hull, etc. are some of such materials available in the market (Beeks and Evans, 2013 b). However, these containers are suitable for horticultural crops and too costly for large-scale production of tree seedlings. Furthermore, the efficacy of such containers for production of tree seedlings with longer periods of retention in forest nurseries is yet to be tested.

In this backdrop attempt was made to develop bio-degradable plant containers specifically suitable for tree species using locally available cheaper materials such as coir pith, cow dung, sugarcane bagasse, arecanut sheath, mud pots, bamboo splits, etc. Also the efficacy of biodegradable materials available in the market such as jiffy pots, nonwoven bag, reinforced cloth bag, bioplastics and treated cardboards were tested for their utility for growing forest tree seedlings. Considering the overwhelming importance of teak (*Tectona grandis*) as the predominant tree species of demand in the forest nurseries of Kerala, the present study was undertaken with teak as the test crop.

The objective of the study is to develop alternate eco-friendly plant container as substitute for conventional polythene bag based containers in forest nurseries.

2. REVIEW OF LITERATURE

The over use of plastic in the plant container production sector raises serious environmental concerns globally. The quest for developing alternative bio-degradable containers is the need of the time and is being tried across the world. The present study attempts to explore the possibility of developing such biodegradable containers for quality seedling production in the tree nurseries. The ensuing chapter gives a brief review of the pertinent works in this field.

2.1. Container type:

There is a paradigm shift presently that conscious consumers are displaying greater interest towards the nursery and greenhouse production practices, which reduce the usage of plastic containers. In order to substitute the conventional polythene bags, such attempts have been made in several parts of the country. Plantable, compostable and recyclable alternative containers are available for growing seedlings (Nambuthiri *et al.,* 2015). However, successful attempts on cost effective, bio-degradable containers for production of long duration tree seedlings are very much limited. Numerous factors play critical roles like the performance of the crop, production efficiency and various environmental factors. These must be accounted prior to adopting alternative containers. Works on various container types have been explained below.

Plantable Container:

These containers are planted directly along with the seedlings. Subsequently, these are subjected to accelerated breakdown, which allows the roots of the plants to infiltrate through these pots in order to spread in the soil. Albeit, these containers may lead to root damage and result in transplanting shock (Khan *et al.,* 2000). This is particularly true for raising tree seedlings which are to be retained in the nursery for longer periods.

Compostable Container:

These containers are required to be separated and composted individually prior to transplanting in the field. These containers are generally made of bio-plastics.

Additionally, they also made up of peat, the pulp of wood, rice hull, and thicker-walled paper (Nambuthiri *et al.*, 2015; Beeks and Evans, 2013b; Sartore *et al.*, 2016; Nambuthiri and Ingram 2014 and Tsakaldimi *et al.*, 2005). Here also trials on their efficacy for raising tree seedlings are very much limited.

Recycled Plastic:

Recycled containers are composed of plastic that is generally recycled from water bottles and soft drinks bottles. The natural biodegradable fibers can be attributed from cotton, jute, leaf fibers, bamboos, etc. are mixed after turning these bottles into liquid. These containers are superior compared to plastic because they will leave behind lesser residue (Nambuthiri *et al.*, 2015).

Materials used for alternate container:

In the present scenario, consumers tending to be more environment conscious are looking for alternatives. Different kinds of materials used as alternate containers are explained as below:

Pressed Fiber:

Hot pressed fibre containers are composed of fibrous materials like peat, rice hull, coconut coir, wood pulp wheat or paddy straw, bamboo, or spruce fibres which are readily available in the market. There are limited studies about their suitability for tree seedling, however they are used for several horticultural species. These containers tend to facilitate the exchange of water and air between rooting and surrounding substrates as they tend to be semi-porous in nature (Nambuthirti *et al*, 2015 and Ruter, 2000b). Bioconatiners reduce the heat stress impact in the root zone and experienced a slow increase in root temperature than in nonporous polythene container and facilitated the exchange of air and water (Ruter 2000b; Arnold and McDonald 2006 and Wang *et al.*, 2012).

Bioplastic:

Bioplastics constitute the biopolymers and petrochemical-based polymers. These plastics are composed of biopolymers that are composed of renewable raw materials such as starch or cellulose from organic feedstocks (such as beet, maize, corn, potato, cassava, sugarcane, palm). Secondly, these may constitute protein from feathers, which are the waste poultry and extracted from soybeans or keratin, lipids come from vegetable oils and animal fats. In the current scenario, the nursery containers deploy two types of bioplastic, namely the starch-based plastic and polylactic acid. These containers can be discarded either by composting or anaerobically digesting to proper plant development (Nambuthiri *et al.*, 2015). Sleeves are yet another type of materials that account for several small-sized containers that grow substrates wrapped in paper, fiber, or bioplastic sleeve like the Ellepot, which is made of paper.

With the advancement of knowledge and growing awareness for environmental sustainability several trials had been carried out by using various materials in order to find out the alternative suitable candidate of poly bag and its efficacy was tested for supporting seedling growth. For instance, in Kerala, conventional containers made from locally available materials such as bamboo splits, leaves of trees and other materials such as gunny bags were tested as containers for growing seedlings but found to be unsuitable for large scale forestry programs (Nandakumar, 1996). Later on, various biodegradable containers were developed and used in the nursery like biodegradable containers made from processed waste poultry feathers and their impact was studied (Evans and Hensley, 2004). The seedlings grown in feathered containers were higher than those grown in peat containers but similar to that of polythene bag containers. Feathered containers need more irrigation to make the walls absorb water. These containers also showed high nitrogen content in the tissues of tomato seedlings.

Tsakaldimi *et al.* (2005) raised two mediterranean Oak species (*Quercus ilex, Quercus coccifera*) in biodegradable containers made up of paper (Paper pot FS 615) and two kinds of plastic containers (Quick pot T18, Plantek 35F) and investigated their root growth, stem growth and field performances. Another study was carried out by Li *et al.* (2015) used two paper bio containers to grow one year old *Betula nigra*, (river birch) species. The biocontainers remained unchanged at the end of the first growing season. However, they were infiltrated to various degrees during the second growing season, depending on the root growth vigour at a given location and type of pots. Nambuthiri and Ingram (2014) incorporated the paper containers and a 4 to 6-

month decomposition timeline was also tested for their efficacy. They found that paper and bioplastic containers began to breakdown after 10 weeks of production and were almost completely degraded after 4 months in the field. Trials suggested that bioplastic, solid rice hull and slotted rice hull containers proved to be a good substitute for plastic containers (Beeks and Evans, 2013). Additionally, materials, such as paper, clay, animal manures, pure organic matter, and partially decomposed leaves used to make jiffy pots, facilitated the commercial transplantation of plants that were raised in the nursery (Khan *et al.,* 2000). However, their utility for forest tree species in the humid tropics is not much studied.

Subsequently, a triaxial sapling braided jute sac was developed as an eco-friendly substitute for polybags by Ghosh *et al.* (2016). In yet another trial biodegradable container made up of cellulose papers and banana sheath were used to grow *Calliandra calothyrsus* seedlings and compared their growth performances in the nursery as well as in the field under varying watering (Muriuki *et al*., 2013). Another set of biocontainers such as rice hull, paper containers and containers made up of 80 percent cedar fibre and 20 percent peat, cow pot and peat container has been evaluated with respect to their physical properties and compared with polybags. It was observed that with the exception of rice hull and OP47 container allowed water to evaporate through the wall of the containers and had high water use than plastic container (Evans *et al.*, 2010). Additionally, Castronuovo *et al*. (2015) tested growth performances of the Poinsettia (*Euphorbia pulcherrima*), an ornamental plant which are in high demand in Europe and North America by growing them in three different forms of biodegradable pots i.e. biodegradable polyester, plain or added with plant fibers. It was observed that plants grown in bio pots added with plant fibers showed increased number of inflorescences, distance between bracts, dry matter and fresh weight of stems. Mechanical test revealed that pots made up of 100% biodegradable polysters had good mechanical resistance. Pots charged with plant fiber were found to be unsuitable for poinsettia cultivation because of rapid fall of tensile strength. Agronomic qualitative as well as quantitative indexes were studied. The physical characteristics of the pots were tested as well.

The trials in these arenas suggested that bioplastic, solid rice hull and slotted rice hull containers proved to be a good substitute for plastic containers (Beeks and

Evans, 2013b). The biodegradable pots that were prepared with protein hydrolysate polyethylase glycol (prepared from waste of leather industries and, poly ethylene glycol (PEG) or produced from epoxidized soybean oil, sawdust showed good mechanical resistance. They entirely degraded when integrated directly in the soil, promoting fertilizing effect on the culture (Sartore *et al*., 2016). Yet another research focused on the waste and by-products from paper, textile and agro-food firms such as tomato peels, seeds and hemp. These materials can be mixed with sodium alginate to minimize this waste as well as to counteract the accumulation of plastic pot waste generated in plant nurseries. This in turn, can be utilized to manufacture decomposable pots for plant transplantation in agriculture (Schettini *et al*., 2013). Furthermore, the bioplastic container that is composed of a biopolymer (Mirel; Metabolix, Cambridge, MA), based on polyhydroxyl alkanoate polymers were produced by fermenting renewable carbon-based feedstocks, which principally contained corn (Nambuthiri and Ingram, 2014).

In a recent trial to enhance the natural preservation activities of coastal sand dunes, a new bio container was developed from beach cast sea grass wrack and a bio-engineered polymer. The long term performances were studied for two seagrasses *Cymodocea nodosa* and *Zostera noltei* and two dune plants, *Euphorbia paralias* and *Thinopyrum junceum*, using this biocontainer in nurseries (Balestri *et al*., 2019).

Despite these, available information on biodegradable containers for the long gestation period for forest tree species is scarce, especially for trees in the humid tropic region. Hence there is an urgent need to undertake studies to develop alternate eco-friendly containers for use in tree nurseries.

2.2. Performance of Seedlings in the container:

Balestri *et al*. (2019) assessed two seagrasses namely *Zostera noltei* and *Cymodocea nodosa* in addition to two dunes plants namely *Thinopyrum junceum* and *Euphorbia paralias. They* observed their long term success by growing them in the nurseries

The long term growth performance of seagrasses (*Zostera noltei* and *Cymodocea nardus*) and dunes plants namely *Thinopyrum junceum* and *Euphorbia* *paralias* seedlings were tested in the nursery in bio-containers and non-biodegradable container made from traditional plastic (Balestri *et al*., 2019). They observed that all the seedlings grown in the bio container grew better compared to non- biodegradable container-grown seedlings. Also nearly after six months 80 per cent of the *C. nardus* nursery plants raised in the bio-container colonized to the nearby substratum, whereas those planted by the conventional method were destroyed. These findings advocated that the containers can sustain the growth of plants and can provide protection and anchorage to the seedlings.

In an extensive study Conneway *et al*. (2015) investigated the efficiency of ten commercially available alternate containers. The study involved experiments on long term greenhouse crop 'Elegans Ice' lavender (*Lavendula angustifolia*) and on short-term greenhouse crop 'Sunpatiens Compacta' impatiens (*Impatiens* ×*hybrida*). The reports showed that plant growth at most locations varied on the dry weight courses in various containers. The observation suggested natural containers like the straw and bioplastic sleeve illustrated better dry weight shooting compared with the pots that were made of plastics. It was also observed that containers made up of cow dung manure showed high pH reading in comparison to peat. In addition, the growth of Geranium, `Cooler Blush' vinca, Janie Bright Yellow' marigold was evaluated constant and uniform irrigation conditions. The containers used were made up of either peat, plastics, or poultry feathers. It was observed that the dry shoot weight was higher in plastic container-grown plants. The second-best growth was observed in the feather containers, and the least growth was observed in the peat containers.

Containers composed of braided jute was found to be one of the eco-friendly, safe replacements for polybags (Ghosh *et al.,* 2016). These jute bags can prevent soil losses in the nursery. Also the jute bag increased the amount of soil nutrients with a noticeable increase in concentrations of phosphorus, potassium, and organic carbon. Other variants of eco-friendly options are jiffy pots which are composed of (Paper + Clay + animal manure of animals). These can additionally contain decayed manure of animals, municipal solid waste, and partially and completely decomposed leaves. The test results of seedling performance of pea and wheat indicated normal root growth of both the seedlings (Khan *et al*., 2000). Scholars like Muriuki *et al*., 2013 assessed the basal diameter and height growth along with the frequency of the water requirements for the seedlings of the *Calliandra calothyrsus* for various biodegradable containers under varied level of water requirement. It was observed that seedlings which were grown in containers made of biodegradable material needed more water than in polythene bags. The seedlings which were produced in the polythene tubes showed better growth in the nursery.

Many reports such the use of plantable containers for developing ground cover plants. The plants grown in the container of 90-mm paper and bioplastic vessels (container) of 80-mm were similar to the plants that were grown in the normal containers made of rigid plastic of 3-inch size. It was observed that they required 20 percent less transplantation time into the landscape and had faster growth after field transplantation (Nambuthiri and Ingram, 2014).

Additionally, a comparison was made to highlight various positives and drawbacks. The comparison highlights the contrasts of the containers made of biomaterials and plastics were recorded during production or establishment in the landscape on plant growth and development. A research was carried in Center for Applied Horticulture Research (CAHR, Vista, CA) on the tomato plants (*Solanum lycopersicum*). When grown in plastic conatiners, they showed higher shoot dry weight in comparison to those grown in several biodegradable pots (like wood fibre, cow dung manure, and coconut coir). Nevertheless, the recycled paper container grown seedlings showed the same shoot dry weight as that of plastic grown seedlings (CAHR, 2009). Of the plants grown in plastic containers, root dry weight was found to be greater than for all other types of containers.

It was reported that *Euphorbia pulcherrima* plant showed substantial improvement in the formation of roots, improved plant height and dry shoot weight when grown in recycled paper for 12 to 16 weeks relative to that grown in straw, sphagnum peat moss, wheat starch-derived bio resin, and those of pulp of wood (Jiffy-Pot), coir of coconut, cow pots that composed of manure of composted cow, Net Pot made of rice hull, (Lopez and Camberato, 2011). In another trial on the suitability of various container for raising *Cyclamen persicum*, it was observed that the plants grown in bioplastic, solid rice hull, slotted rice hull, paper, peat, dairy manure, rice straw and coconut fiber container had significantly higher dry shoot weight than plants grown in plastic containers (Beeks and Evans, 2013a).

Despite such vast information on the utility of containers for agronomic crops such reports on tree seedlings are very much lacking. In a trial, the performance of *Quercus ilex* and *Quercus coccifera* were tested in three container types and results showed that seedlings of *Quecus ilex* grown in *paper-pot* performed considerably better in terms of height, diameter, shoot and root biomass and root volume than the seedlings grown in the plastic containers. Likewise, seedlings *of Q. coccifera* grown in *paper-pot* exhibited significantly greater above and below ground growth than those grown in the plastic of containers. Also, the *paper-pot* seedlings of the two oak species demonstrated improved field efficiency two years after the out planting (Tsakaldimi *et al*., 2005).

Schrader *et al*. (2015) developed and tested 46 new biodegradable containers (35 injection-molded bioplastics or biocomposites and 11 biopolymer-coated fiber containers) in green house, nursery, and landscape studies. The greenhouse and nursery tests found that most of the injection-molded bioplastics function for crop containers showed similar or better than, petroleum plastics. Bioplastic and poly lactic acid (PLA) from composite soy materials have been shown to release nitrogen (N) at a rate appropriate to sustain plant growth (Currey *et al*., 2016).

2.3. Container Characteristic:

The production of seedling has been highly affected by container capacity, rising density and container construction characteristics. Large containers produce large size seedlings. Optimum container size, however varies with growing density of the species, environmental situation and length of the growing period (Tsakaldimi *et al*., 2005). Alternative containers during manufacturing and distribution differ in quality as well as in intensity. Greenhouse managers reported loss of saleable products and biodegradable containers are susceptible to injury and are easily broken during transportation. The physical strength of cow manure and peat containers was observed by Koeser *et al*., (2013) who suggested that, during greenhouse growth, packaging, shipping, and retailing, some biocontainers can tear or break, particularly in wet condition. So, they need to be handled carefully.

Certain biocontainers like coir, rice hull and recycled paper containers are having highest wet and dry vertical and lateral strength similar to that of traditional containers among other biocontainers like straw containers and bioplastic (Evans *et al*., 2010). These containers also showed no incidence of algal or fungal growth in their walls, while containers those absorb moisture with sidewalls will soften and promote algal and fungal growth and consequently decrease strength (Evans and Karcher, 2004).Terra Shell/OP47 containers with thin wall had the lowest dry punch strengths. Containers made from fiber, composted manure, or peat had low wet vertical strength and moderate dry vertical strength. Wood fiber (Fertil), peat (Jiffy-Pot) and composted manure pot have low strength when they are wet. In a 14-week greenhouse evaluation of 'Eckespoint Classic Red' poinsettia production, the color and integrity of plastic, rice hull, wheat starch (TerraShell/OP47), and recycled paper containers remained unchanged, while acceptable quality plants grown in peat (Jiffy-Pot) and composted cow manure (Cow Pot) containers were not marketable due to loss of container integrity or mold and/or algal growth resulting poor appearance (Lopez and Camberato, 2011). Similarly, in a 15-week greenhouse study with 'Rainer Purple' cyclamen it was found that bioplastic, solid rice hull, and slotted rice hull containers were good plastic alternatives (Beeks and Evans, 2013b). These containers had similar irrigation requirements, retained high levels of punch and tensile strength, and did not support growth of microorganism. However, due to heavy infestation of microbes, weak strengths of containers and more frequent irrigation requirements containers made of rice straw, wood fiber, cow manure and peat were not acceptable alternatives to plastic containers (Beeks and Evans, 2013b ; Conney *et al*., 2015).

Reports on attempts to reinforce the bio-degradable containers using desirable constituents has been attempted by many. In an experiment, the addition of poly butylene adipate-co-terephtalate has enhanced the elasticity of bio-containers based on poly lactic acid. The Presence of thermo plasticised starch facilitated higher container biodegradation rate and the containers did not exhibit plant phytotoxic effect (Castillo *et al*., 2019). In yet another study, bio-containers made from rice straw and starch adhesives modified by polyvinyl alcohol, heat treatment and polyamide resin were studied for hygroscopicity, degradability, and the thermo gravimetric analysis. The findings revealed that both procedures had improved the dry strength of the container. Due to heat treatment, wet strength of the planting container increased, while the wet strength of planting containers decreased due to polyamide resin. With heat treatment and polyamide resin the hygroscopicity of the planting containers decreased. The heat treatment containers where used for planting were not readily susceptible to mildew. The thermo gravimetric analysis (TGA) has shown that heat treatment may increase thermal stability, while the polyamide resin has been reported to facilitate planting container deterioration (Wu *et al*., 2013).

Schrader *et al*. (2015) found that cost and weight can be reduced and processability and decomposition of the bioplastics can be increased by using bio-fibres to shape injection-molded bio-composite containers. Also water-use efficiency and longevity of containers can be increased by coating fibre containers with bio-plastics. Several field studies proved that most of the bioplastics based containers and bio-composites degraded in the soil naturally suggesting that containers prepared from such materials may finish their life cycle as degraded organic matter in soil, rather than joining the solid waste system. Hence sustainability could be boost by replacing petroleum-plastic containers with bioplastic without losing features.

Sun *et al*., (2015) conducted field studies with seven plantable bio-based containers (wood fibers, peat, rice hull, straw, coir, manure and soil wrap) to determine the impact growth and development of seedlings as well as container decomposition rate. After 3 to 4 months in the field, manure containers had on average the highest decomposition rate at 88 per cent. The decomposition rates of rice hull, coir, peat, soil wrap, wood fibres and straw were 18%, 25%, 38%, 42%, 46% and 47% respectively. The plant establishment and post-transplant growth were not hindered by plantable containers. Compared to location (climate) the container had lower effect on plant growth. The effect of plant species on pot decomposition was similarly lower compared to that of container material.

3. MATERIALS AND METHODS

The present nursery trial titled “Evaluation of biodegradable containers for seedling production in tree nurseries” was carried out at College of Forestry, Kerala Agricultural University (KAU), Thrissur during 2019-2020. Details about the experimental site, materials used and methodology adopted during the course of investigation are discussed in this chapter.

3.1 Experimental site

3.1.1 Location

The experimental site is located inside the campus of College of Forestry, KAU, Thrissur which is situated at $10^0 32'$ N latitude and $76^0 26'$ E longitude with an altitude of 40 m above mean sea level. The location map is presented in Fig 1.

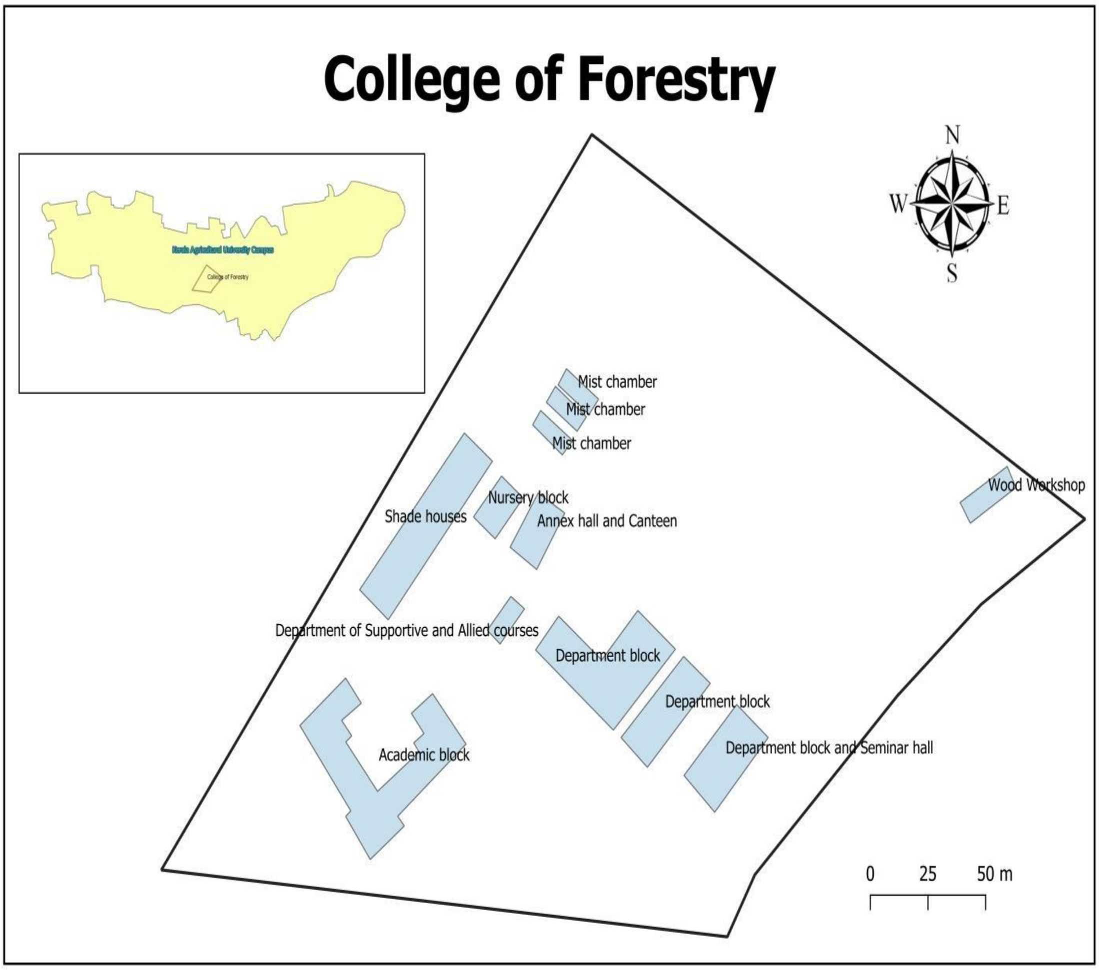


Fig1. Location of study area

3.1.2 Climate and weather conditions

The study area is coming under the humid tropical zone. The area enjoys warm humid tropical climate with mean annual rainfall ranging from 2650 to 3200mm with almost bulk share of the rains received during June-August. The mean maximum temperature during the study period was 36^0C (March) and mean minimum temperature 23 ^{0}C (January). The soil of the experimental site was deep well drained sandy clay loam of Ultisol order (Typic plinthustult- Vellanikkara series midland laterite- Ustic moisture regimes (dry period – February- May) and Isohyperthermic temperature regimes).

3.2 Experimental details

3.2.1 Preliminary trial (Experiment No.1)

The study was carried out in a phased manner with a preliminary screening of locally available biodegradable materials to serve as plant containers in 2019. Eleven types of containers were used in the preliminary trial which included containers made from locally available biodegradable materials. Also biodegradable materials available in the market were also used to develop containers. The containers were filled with the potting media (2 soil: 1coir pith: 1vermicompost by volume). Details about the various materials and their method of container production are described below:

1. Bamboo splits

The culms of mature bamboos (*Bambusa vulgaris*) were collected from the KAU campus and cut into appropriate sizes having capacity 15 cm height x 12 cm diameter. The bamboo culms were cut in such a manner that the nodal separation will act as the base of the container. After cutting to appropriate dimensions, the bamboo containers were longitudinally splitted into two equal halves and were tied with coconut sheath. The objective of splitting and tying was to facilitate easy dispensing of the seedlings at the time of field planting. This also facilitates the reuse of the bamboo splits as containers.

2. Mud Pot

The specially prepared mud pot containers were arranged from the local sources as per the required size specifications for the present study (capacity 15 cm height and 12 cm diameter) and were filled with the potting media.

3. Treated Card board pot

The cardboard sheets (thickness 3mm) were arranged from the local market and were cut into appropriate sizes (capacity 15cm x 12cm). The sheets were folded on both sides such that it turned into circular shape. The joined sides were stitched manually using jute lace. In order to enhance the durability and strength, these containers were treated with Cashewnut Shell Liquid twice and were adequately sun dried. The card board containers were filled with potting media.

4. Cloth bag

Thick cloth materials made of cotton were collected from the market and were stitched to container shapes as per the required dimensions (capacity 15 cm height x 12 cm diameter) with the help of local tailor.

5. Nonwoven cloth bag

The reinforced cloth materials were collected from the market and stitched to the required size (capacity 15cm x 12cm) and used as containers.

6. Coco pot

These pots made up of coco fibre were collected from the organization called Saintjo innovations, Kochi, Kerala. The coco fibres were pressed and glued appropriately to make the containers of standard dimensions.

7. Arecanut sheath

The matured fallen arecanut sheaths were collected and soaked in water for overnight such that it turned soft and foldable. Then the next day these sheaths were cut into 15cm length and folded in circular fashion in such a manner that it had a diameter of 12 cm inside. The folded ends of the sheaths were stitched manually with thread and needle.

8. Cowdung Pot

The pots made up of dry cow dung and pressed have been ordered from local manufacturer as per the required size specifications.

9. Sugarcane bagasees

The sugarcane bagasses were compressed and made into smooth plate which were then cut into required sizes and then stitched and used as containers.

10. Bioplastic bag

The thin sheets of bioplastic bags (180 gauge) were collected from Saintjo innovations, Cochin and used as containers.

11. Bamboo baskets

The bamboo baskets of required sizes were collected from bamboo artisans and used as containers.

Nursery activities in Preliminary trial

With a view to ensure the uniformity in the container volume, the size followed in the KAU nursery (12 cm diameter inside x 15cm height inside) was chosen as the standard for all the selected materials. Also the standard potting media (soil: coir pith: vermin compost @ 2:1:1 by volume) was used for filling the containers. Being the most dominant species raised in the forest nurseries, teak (*Tectona grandis*) was taken as the test plant.

Ten containers belonging to each of the above materials were prepared as described above and were filled with the standard potting mixture. Mature teak seeds of Nilambur origin were pre-treated by subjecting to alternate wetting and drying for one week. The pre-treated teak seeds were sawn in raised mother beds of size 2m x 1m. The seedlings were transplanted to the containers when they developed four leaves (15 days old). Care was taken to transplant uniform seedlings. The watering and weeding were carried out regularly.

The seedling growth (height and number of seedlings) and container attributes such as physical suitability for watering, durability, ability to hold the potting media, insect/ pest attack to the containers, cost and feasibility, etc. were observed at regular intervals for a period of three months.

3.2.2 Main trial (Experiment No.2)

Based on the preliminary trail of the year 2019, five best performing biodegradable materials were selected for detailed investigations to assess their long term suitability in the year 2020. These containers were: nonwoven cloth bag, coco pot, mud pot, bamboo splits and CNSL treated cardboard. Detailed investigations were made on the performance of these selected container types in the nursery at College of Forestry. In addition to the best five container types selected from the preliminary trial the coir root trainer (CRT) container supplied by the Kerala Forest Department also was included for detailed examination.

Experimental details:

Treatments: 6 container types

T_1- Nonwoven cloth bag

T_2- Coco pot

T_3- Mud pot

T_4- Bamboo splits

T_5- CNSL treated cardboard

T_6- Coir root trainer (CRT)

Experimental design: Completely Randomized Design

Replication: 3

Number of containers per replication: 30

Total number of containers: 540 (6 container type x 30 numbers x 3 replications)

Nursery operations for Main trial (Experiment No.2)

The raised nursery beds were prepared in 1st week of March, 2020.Teak seeds were collected from known superior source (Nilambur source) and were subjected to pre-treatment by overnight soaking of seeds filled in gunny bags and drying in open sun during day time. This process was repeated for seven days such that the seeds were sufficiently soft. The seeds were sown in raised mother beds at a spacing of 10cm x 10 cm and mulched with leaves. Intercultural operations like weeding and watering carried out regularly. The uniform germination achieved within two weeks after sowing. The selected six container types (90 bags for each container type) were filled with potting media (soil: coir pith: vermi compost @ 2:1:1 by volume). The healthy uniform seedlings of 15-day old (4-leaved) were pricked out from mother bed and transplanted in containers.

The performances of the seedlings in the containers were monitored at fortnightly intervals for a period of 2.5 months after transplanting (till 3-month old) wherein all the growth and biometric observations of the seedlings were taken. Samples from six containers for each of the materials were tested for root growth characteristics such as biomass, root distribution at quarterly intervals. The physical suitability of the container for irrigation and resistance to termite and other damages were monitored continuously. Detailed investigation on the economic feasibility of the technology was also carried out.

3.3 Observations recorded

3.3.1. Nondestructive sampling for growth parameters

Survival percent: The percentage of seedlings survived after each reading was recorded. This was calculated by number of seedlings survived out of total number of seedlings transplanted expressed in per cent.

Seedling height: The height of teak seedlings was measured from ground level to the tip of the main shoot with the help of scale and recorded in cm.

Collar diameter: The collar diameter of the teak seedlings was measured with the help of vernier calliper in two directions and average was computed and recorded in mm.

Number of leaves: The number of fully grown and green leaves of the seedlings was counted.

Number of branches: The number of branches developed in each seedling was counted.

3.3.2. Destructive sampling for biometric observations

During each of the sampling period (fortnight), five plants were randomly selected for destructive sampling for biometric observations such as shoot and root dry weight, root: shoot ratio, root length, root coiling, leaf area etc.

Leaf area: The Leaf area of the seedlings was measured by using leaf area meter (Li Cor, USA).

Shoot and root dry weight: The seedlings selected for sampling were carefully separated without affecting the roots. After removal of extraneous materials, the seedlings were washed carefully in running water. The seedlings were separated at the collar region by giving sharp cut. After air drying, the shoot and root portion of the each of the seedlings were transferred to separate paper covers and oven dried at 70^0C for 48 hours. The oven dry weights were recorded using digital precision balance to four decimals (Amur) and recorded in gram.

Primary root length: The primary root length of the seedlings was measured by scale and recorded at quarterly intervals in cm.

Number of secondary and tertiary roots: The number of secondary and tertiary roots was counted.

Lateral root spread: The length of secondary roots (lateral spread) was measured and recorded in cm.

Tendency of root coiling: The tendency of root coiling has been observed and recorded in cm.

Root length: shoot length ratio: The root length: shoot length ratio of the seedlings was computed from seedling height and primary root length.

Quality Index of seedlings: The quality index (QI) of each teak seedling was calculated as per the formula given by Dickson (1960) mentioned as below.

$$QI = \frac{Total\ Dry\ Matter\ (g)}{\frac{Shoot\ Height\ (cm)}{Shoot\ Base\ Diameter\ (mm)} + \frac{Shoot\ Dry\ Matter (g)}{Root\ Dry\ Matter (g)}}$$

The Dickson Quality Index - DQI is a tool to evaluate seedling quality as a function of total dry matter, shoot height, stem base diameter, shoot dry matter and root dry matter.

3.4. Economics of raising teak seedlings raised in different containers

The cost of plant raised in biodegradable containers was calculated by taking cost of container, cost of soil mixture, cost of labour and other inputs and also survival percent of seedlings. For comparing with the conventional method of raising seedling in polythene bag, in the table polythene bag of same capacity has also been included. The benefit: cost was calculated by using the following formula:

$$\text{Benefit : Cost ratio} = \frac{Gross\ benefit}{Totalcost}$$

3.5. Physical soundness of the containers

The container attributes such as durability, physical strength to hold the potting media for longer periods, response of containers to irrigation and fertilization, resistance to fungal and termite attack and other forms of degradation, etc. were monitored at regular intervals. The performance of each of the individual bag belonging to different container types were separately observed and recorded. Photographs of the containers were taken at regular intervals to observe the time course of such changes.

3.6. Statistical analysis

The data on various growth and biometric attributes of the seedlings grown in various container types were analysed statistically following one-way analysis of variance (SPSS version 21). The mean separation was computed following Duncan's Multiple Range Test (DMRT).

4. RESULTS

The study on the suitability of various biodegradable containers in tree nurseries was conducted during 2019-20. The study included a preliminary trial involving the screening of eleven locally available biodegradable materials as plant containers. The second trial was undertaken to make detailed investigation on the efficacy of the better performing container types selected from the preliminary trial. The test tree species for the nursery study was *Tectona grandis* (teak). Results are presented in this chapter.

4.1. Performance of the biodegradable containers in the preliminary trial

4.1.1. Durability of containers and growth of plants

Durability of containers: The durability of different containers in the nursery trial evinced considerable variation from one another in the preliminary trial (Table 1). It varied from one month to twenty-four months among the containers. Bamboo split pot demonstrated highest longevity in nursery (24 months) while the containers such as arecanut sheath pot, cow dung pot, sugarcane bagasee pot, bamboo basket, bioplastic bag and cloth bag degraded within one month. The remaining container types lasted for 12-15 months. The order of durability of container in nursery was found to be Bamboo splits > nonwoven bag = mud pot > coco pot = treated cardboard> arecanut sheath pot (T_6) = cowdung pot (T_7) = sugarcane bagasse pot (T_8) = bamboo basket (T_9) = bioplastic bag (T_{10}) = cloth bag (T_{11}).

Survival period of seedlings: The data pertaining to survival period of the seedlings manifested sound variation among different containers in nursery (Table 1). It was observed that the teak seedlings in the containers such as non-woven bag, coco pot, mud pot, bamboo splits recorded more than 24 weeks of survival while seedlings raised in sugarcane bagasee pot and bioplastic bag survived hardly for one week. The survival of seedlings in containers like arecanut sheath pot, cowdung pot, bamboo basket and cloth bag was for 2 - 4 weeks only.

Survival percent of seedlings: The survival percent of seedlings at 3 months after planting were exhibited good variation among different containers (Table 1). It ranged from 0 – 100%. The container made by bamboo splits registered maximum survival of 100%. On the other hand seedling survival in the container types such as arecanut sheath pot, cow dung pot, sugarcane bagasee pot, bamboo basket, bioplastic bag, cloth bag were nil at the end of three months of study. The seedling longevity in nonwoven bag, coco pot, CNSL treated card board pot ranged from 92 – 97% while mud pot recorded 72% survival of teak seedlings at the end of three months. The order of survival percent of seedlings in different containers was Bamboo split > Coco pot> Nonwoven bag > Treated cardboard pot > Mud pot > Arecanut sheath pot = Cowdung pot = Sugarcane begasse pot = Bamboo basket = Bioplastic bag = Cloth bag.

Table 1. Performance of the biodegradable containers in the preliminary trial of raising teak seedlings at Vellanikkara, Thrissur

Treatment code	Type of container	Durability of container in nursery (month)	Period of survival of seedlings (week)	Survival % of seedlings at 3 months after planting	Height of seedlings at 3 months after planting (cm)	Collar diameter of seedlings at 3 months after planting (mm)
T_1	Nonwoven bag	15	> 24	95	19.3	7.4
T_2	Coco pot	12	> 24	97	15.5	6.2
T_3	Mud pot	15	> 24	72	11.3	4.5
T_4	Bamboo split	24	> 24	100	16.7	6.5
T_5	Treated cardboard pot	12	≤ 16	92	13.2	5.1
T_6	Arecanut sheath pot	1	≤ 2	NA	NA	NA
T_7	Cowdung pot	1	≤ 3	NA	NA	NA
T_8	Sugarcane begasse pot	1	≤ 1	NA	NA	NA
T_9	Bamboo basket	1	≤ 4	NA	NA	NA
T_{10}	Bioplastic bag	1	≤ 1	NA	NA	NA
T_{11}	Cloth bag	1	≤ 4	NA	NA	NA

Height of seedlings: The height of seedling at 3 months after planting in the preliminary trial exerted good variation among containers (Table 1). It ranged from 11.3 -19.3 cm. Nonwoven bag achieved maximum seedling height growth (19.3 cm) while containers such as arecanut sheath pot, cowdung pot, sugarcane bagasse pot, bamboo basket, bioplastic and cloth bag could not record perceptible change in height growth as the seedlings in the respective containers died before 3 months after planting. Among the seedling surviving container types the order of seedling height was observed to be nonwoven bag > bamboo split > coco pot > treated card board > mud pot.


Seedlings in cowdung pot


Seedlings in mud pot


Seedlings in coco pot


Seedlings in bamboo basket


Seedlings in arecanut sheath pot


Seedlings in bioplastic bag


Seedlings in treated card board


Seedlings in sugarcane begasse pot


Seedlings in cloth bag


Seedlings in bamboo splits


Seedlings in nonwoven bag

Plate 1. Teak seedlings grown in different biodegradable containers

Collar diameter of seedlings: The seedling collar diameter also varied among different containers at 3 months after planting (Table 1). Nonwoven bag registered maximum value of 7.4 mm followed by bamboo splits and coco pot. As mentioned earlier, consequent to the damages to the containers and the associated seedling mortality, the collar diameter growth was nil in the in pots like arecanut sheath pot, cow dung pot, sugarcane bagasee pot, bamboo basket, bioplastic bag and cloth bag three months after the start of the experiment.

4.1.2. Merits and demerits of biodegradable containers in the preliminary trial

Cost of containers: The perusal of data in Table 2 reveals that cost of container varied considerably from one another. The cost was maximum per container for coco pot (Rs. 55) while the minimum per container was for nonwoven bag (Rs. 4). Among the containers reasonable cost of less than Rs. 10/- was reported for bamboo split, treated cardboard pot, bioplastic bag and cloth bag. The order of cost per container was: cocopot > mud pot > bamboo basket > cowdung pot = sugarcane begasse pot > arecanut sheath pot> treated cardboard > bamboo split = cloth bag > bioplastic bag > nonwoven bag.

Number of seasons container can be used: It was observed from the preliminary trial that the durability of container for raising teak seedlings varied from 0 – 2 seasons. The pot made by bamboo splits was found to be usable for two seasons. On the other hand containers such as arecanut sheath pot, cow dung pot, sugarcane bagasee pot, bamboo basket, bioplastic bag and cloth bag could not be used for even one full season. All the other pots could be used for one season.

Merits of containers: The data presented in Table 2 reflect the potential merits of different biodegradable containers for raising teak seedlings. Nonwoven bag was found as a low cost container supporting good growth of plants with good longevity and consistency for frequent irrigation. It has the ability to withstand degradation for the entire season of seedling production in the nursery. Bamboo split also supported good growth. It can be used for two consecutive seasons. Afterwards the bamboo splits can be used for other uses as fuel wood. Coco pot and mud pot can be used for one season after which these may degrade.

Demerits of containers: Certain demerits were observed in different biodegradable containers (Table 2). The containers like arecanut sheath pot, cow dung pot, sugarcane bagasse pot, bamboo splits, bioplastic bag and cloth bag were found very susceptible to frequent irrigation and degrade within a month in the nursery condition.

Table 2. Merits and demerits of the biodegradable containers tried in the preliminary trial for raising teak seedlings at Vellanikkara, Thrissur

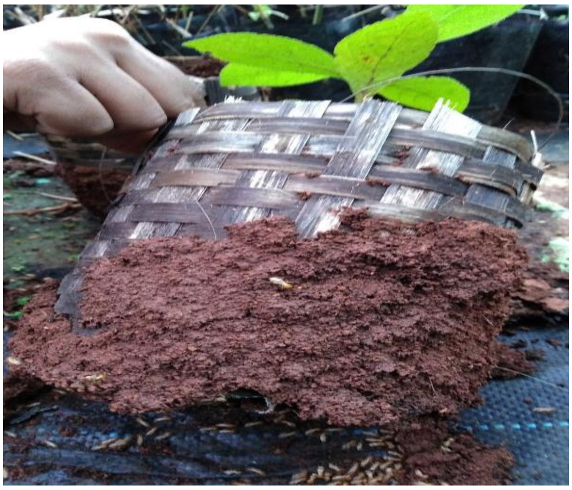
Type of Container	Cost of one container (Rs)	Number of seasons container can be used for raising teak seedling	Merits	Demerits
Nonwoven bag	4.0	1	-Relatively low cost -Degradable after one season -Good growth	-Partly plastic
Coco pot	55.0	1	-Degradable after one season	- Very high cost
Mud pot	40.0	1	- Degradable in soil after planting in due course of time	-High cost -Poor aeration -Poor growth
Bamboo split	7.0	2	-Can be used for 2 seasons -After that can be used as fuel -Good growth	Difficulty in handling due to bulky size
Treated cardboard pot	8.0	1	-	-Very susceptible to water -Does not last even for a season
Arecanut sheath pot	10.0	0	-	-Very susceptible to water - susceptible to fungi
Cowdung pot	20.0	0	-	-High cost -Very susceptible to water
Sugarcane begasse pot	20.0	0	-	-High cost -Very susceptible to water - susceptible to water
Bamboo basket	30.0	0	-	-High cost -Very susceptible to water - susceptible to termite
Bioplastic bag	5.0	0	-	-Very susceptible to water -Very susceptible to fungi
Cloth bag	7.0	0	-	-Very susceptible to water -Does not stand erect -Difficult to handle the plant


Cowdung pot infested with termite


Fungus attack on sugarcane bagasee pot


Disintegration of Arecanut sheath pot


Physical disintegration of Bioplastic bag


Termite attack on bamboo basket


Fungus growth on cloth bag

Plate 2. Demerits of some biodegradable containers

They failed to support the teak seedlings for more than one month. Also most of these containers were costly and unsuitable for commercial production of teak seedlings. Bamboo basket had severe problem of attack by termites. Coco pot and mud pot were too costly for commercial production. Further, mud pot showed poor growth of teak seedlings. Fungal growth was rampant in sugarcane bagasee pots and cloth bag which severely affected the growth of seedlings.

4.2. Main trial on the performance of selected biodegradable containers

Among the eleven containers developed from locally available biodegradable materials, five container types viz. Nonwoven bag (T_1), Coco pot (T_2), Mud pot (T_3), Bamboo split (T_4), Treated cardboard pot (T_5) were finally screened based on the overall performance for supporting seedling growth. In addition to these the Coir root trainer (CRT) (T_6) supplied by Kerala Forest Department was also included. They were later subjected to detailed investigations by raising teak seedlings. The pertinent observations are presented here under.

4.2.1. Seedling survival

The perusal of data on survival of teak seedlings in different biodegradable containers reflected significant variation at different stages of seedling growth except for the first month which registered complete survival (100%) for all the six selected container types (Table 3). In general, all the container types recorded better seedling survival during the entire period of observations. Except for the mud pot, almost all the container types showed higher survival (> 90%) even after 75 days of seedling

Table 3. Survival percent of teak seedlings in different biodegradable containers at Vellanikkara, Thrissur

Type of container (T)	Survival percent of teak seedlings				
	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP
Nonwoven bag (T_1)	100	98^{ab}	96^{a}	96^{a}	96^{a}
Coco pot (T_2)	100	100^{a}	98^{a}	98^{a}	98^{a}
Mud pot (T_3)	100	89^{b}	83^{b}	73^{b}	71^{b}
Bamboo split (T_4)	100	100^{a}	100^{a}	100^{a}	100^{a}
Treated cardboard pot (T_5)	100	97^{ab}	95^{a}	94^{a}	94^{a}
Coir root trainer (CRT) (T_6)	100	95^{ab}	94^{a}	93^{a}	93^{a}
p- value	-	0.162	0.066	0.007	0.007

***** *Means with same letter are not significantly different*
* DAP- Days after planting

growth. Among the containers, bamboo splits registered 100% survival of seedlings throughout the period of observation. However, mud pot showed consistent reduction in seedling survival with increase in seedling age with a lower value of 71% at 75 days after planting. The order of survival percent was Bamboo split (T_4) > coco pot (T_2) > nonwoven bag (T_1) > treated cardboard (T_5) >Coir root trainer (CRT) (T_6) > mud pot (T_3).

4.2.2. Seedling growth

Height growth: The height growth of teak seedlings exhibit significant variation among different containers at different stages of seedling growth (Table 4). Except for the initial period (15 DAP) the seedling height varied significantly among the container types. There was consistent increase in seedling height in all the container types with increase in days after planting, though it varied among the container types. Among the containers nonwoven bags recorded consistently higher seedling height during all the periods under observation. For instance, there was 4.7-fold increase in seedling height for nonwoven bag seedlings at 75 DAP as compared to the height growth at 15 DAP. This was followed by containers based on bamboo splits which also recorded fair height growth at the end of the study period (4.2-fold increase). However, among the container types mud pots showed lowest seedling height growth

Table 4. Height growth of teak seedling in different biodegradable containers at Vellanikkara, Thrissur

Type of container (T)	Seedling height (cm)				
	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP
Nonwoven bag (T_1)	3.7^{a}	7.0^{a}	10.2^{a}	14.1^{a}	17.6^{a}
Coco pot (T_2)	3.5^{a}	6.0^{abc}	8.3^{bc}	11.1^{b}	13.6^{bc}
Mud pot (T_3)	3.2^{a}	4.6^{d}	5.8^{d}	7.2^{c}	9.0^{e}
Bamboo split (T_4)	3.6^{a}	6.7^{ab}	9.2^{ab}	12.2^{b}	15.2^{ab}
Treated cardboard pot (T_5)	3.5^{a}	5.6^{bcd}	7.8^{bc}	9.1^{c}	12.2^{cd}
Coir root trainer (CRT) (T_6)	3.4^{a}	5.0^{cd}	6.9^{cd}	8.8^{c}	10.6^{de}
p- value	0.814	0.004	0.001	0.000	0.000

***** *Means with same letter are not significantly different*
*DAP- Days after planting

at the end of 75 days after planting. Coir root trainer containers also registered poor seedling height (10.6 cm) at the end of study (75 DAP) which however was on par with mud pot containers. All the remaining container types represented moderate seedling height growth at the end of 75 DAP. Despite the moderate seedling height growth in the treated card board pots, they showed higher percentage increase in height (34%) during the last fortnight period (60 to 75 DAP) while all the other containers registered around 20-25% increase in seedling height during this corresponding period. The trend of height growth at 75 DAP was in the decreasing order of nonwoven bag (T_1)> bamboo split (T_4) > coco pot (T_2) > treated cardboard (T_5)> Coir root trainer (CRT) (T_6) > mud pot (T_3).

Collar diameter: The data on collar diameter growth of teak seedlings are presented in Table 5. Significant variation of collar diameter was noticed among containers. Non-woven bag, bamboo splits and coco pots recorded better seedling collar diameter during all stages of seedling growth. At 75 DAP, the highest collar diameter was

Table 5. Collar diameter growth of teak seedlings in different biodegradable containers at Vellanikkara, Thrissur

Type of Container (T)	Collar diameter (mm)				
	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP
Nonwoven bag (T_1)	1.8^{a}	2.2^{a}	3.0^{a}	4.2^{a}	6.2^{a}
Coco pot (T_2)	1.7^{a}	1.8^{bc}	2.4^{bc}	3.1^{bc}	4.5^{bc}
Mud pot (T_3)	1.2^{c}	1.4^{c}	1.7^{e}	2.0^{e}	2.8^{d}
Bamboo split (T_4)	1.8^{a}	2.1^{ab}	2.7^{ab}	3.6^{b}	5.2^{b}
Treated cardboard pot (T_5)	1.5^{abc}	1.7^{c}	2.2^{cd}	2.6^{cd}	4.1^{c}
Coir root trainer (CRT) (T_6)	1.4^{bc}	1.6^{c}	1.8^{de}	2.2^{de}	3.2^{d}
p value	0.010	0.005	0.000	0.000	0.000

***** *Means with same letter are not significantly different*
* DAP- Days after planting

given by non-woven bagged seedlings (6.2 cm) followed by bamboo split containers (5.2 cm) and coco pot (4.5 cm). However, seedlings in mud pots registered the lowest collar diameter growth among the containers. Performance of other container types in terms of seedling collar diameter growth was moderate during all stages of seeding growth. The order of collar diameter growth was found to be: nonwoven bag(T_1)> bamboo split (T_4) > coco pot(T_2) > treated cardboard (T_5)> Coir root trainer (CRT)(T_6)> mud pot(T_3).

Number of leaves: The Table 6 represents the data on number of leaves of teak seedlings for various container types. Significant variation of leaf numbers was noticed among containers (p= 0.0001). Non-woven bag, bamboo splits and coco pots recorded more number of leaves during all stages of seedling growth. The container types did not show perceptible change in number of leaves during the first two sampling periods (15 and 30 DAP) while the changes were significant during the remaining sampling periods. At 75 DAP, the highest number of leaves was produced by non-woven bagged seedlings (13.8) followed by bamboo split containers (13) and coco pot (11). However, seedlings in mud pots registered the lowest number of leaves (8.8) among the containers. Performance of other container types in terms of number of leaves was moderate during all stages of seeding growth.

Table 6. Number of leaves of teak seedlings in different biodegradable containers at Vellanikkara, Thrissur

Type of container (T)	Number of leaves				
	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP
Nonwoven bag (T_1)	8.3	9.2^{a}	10.7^{a}	12.3^{a}	13.8^{a}
Coco pot (T_2)	8.0	8.7^{a}	9.6^{abc}	10.8^{ab}	11.0^{b}
Mud pot (T_3)	7.4	7.6^{a}	7.9^{c}	8.3^{c}	8.8^{c}
Bamboo split (T_4)	8.3	9.1^{a}	10.3^{ab}	11.7^{a}	13.0^{a}
Treated cardboard pot (T_5)	7.6	8.1^{a}	8.7^{bc}	9.5^{bc}	10.3^{bc}
Coir root trainer (CRT) (T_6)	7.5	7.8^{a}	8.3^{c}	8.8^{c}	9.3^{bc}
p- value	0.621	0.203	0.029	0.002	0.000

***** *Means with same letter are not significantly different*
* DAP- Days after planting

The trend of leaf production was nonwoven bag (T_1)> bamboo split (T_4) > coco pot (T_2) > treated cardboard (T_5)> Coir root trainer (CRT) (T_6)> mud pot (T_3).

Leaf area: Leaf area of teak seedlings was exhibit significant variation among different containers at different stages of seedling growth (Table 7). There was consistent increase in leaf area in all the container types with increase in days after planting, though it varied among the container types. Nonwoven bags recorded consistently larger leaf area during all the periods under observation. For instance, there was about 2-fold increase in leaf area for nonwoven bag seedlings at 75 DAP as compared to the leaf area at 15 DAP. This was closely followed by containers based on bamboo splits which also recorded fair leaf area at the end of the study period (2-fold increase). However, among the container types mud pots produced smaller sized

Table 7. Leaf area of teak seedling in different biodegradable containers at Vellanikkara, Thrissur

Type of container (T)	Leaf area of teak seedlings (cm^2)				
	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP
Nonwoven bag (T_1)	13.0^{a}	16.0^{a}	20.0^{a}	24.2^{a}	28.2^{a}
Coco pot (T_2)	12.0^{a}	13.8^{ab}	17.2^{ab}	22.6^{a}	25.2^{ab}
Mud pot (T_3)	7.4^{b}	8.8^{c}	12.8^{c}	16.2^{b}	18.4^{d}
Bamboo split (T_4)	12.8^{a}	15.0^{ab}	18.4^{ab}	23.2^{a}	27.4^{ab}
Treated cardboard pot (T_5)	11.0^{a}	13.2^{b}	16.0^{bc}	20.2^{ab}	23.2^{bc}
Coir root trainer (CRT) (T_6)	8.0^{b}	9.8^{c}	13.6^{c}	17.2^{b}	20.0^{cd}
p value	0.000	0.000	0.002	0.003	0.002

***** *Means with same letter are not significantly different*
* DAP- Days after planting

leaves at the end of 75 days after planting (18.4 cm^2). Coir root trainer containers also registered less leaf area (20 cm^2) at the end of study (75 DAP) which however was on par with mud pot containers. All the remaining container types represented moderate seedling height growth at the end of 75 DAP. The order of container performance with regard to leaf area was: nonwoven bag (T_1)> bamboo split (T_4) > coco pot (T_2) > treated cardboard (T_5)> Coir root trainer (CRT) (T_6) > mud pot (T_3).

Primary root length: The data on primary root length of teak seedlings in the various container types are presented in Table 8. The primary root length among different containers at various ages differed considerably. The changes were moderate during the first two sampling periods (15 and 30 DAP) while considerable variation in primary root length was observed during the all the subsequent sampling periods. Nonwoven bag, bamboo splits and coco pots recorded the longest primary root length during all stages of seedling growth. At 75 DAP, Nonwoven bag produced longest primary root (20.1 cm) closely followed by bamboo split containers (18 cm) and coco pot (17.7 cm). Interestingly the primary root length in the non-woven bag was moderate till 45 DAP and the growth was faster thereafter. Seedlings in mud pots registered the lowest root length (12.3 cm) among the containers.

Table 8. Primary root length of teak seedlings in different biodegradable containers at Vellanikkara, Thrissur

Type of container (T)	Primary root length of teak seedlings (cm)				
	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP
Nonwoven bag (T_1)	9.9^{a}	12.3^{a}	13.7^{a}	17.3^{a}	20.1^{a}
Coco pot (T_2)	9.2^{a}	10.9^{ab}	12.7^{ab}	14.7^{abc}	17.7^{ab}
Mud pot (T_3)	8.2^{a}	9.2^{b}	10.1^{c}	11.2^{d}	12.3^{c}
Bamboo split (T_4)	9.6^{a}	11.4^{ab}	13.4^{ab}	15.6^{ab}	18.0^{a}
Treated cardboard pot (T_5)	8.7^{a}	10.3^{ab}	11.6^{abc}	13.4^{bcd}	15.0^{bc}
Coir root trainer (CRT) (T_6)	8.5^{a}	9.7^{b}	11.1^{bc}	12.5^{cd}	13.7^{c}
p value	0.275	0.066	0.024	0.005	0.001

***** *Means with same letter are not significantly different*
* DAP- Days after planting

The order of primary root length found was: nonwoven bag(T_1)> bamboo split (T_4) >coco pot(T_2) > treated cardboard (T_5)> Coir root trainer (CRT)(T_6)> mud pot(T_3).

Length of primary root coiled: The Table 9 shows the extent of root coiling observed for seedlings grown in different containers. No such coiling was observed for seedling till 60 DAP for any of the container types. However, root coiling was evident at 75 DAP with maximum value reported for non-woven bags (5.1 cm) followed by those seedlings grown in bamboo splits (3.0 cm). Non- woven bag started the root coiling tendency from the 60th day onwards.

Table 9. Length of primary root of teak seedlings coiled in different biodegradable containers at Vellanikkara, Thrissur

Type of container (T)	Length of primary root coiled (cm)	
	60 DAP (D_4)	75 DAP (D_5)
Nonwoven bag (T_1)	2.3^{a}	5.1^{a}
Coco pot (T_2)	0.0^{c}	1.7^{c}
Mud pot (T_3)	0.0^{c}	0.0^{d}
Bamboo split (T_4)	0.6^{b}	3.0^{b}
Treated cardboard pot (T_5)	0.0^{c}	0.2^{d}
Coir root trainer (CRT) (T_6)	0.0^{c}	0.0^{d}
p- value	0.000	0.000

***** *Means with same letter are not significantly different*
* DAP- Days after planting

Root length: Shoot length ratio: The perusal of data regarding root length: shoot length ratio of teak seedlings (Table 10) reveals no appreciable variation among containers during the period under observation. In general, the root: shoot length data varied from 1.34 - 1.74 with Mud pot (T_3) registering maximum ratio (1.74) while nonwoven bag (T_1) recorded minimum ratio (1.34). Only modest variation in root: shoot length ratio was discernible during various periods of observation. However, it is interesting to observe that there was consistent decline in root: shoot length with increasing seedling age for all the container types.

Table 10. Root length: Shoot length ratio of teak seedlings in different biodegradable containers at Vellanikkara, Thrissur

Type of container (T)	Root : Shoot ratio of teak seedlings				
	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP
Nonwoven bag (T_1)	2.67	1.75	1.34	1.22	1.14
Coco pot (T_2)	2.62	1.81	1.53	1.32	1.22
Mud pot (T_3)	2.56	2.00	1.74	1.55	1.36
Bamboo split (T_4)	2.66	1.70	1.45	1.27	1.18
Treated cardboard pot (T_5)	2.48	1.83	1.48	1.47	1.24
Coir root trainer (CRT) (T_6)	2.50	1.94	1.60	1.42	1.30
p- value	0.935	0.508	0.131	0.070	0.278

***** *Means with same letter are not significantly different*
* DAP- Days after planting

Number of secondary roots of seedlings: The data presented in Table 11 evinced that the number of secondary roots of teak seedlings varied appreciably among containers at different periods of study. There was consistent increase in the number of secondary roots in all the container types with increase in days after planting, though it varied among the container types. Among the containers nonwoven bags recorded consistently higher number of secondary roots during all the periods under observation. For instance, there was 3.7-fold increase in secondary root numbers for nonwoven bag seedlings at 75 DAP as compared to the roots at 15 DAP. This was followed by containers based on bamboo splits which also recorded fair number of roots at the end of the study period (3.4-fold increase). However, among the container types mud pots showed lowest number of roots at the end of 75 days after planting. Coir root trainer containers also registered less number of secondary roots (22) at the end of study (75 DAP) which however was on par with mud pot containers. Despite the lowest number of secondary roots in mud pots, they showed higher percentage increase (25%) during the last fortnight period (60 to 75 DAP) followed by treated cardboard (21%), while all the other containers registered around 14-18% increase in seedling height during the corresponding period.

Table 11. Number of secondary roots of teak seedling in different biodegradable containers at Vellanikkara, Thrissur

Type of container (T)	Number of secondary roots of teak seedling				
	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP
Nonwoven bag (T_1)	12^{a}	23^{a}	32^{a}	38^{a}	45^{a}
Coco pot (T_2)	9^{b}	16^{b}	23^{c}	28^{c}	32^{c}
Mud pot (T_3)	8^{b}	12^{c}	15^{d}	16^{e}	20^{d}
Bamboo split (T_4)	11^{a}	20^{a}	27^{b}	33^{b}	38^{b}
Treated cardboard pot (T_5)	9^{b}	14^{bc}	19^{d}	23^{d}	28^{c}
Coir root trainer (CRT) (T_6)	8^{b}	13^{bc}	16^{d}	19^{de}	22^{d}
p value	0.002	0.000	0.000	0.000	0.000

***** *Means with same letter are not significantly different*
* DAP- Days after planting

The order of secondary root number was nonwoven bag (T_1)> bamboo split (T_4) > coco pot (T_2)> treated cardboard (T_5)> Coir root trainer (CRT)(T_6)> mud pot (T_3).

Lateral root length: The data pertaining to lateral root length of teak seedling manifested significant difference among different containers at several ages (Table 12). The lateral root length among different containers at various ages differed remarkably. Nonwoven bag, bamboo splits and coco pots recorded longest lateral root length during all stages of seedling growth. At 75 DAP, Nonwoven bag produced longest lateral root (13.1 cm) closely followed by bamboo split containers (12.4 cm) and coco pot (10.7 cm). However, seedlings in mud pots registered the

Table 12. Lateral root length of teak seedlings in different biodegradable containers at Vellanikkara, Thrissur

Type of container (T)	Lateral root length of teak seedlings (cm)				
	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP
Nonwoven bag (T_1)	5.7^{a}	8.2^{a}	10.4^{a}	11.9^{a}	13.1^{a}
Coco pot (T_2)	4.7^{b}	6.9^{bc}	8.6^{bc}	9.8^{bc}	10.7^{bc}
Mud pot (T_3)	4.1^{b}	5.6^{d}	6.8^{d}	7.8^{d}	8.7^{c}
Bamboo split (T_4)	5.0^{ab}	7.4^{ab}	9.6^{ab}	11.3^{ab}	12.4^{ab}
Treated cardboard pot (T_5)	4.5^{b}	6.4^{bcd}	8.0^{bcd}	9.2^{cd}	10.0^{c}
Coir root trainer (CRT) (T_6)	4.2^{b}	5.9^{cd}	7.3^{cd}	8.4^{cd}	9.2^{c}
p value	0.015	0.004	0.002	0.002	0.002

***** *Means with same letter are not significantly different*
* DAP- Days after planting

lowest root length (8.7cm) among the containers. Bamboo split containers showed 2.48fold increase in lateral root length at 75DAP as compared to 15DAP followed by nonwoven bag with 2.3-fold increase in lateral root length. The order of lateral root length under different containers was: Nonwoven bag> bamboo splits > cocopots> treated cardboard pots>coir peat pot> mud pot.

Number of tertiary roots: The Table 13 shows the changes in tertiary root production for seedlings grown in different container types. Data showed significant variation among container types during the various periods under observation. There was only modest variation in secondary root production during the early period of seedling growth (15 DAP) though the changes were statistically significant. However, the variation in tertiary root counts were more pronounced with increase in seedling growth. Among the container types, teak seedlings in non-woven bags recorded highest number of tertiary roots during all stages of observation followed by seedlings in bamboo splits. Seedlings grown in the mud pots however showed consistently lower tertiary roots during the reporting period. Seedlings at 45 DAP showed higher root number for non-woven bags (38) followed by bamboo splits (33) which however were at par. Coco pots also registered fairly high tertiary root count with an average number of 29 roots at the end of 45 DAP. Among the container types, the tertiary root production was the lowest for mud pots and coir peat pots. Trends were the same for the remaining periods of observation. At the final observation period (75 DAP) the non-woven bagged seedlings recorded the highest number of tertiary roots (53 numbers) with more than 200% increase as compared to the number at 15 DAP. The second best container in terms of tertiary root production was bamboo splits which also recorded considerable increase at final sampling period (>200% increase). However, among the container types mud pots showed lowest number of roots at the end of 75 days after planting (29 numbers) followed by coir root trainer containers (32) at the end of study (75 DAP) which however was on par with mud pot containers. Despite the lowest number of tertiary roots in mud pots, they showed higher percentage increase (20.8%) during the last fortnight period (60 to 75 DAP) which all the other containers registered around 12-17% increase in seedling height during the corresponding period.

Table 13. Number of tertiary roots of teak seedlings in different biodegradable containers at Vellanikkara, Thrissur

Type of container (T)	Number of tertiary roots of teak seedlings				
	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP
Nonwoven bag (T_1)	17^{a}	29^{a}	38^{a}	47^{a}	53^{a}
Coco pot (T_2)	14^{bc}	22^{bc}	29^{bc}	35^{bc}	41^{bc}
Mud pot (T_3)	12^{c}	17^{d}	20^{d}	24^{e}	29^{d}
Bamboo split (T_4)	15^{ab}	26^{ab}	33^{ab}	41^{ab}	48^{ab}
Treated cardboard pot (T_5)	14^{bc}	21^{cd}	26^{c}	31^{cd}	36^{cd}
Coir root trainer (CRT) (T_6)	12^{c}	18^{cd}	20^{d}	28^{de}	32^{d}
p value	0.014	0.000	0.000	0.000	0.000

***** *Means with same letter are not significantly different*
* DAP- Days after planting

The trend of tertiary root production was nonwoven bag (T_1) > bamboo split (T_4) > coco pot (T_2) > treated cardboard (T_5) > Coir root trainer (CRT) (T_6) > mud pot (T_3).

Shoot dry weight: The shoot dry weight of teak seedlings manifested significant variation among different containers under study (Table 14). Nonwoven bag, bamboo splits and coco pots recorded to have highest shoot dry weight during all stages of seedling growth. At 75 DAP, Nonwoven bag produced higher shoot biomass over others (2.34 g/seedling) followed by bamboo split containers (2.0 g/seedling) and coco pot (1.70 g/seedling). However, seedlings in mud pots registered the lowest shoot biomass (0.90 g/seedling) among the containers. Seedlings in coir root trainer container also performed similar to mud pot. Almost 11fold increase in shoot biomass has been observed for Nonwoven bag at 75DAP as compared to 15DAP. Bamboo split also registered such faster increase in

Table 14. Shoot dry weight of teak seedlings in different biodegradable containers at Vellanikkara, Thrissur

Type of container (T)	Shoot dry weight of teak seedlings (g)				
	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP
Nonwoven bag (T_1)	0.20^{a}	0.72^{a}	1.26^{a}	1.85^{a}	2.34^{a}
Coco pot (T_2)	0.18^{abc}	0.49^{bc}	0.84^{bc}	1.27^{c}	1.70^{c}
Mud pot (T_3)	0.13^{d}	0.28^{e}	0.46^{d}	0.68^{d}	0.90^{e}
Bamboo split (T_4)	0.19^{ab}	0.54^{b}	0.99^{b}	1.53^{b}	2.00^{b}
Treated cardboard pot (T_5)	0.16^{bcd}	0.41^{cd}	0.72^{c}	1.07^{c}	1.40^{d}
Coir root trainer (CRT) (T_6)	0.15^{cd}	0.33^{de}	0.55^{d}	0.82^{d}	1.10^{e}
Pvalue	0.002	0.000	0.000	0.000	0.000

***** *Means with same letter are not significantly different*
* DAP- Days after planting

shoot biomass (11 times) after 75 days of seedling growth. The order of shoot biomass production was nonwoven bag (T_1)> bamboo split (T_4) > coco pot (T_2)> treated cardboard (T_5)>Coir root trainer (CRT) (T_6)> mud pot (T_3).

Root dry weight: The scrutiny of data in Table 15 reveals appreciable variation of root dry weight among containers during various sampling periods. Again, Nonwoven bag, bamboo splits and coco pots recorded to have higher root dry weight during all stages of seedling growth. At 75 DAP, Nonwoven bag produced higher root biomass over others (1.00 g/seedling) followed by bamboo split containers (0.89 g/seedlings) and coco pot (0.72 g/seedlings). Seedlings in mud pots registered the lowest root biomass (0.34 g/seedling) among the containers. Treated cardboard pot, coir root trainer also performed similar to mud pot. Bamboo splits recorded 7.4 times increase in shoot biomass at 75DAP as compared to 15DAP while mud pot registering moderate increase in shoot biomass. The order of root dry weight was nonwoven bag (T_1)> bamboo split (T_4) > coco pot (T_2) > treated cardboard (T_5)> Coir root trainer (CRT) (T_6)> mud pot (T_3).

Table 15. Root dry weight of teak seedlings in different biodegradable containers at Vellanikkara, Thrissur

Type of container (T)	**Root dry weight of teak seedlings (g)**				
	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP
Nonwoven bag (T_1)	0.14^{a}	0.31^{a}	0.52^{a}	0.72^{a}	1.00^{a}
Coco pot (T_2)	0.11^{bc}	0.21^{bc}	0.35^{bc}	0.49^{c}	0.72^{bc}
Mud pot (T_3)	0.09^{c}	0.13^{e}	0.18^{e}	0.25^{e}	0.34^{d}
Bamboo split (T_4)	0.12^{ab}	0.24^{b}	0.41^{b}	0.58^{b}	0.89^{ab}
Treated cardboard pot (T_5)	0.11^{bc}	0.18^{cd}	0.29^{cd}	0.41^{cd}	0.61^{c}
Coir root trainer (CRT) (T_6)	0.10^{bc}	$0.15d^{e}$	0.24^{de}	0.33^{de}	0.46^{c}
p value	0.005	0.000	0.000	0.000	0.001

***** *Means with same letter are not significantly different*
* DAP- Days after planting

Total dry weight: The total dry weight of teak seedlings varied significantly among the containers (Table 16). There was consistent increase in the total dry weight of seedlings in all the container types with increase in days after planting, though it varied among the container types. As observed earlier for other seedling parameters, nonwoven bag recorded the highest total plant dry weight during all sampling periods. Bamboo splits and coco pots were the other containers that showed higher plant dry weights. Teak seedling grown in mud pots and coir peat containers registered consistently the lowest dry weight during all the observational periods. At the end of the study period (75 DAP), the seedling dry weight accumulation was in the range of 3.34, 2.42, 1.24, 2.89, 2.01 and 1.56g for Nonwoven bag (T_1), Coco pot (T_2), Mud pot

Table 16. Total dry weight of teak seedlings in different biodegradable containers at Vellanikkara, Thrissur

Type of container (T)	Total dry weight of teak seedlings (g)				
	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP
Nonwoven bag (T_1)	0.34^{a}	1.03^{a}	1.78^{a}	2.57^{a}	3.34^{a}
Coco pot (T_2)	0.29^{abc}	0.70^{bc}	1.19^{bc}	1.76^{c}	2.42^{c}
Mud pot (T_3)	0.22^{d}	0.41^{e}	0.64^{d}	0.93^{d}	1.24^{e}
Bamboo split (T_4)	0.31^{ab}	0.78^{b}	1.40^{b}	2.11^{b}	2.89^{b}
Treated cardboard pot (T_5)	0.27^{bcd}	0.59^{cd}	1.01^{c}	1.48^{c}	2.01^{d}
Coir root trainer (CRT) (T_6)	0.25^{cd}	0.48^{de}	0.79^{d}	1.15^{d}	1.56^{e}
P value	0.004	0.000	0.000	0.000	

***** *Means with same letter are not significantly different*

* DAP- Days after planting

(T_3), Bamboo split (T_4), Treated cardboard pot (T_5) and Coir root trainer (CRT) (T_6) respectively. Despite the higher total dry weight of seedlings in coco pots, they showed lowest percentage increase (29.96%) during the last fortnight period (60 to 75 DAP) while all the remaining containers registered around 33-37% increase in seedling height during the corresponding period. The order of total dry weight production was in the order nonwoven bag (T_1)> bamboo split (T_4) > coco pot (T_2)> treated cardboard (T_5)>Coir root trainer (CRT) (T_6)> mud pot (T_3).

Quality Index of seedling: As evident from Table 17, the quality index of seedlings varied significantly among the containers studied. Among the containers nonwoven bags reported produce good quality seedlings during all the periods under observation. Quality index improved consistently for all the container types with increase in seedling residence time in the

Table 17. Quality Index of teak seedling in different biodegradable containers at Vellanikkara, Thrissur

Type of container (T)	Quality Index of teak seedlings				
	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP
Nonwoven bag (T_1)	0.10^{a}	0.19^{a}	0.30^{a}	0.43^{a}	0.64^{a}
Coco pot (T_2)	0.08^{bc}	0.12^{bc}	0.20^{c}	0.28^{c}	0.45^{c}
Mud pot (T_3)	0.05^{e}	0.07^{e}	0.10^{e}	0.15^{d}	0.22^{d}
Bamboo split (T_4)	0.09^{ab}	0.14^{b}	0.24^{b}	0.35^{b}	0.56^{b}
Treated cardboard pot (T_5)	0.07^{cd}	0.10^{cd}	0.16^{d}	0.24^{c}	0.38^{c}
Coir root trainer (CRT) (T_6)	0.06^{de}	0.09^{de}	0.13^{de}	0.17^{d}	0.29^{d}
p Value	0.000	0.000	0.000	0.000	0.000

***** *Means with same letter are not significantly different*
* DAP- Days after planting

containers. At the end of the study period (75 DAP) the teak seedlings significant variation in quality index among the container types ($p < 0.001$). For instance, seedlings grown in Non-woven bags showed highest quality index (0.64) followed by bamboo splits (0.56) while the mud potted seedlings recorded the lowest quality index (0.22) which however was on par with seedlings in coir peat pots.The order of seedling quality was found to be nonwoven bag (T_1)> bamboo split (T_4) > coco pot (T_2)> treated cardboard (T_5)> Coir root trainer (CRT) (T_6)> mud pot (T_3).

Correlation between various growth parameters for teak seedlings grown in nonwoven bag and bamboo splits

Attempts were made to correlate the seedling growth parameters for most performing container types viz nonwoven bag and bamboo splits (Table 18 and 19). Interestingly all the seedling growth variables showed significantly high positive correlation among one another both for nonwoven bag and bamboo splits. For instance, height growth had high correlation with root weight, shoot weight, total weight and root length of the seedlings with correlation coefficient >0.98 for nonwoven bagged seedlings. Collar diameter also showed similar good correspondence with other seedling growth variables. Yet another striking observation is that aboveground growth variables such as height, collar diameter and shoot weight registered higher correlation coefficient.

Table 18. Correlation between various growth parameters for teak seedlings grown in nonwoven bag

	Height	Diameter	Root weight	Shoot weight	Total weight	Root length
Height	1					
Diameter	0.95	1				
Root weight	0.99	0.97	1			
Shoot weight	0.98	0.95	0.98	1		
Total weight	0.98	0.96	0.99	0.99	1	
Root length	0.98	0.97	0.98	0.98	0.98	1

Table 19. Correlation between various growth parameters for teak seedlings grown in bamboo split containers

	Height	Diameter	Root weight	Shoot weight	Total weight	Root length
Height	1					
Diameter	0.95	1				
Root weight	0.98	0.98	1			
Shoot weight	0.98	0.96	0.97	1		
Total weight	0.99	0.97	0.99	0.99	1	
Root length	0.99	0.96	0.98	0.97	0.99	1

Also root length showed significantly higher positive correlation with all the other growth variables. The same trend was discernible for bamboo splits as well.

4.3. Economics of raising teak seedling in different containers

The data in Table 20 reflect various attributes governing economics of raising teak seedling (3-month old i.e. 15 - day old transplant plus 75 DAP) in different biodegradable containers. The cost factor included cost of container, cost of soil mixture, cost of labour and other inputs and also survival percent of seedlings. The cost of container and survival of seedling have also been reflected in Table 2 and Table 3, respectively. The cost of soil mixture has been considered Rs. 1.5 for each plant and also cost of labour and other inputs have been taken as Rs. 2.5 per plant. The total cost of raising one seedling which survived was calculated as Rs 8.3 for T_1, Rs 60.2 for T_2, Rs 62.0 for T_3, Rs 11.0 for T_4, Rs 12.8 for T_5, Rs 25.8 for T_6. The sale price for 3- month old teak seedling have been considered Rs 20 for T_1, T_2, T_3, T_5 and T_6 and Rs 27 for T_4 (bamboo split pot). In case of seedlings grown in bamboo split pot sale price has been considered Rs 7 more because the container can be used for another season whose price is Rs.7. The conventional container 'polythene bag' has been included as check for comparison in which cost seedling goes to Rs 5.00.

Table 20. Economics of raising teak seedlings (3-month old) in different biodegradable containers at Vellanikkara, Thrissur

Type of container	Cost of one container (Rs)	Cost of soil mixture for one teak seedling (Rs)	Cost of labour& other inputs for one teak seedling (Rs)	Survival % of seedling at 3-month	Total cost of raising one 3-month old teak seedling (Rs)	Sale price of one 3-month old teak seedling (Rs)	Benefit:Cost ratio
Nonwoven bag (T_1)	4.0	1.5	2.5	96	8.3	20.0	2.41
Coco pot (T_2)	55.0	1.5	2.5	98	60.2	20.0	0.33
Mud pot (T_3)	40.0	1.5	2.5	71	62.0	20.0	0.32
Bamboo split pot (T_4)	7.0	1.5	2.5	100	11.0	27.0	2.45
Treated cardboard (T_5)	8.0	1.5	2.5	94	12.8	20.0	1.56
Coir root trainer (CRT) (T_6)	20.0	1.5	2.5	93	25.8	20.0	0.76
Polythene bag (Check)	0.50	1. 5	2. 5	90	5. 0	20. 0	4.00

The benefit: cost ratio of raising 3- month old teak seedling varied remarkably among different biodegradable containers. It ranged from 0.33 to 2.45. The value was highest in case of seedlings raised in bamboo split pot (T_4) followed by nonwoven bag (T_1), treated cardboard (T_5), Coir root trainer (CRT) (T_6), coco pot (T_2) and mud pot (T_3). The conventional container polythene bag was found to be lowest cost (Rs 5.00) and highest benefit: cost ratio (4.0) among these containers.

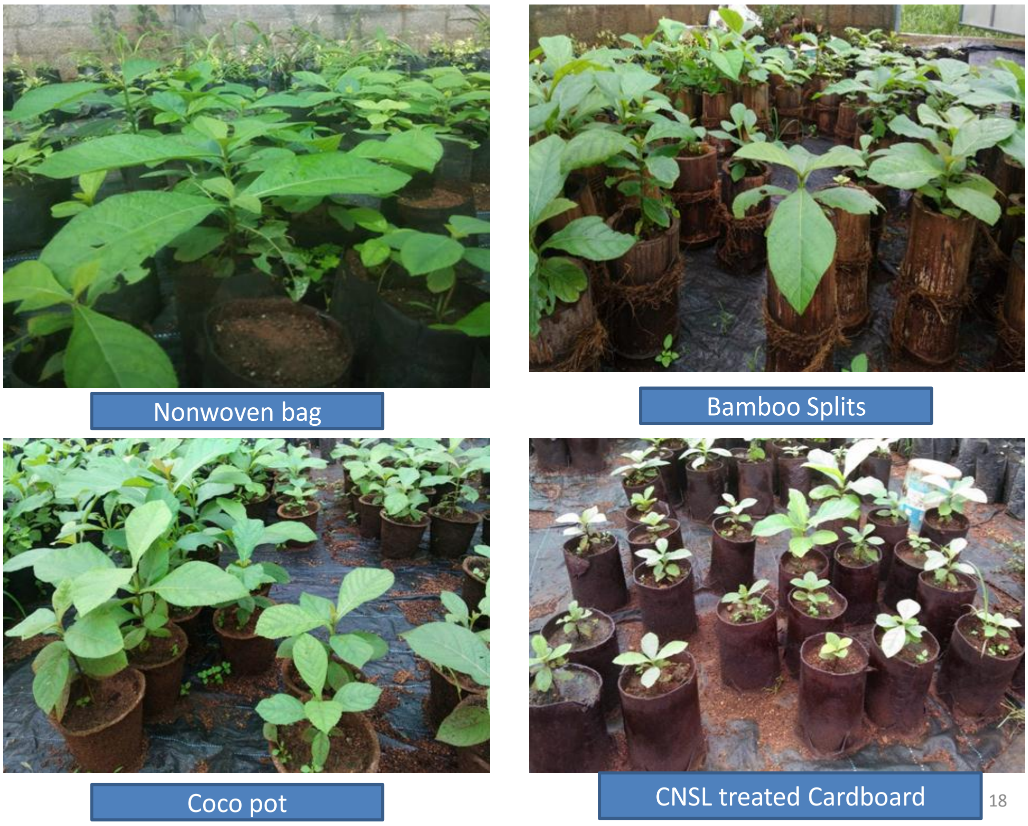
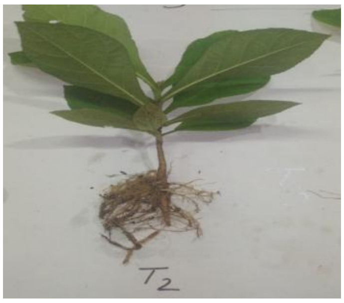


Plate 3. Teak seedlings of 2-month old in different biodegradable containers

Plate 4. Teak seedlings of 3-month old in coco pot, bamboo splits and nonwoven bag

Root growth in Nonwoven bag



Root growth in Coco pot

Root growth in Mud pot

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Root growth in Bamboo splits

Root growth in treated cardboard pot

Root growth in coir root trainer

Plate 5. Root growth of 3-month old teak seedlings raised in different container types

5. DISCUSSION

The nursery trial on the utility of various biodegradable materials as containers for raising forest plants was carried out at College of Forestry, Vellanikkara, Thrissur, Kerala during the period 2019-20. The study involved preliminary investigation of 11 locally available biodegradable materials as plant containers. The six better performers among these were subjected to detailed study to screen out the best container type for mass production of forest seedlings. Teak was considered as the test species for the study. The salient results are discussed hereunder.

5.1. Performance of the biodegradable containers in the preliminary trial

The different parameters like durability of the containers, survival period of the seedlings, survival percent of seedlings, height growth and diameter growth of the seedlings, cost of the containers and the number of seasons containers can be used are discussed in this chapter.

The durability of different containers showed considerable variation from one another in the preliminary trial ranging from one month to twenty-four months (Table 1 and Fig 2). Bamboo split pot (T_4) demonstrated highest longevity in nursery while the containers such as arecanut sheath pot, cow dung pot, sugarcane bagasee pot, bamboo basket, bioplastic bag and cloth bag existed for one month only. This may be ascribed to variation in physical properties of biocontainers. The bamboo pot was wooden material with maximum physical strength and resistance to water and fungi in comparison to other containers tested. Similar findings have been reported by Nandakumar (1996), Koeser *et al.* (2013), Muriuki *et al.* (2013), Beeks *et al.* (2013), Nambuthiri, *et al.* (2015), Conneway *et al.* (2015) and Sun *et al.* (2015).

The survival period of the seedlings expressed sound variation among different containers in nursery (Table 1). In the preliminary observation it varied from one week to more than 24 weeks with container types. The teak seedling survival percentage is closely related to the physical suitability of the containers for supporting seeding growth. Since the soil volume and the composition of the potting mixture remained the same for all the container types, the variability in seedling survival could be primarily on account of the physical condition of the containers to support seedling growth. For instance, bamboo split pot and nonwoven bag showed highest seedling longevity in nursery while the containers such as arecanut sheath pot, cow dung pot, sugarcane bagasee pot, bamboo basket, bioplastic bag and cloth bag existed for just one month only. The biodegradable materials often show poor flexibility and

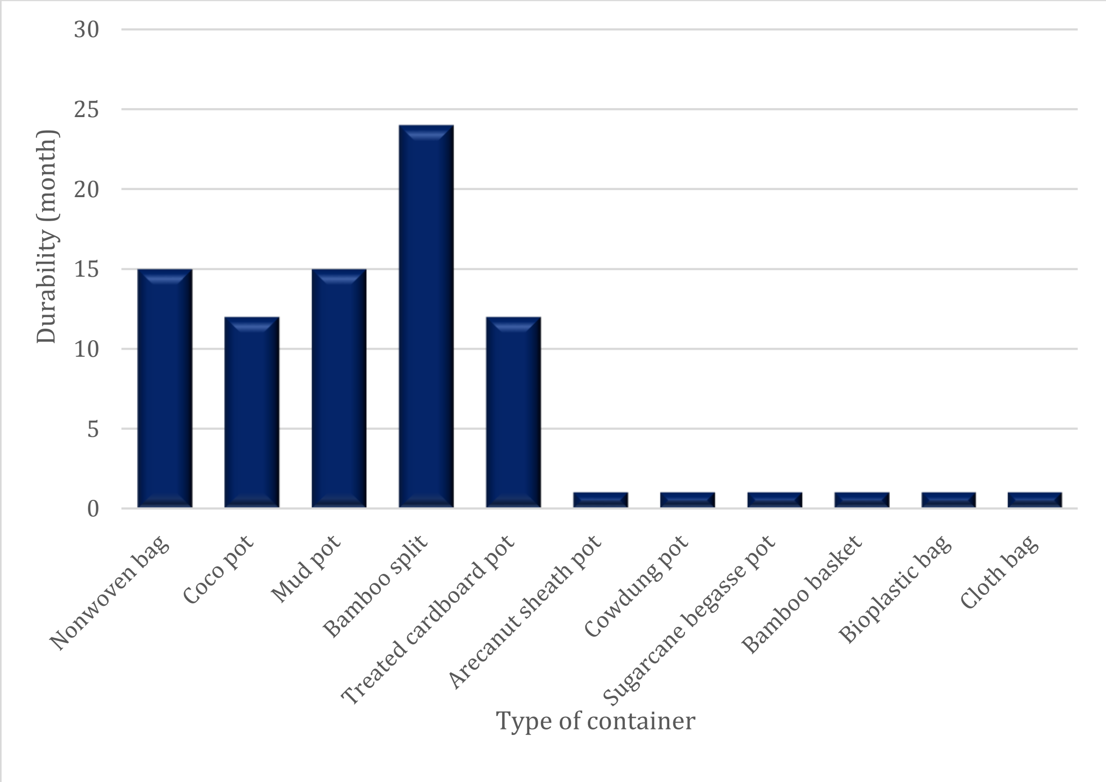

Fig 2. Durability of different biodegradable containers in nursery

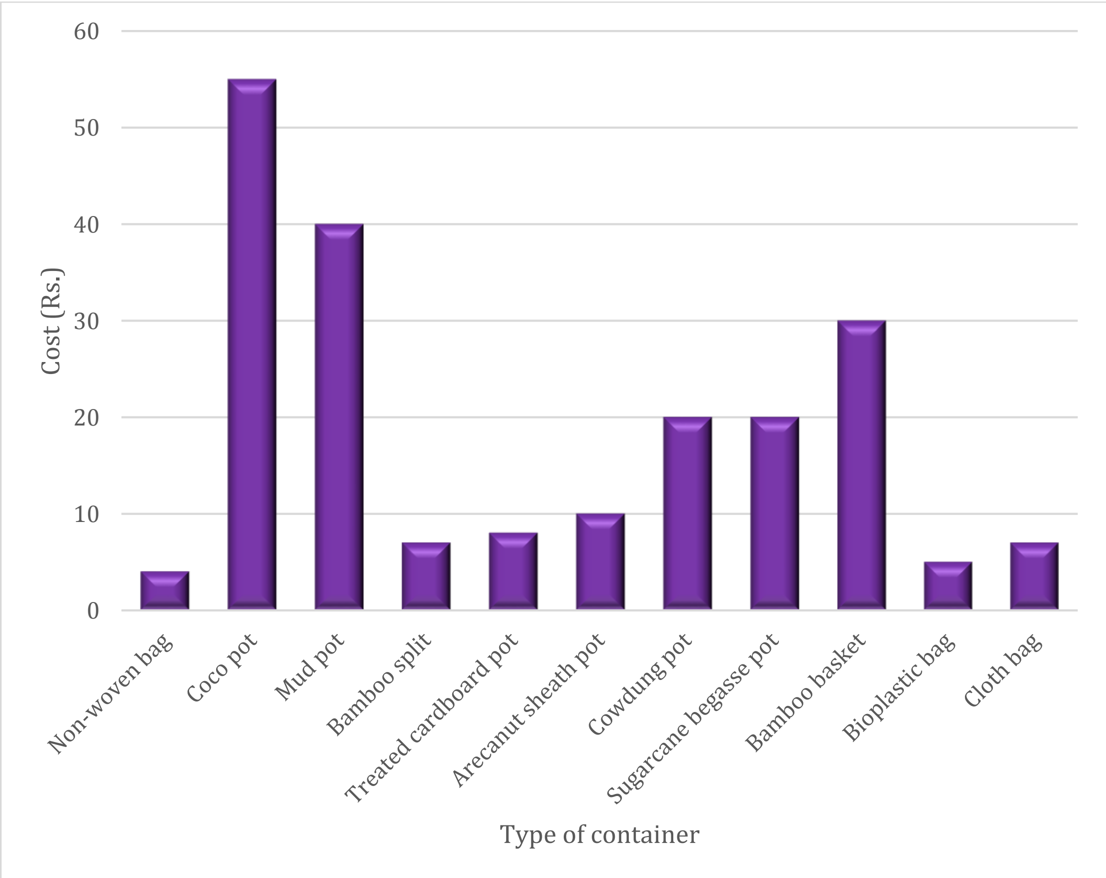

Fig 3. Cost of different biodegradable containers

endurance to withstand harsh climatic conditions. All of them being made of biomaterials, the chances of susceptibility to continued wetting may prompt them to wither away with in short time. For instance, materials such as arecanut sheath pot, cow dung pot, sugarcane bagasee pot, cloth bag, etc soften fast in contact with water and lose their physical strength to support soil volume. Moreover, these materials being biodegradable, chance of the materials being infested with degrading agents such as fungi, termites, bacterial infections are very high. For instance, bioplastic bag survived hardly for one week while the seedlings in containers like arecanut sheath pot, cowdung pot, bamboo basket and cloth bag survived for 2 - 4 weeks only. The high cellulose content in these materials provides congenial ground for the infestation especially termites. It was observed that despite their bio-origin, there are differences in the strength properties of containers leading to variable range of durability. The high durability of containers made up of bamboo splits and coco pots suggest their potential to resist degrading agents. Obviously, the higher seedling survival period in nonwoven bag, coco pot, mud pot, bamboo splits and Coir root trainer (CRT) was due to better stability and strength to hold the soil for seedling survival.

Many studies suggest the limitation of biodegradable materials in functioning as plant containers (Nandakumar, 1996; Khan *et al.*,2000; Lopez *et al.*,2011; de Oliveira and Miglioranza, 2015, Balestri *et al.*,2019 and Castronuovo *et al.*, 2019. In these studies, containers were not marketable due to loss of container integrity or mold and/or algal growth resulting poor appearance. This is particularly true when containers have to be retained in the nursery for longer periods. Being long duration plants, most of the forest tree seedlings demand retention in the nursery for minimum six months.

Among the eleven container types tested in preliminary trial, only five emerged better viz. bamboo splits, nonwoven bag, coco pot, CNSL treated card board pot, and mud pots which registered seedling survival ranging from 72 to 100% of teak seedling survival at the end of three months of preliminary study. At three months of seedling age bamboo splits remained steady (maximum durability) with perhaps good aeration supporting highest survival of seedling. Similar biophysical conditions might have provided by nonwoven bag, coco pot, CNSL treated card board pot and Coir root trainer (CRT). Eventually, the containers which could not sustain for three months recorded total seedling mortality. The finding is in agreement with the finding of (Nandakumar, 1996), in the way that an experiment conducted in KFRI by using locally available materials like bamboo split, arecanut sheath, reed and teak leaves showed the similar kind of results. Except in bamboo splits the seedling survival percentage was less than 100%. This was due to lightness of materials, lack of rigid wall, lack of moisture regulation mechanism, affected by fungus and termite.

5.1.2. Seedling height and collar diameter growth in preliminary trial

The data pertaining to height of seedling at 3 months after planting in the preliminary trial (Table 1) revealed good variation (0 - 19.3 cm) among containers. Nonwoven bag registered maximum height growth while containers such as arecanut sheath pot, cowdung pot, sugarcane bagasse pot, bamboo basket, bioplastic and cloth bag could not show any height growth because seedlings died before 3 months after planting as the containers degraded. This may be ascribed to difference in degradability of containers and growing atmosphere of containers. The collar diameter in the preliminary trial followed the same trend like height at 3 months after planting and ranged 0 - 7.4 mm (Table 1). Height and collar diameter growth of seedlings during the nursery stage are very much important which represent the cumulative health of the seedlings in the containers. Thebetter height growth often reflects the ability of the soil medium to supply water and nutrients and the potential of the root system to absorb them for plant growth. The physical unsuitability of many of the containers to hold the potting medium and thereby the inability to supply water and minerals lead to their premature mortality.

In addition to the physical suitability of the containers to hold the potting mixture to supply water and minerals for longer periods, the cost of production of the container also contribute their choice especially for mass production of seedlings. For instance, despite the better performance of coco pots as containers, the high cost of production exerts serious limitation on the use of these containers for mass production of teak seedlings. Interestingly, among the containers tested, the two better performing containers in terms of seedling growth and physical stability were nonwoven bag and bamboo splits which also had lower cost of production, qualifying their suitability as plant containers. Often there could be conflicting scenarios where the low cost container may have poor suitability to support plant growth and vice versa. Hence there is of need a better trade off that offer cheaper cost of production without compromising the quality. The experience with this brief trial suggests the scope for further investigations in this line by using other locally available materials. Cost may be further reduced when there will be large scale production.

Merits and demerits of containers

Different merits were observed under various biodegradable containers tested (Table 2). Nonwoven bag was obtained as a low cost container (Fig 3) supporting good growth of plants. This has ability to degrade after one season of raising seedlings. Bamboo split also supported good growth. It can be used for 2 seasons and after raising seedlings for twice the material can be used as fuel. Coco pot, mud pot and coir peat pot can be used for one season after which these will degrade. It was found in the preliminary trial that various biodegradable containers possessed some demerits (Table 2). The containers like arecanut sheath pot, cow dung pot, sugarcane bagasse pot, bamboo splits, bioplastic bag and cloth bag were found very susceptible to frequent irrigation and degraded within a month in nursery after application of irrigation water. Those could not support the teak seedlings for more than one month. A study conducted by Khan *et al*., (2000) found that pots made up of cow dung and animal manure decayed in three days whereas pots made of clay and paper, clay animal manure took five and six days to decompose. Also most of these containers have high cost factor (Nandakumar, 1996). Bamboo basket had additional problem of attack by termites. In case of coco pot and mud pot, cost of containers is very high. Despite the good physical strength, the mud pot showed poor growth of seedlings especially height and collar diameter growth. Sugarcane bagasee pot and cloth bags developed high fungal growth that had deleterious effect on the seedling growth. The containers attract insects and microorganisms (Nandakumar,1996).

Over all, the preliminary trial on the suitability of locally available bio-degradable containers revealed large scale variation in their suitability as plant containers. Six among the ten container types viz. nonwoven bag, mud pot, bamboosplit pot, Coir root trainer (CRT), treated cardboard, coco pot emerged fairly suitable as plant containers. The selected containers were subjected to detailed investigation for their comparative soundness for long term retention of forest plants in the nursery for quality seedling production.

5.2. Detailed investigations (main trial) on performance of selected biodegradable containers

The selected six containers types namely, nonwoven bag, mud pot, bamboosplit pot, Coir root trainer (CRT), treated cardboard, coco pot were further subjected to detailed studies on the quality attributes of the test plant teak seedlings. The results are briefly discussed below:

5.2.1. Seedling survival

As it was obvious from the preliminary study, all the selected container types showed fairly good seedling survival in the detailed study (Table 3 and Fig 4). However, there were significant variations among the container types with respect to seedling survival during the different observational periods. The seedling survival rate was highest for bamboo splits (100%) which was at part with non-woven bag while the mud pots registered the lowest seedling survival (71%) at the end of 75 days of seedling growth. As observed in the preliminary trial, the variation in seedling survival could be attributed to the variability in the biophysical conditions associated with different plant containers. Despite the uniform soil potting mixture used for the study, there were considerable differences in seedling survival. The container types that offered good soil aeration and less degradability supported higher survival percent. The poor survival for seedlings grown in mud pots could be partly due to the soil compaction and poor water drainage when the seedlings are kept for longer storage. Soil compaction leads to decrease in root penetration, root growth and root proportion which affect the survival of seedlings due to due to the resistance of the substrate to be penetrated (Day and Bassuk, 1994; Kozlowski, 1999; Bassett *et al*., 2005; Alameda and Villar 2009). Seedling mortality occurs mostly when they are exposed to severe conditions such as moisture stress or non-availability of essential nutrients. Soil compaction reduces soil aeration. In less extreme situation it reduces soil macroporosity (Mc Nabb *et al*., 2001) and make the soil anaerobic. Limitation in soil aeration may impede the root growth by reducing the noncapillary pore space and by providing excess moisture (Kramer, 1995) which leads to reduced root growth and diminished physiological activity and in turn leading to seedling mortality (Huang 1999). The variation in seedling survival rate for different bio-degradable containers could be partly attributed to such growth limitations. The container with good aeration and less degradability supported higher survival percent and root growth (Muriuki *et al.,* 2013) and reduce the transplanting shock (Gerlach, 2007). The seedlings in mud pot might have been suffered from poor aeration and drainage as teak is very sensitive to these factors.

5.2.2. Growth of seedlings

Height growth: The height growth is one of the most important growth parameters that determines the seedling quality. Attainment of plantable height varies with species and the growth habit. Normally for most of the tropical fast growing trees show early height

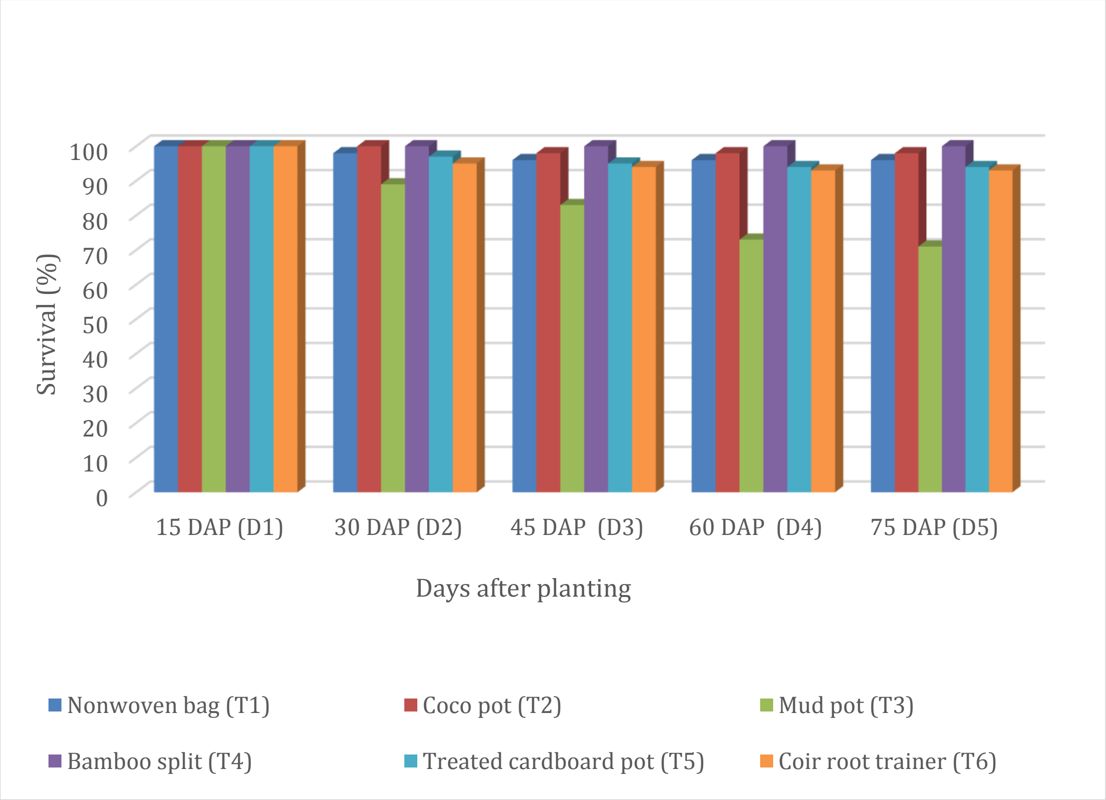

Fig 4. Survival percent of teak seedlings in different biodegradeable containers

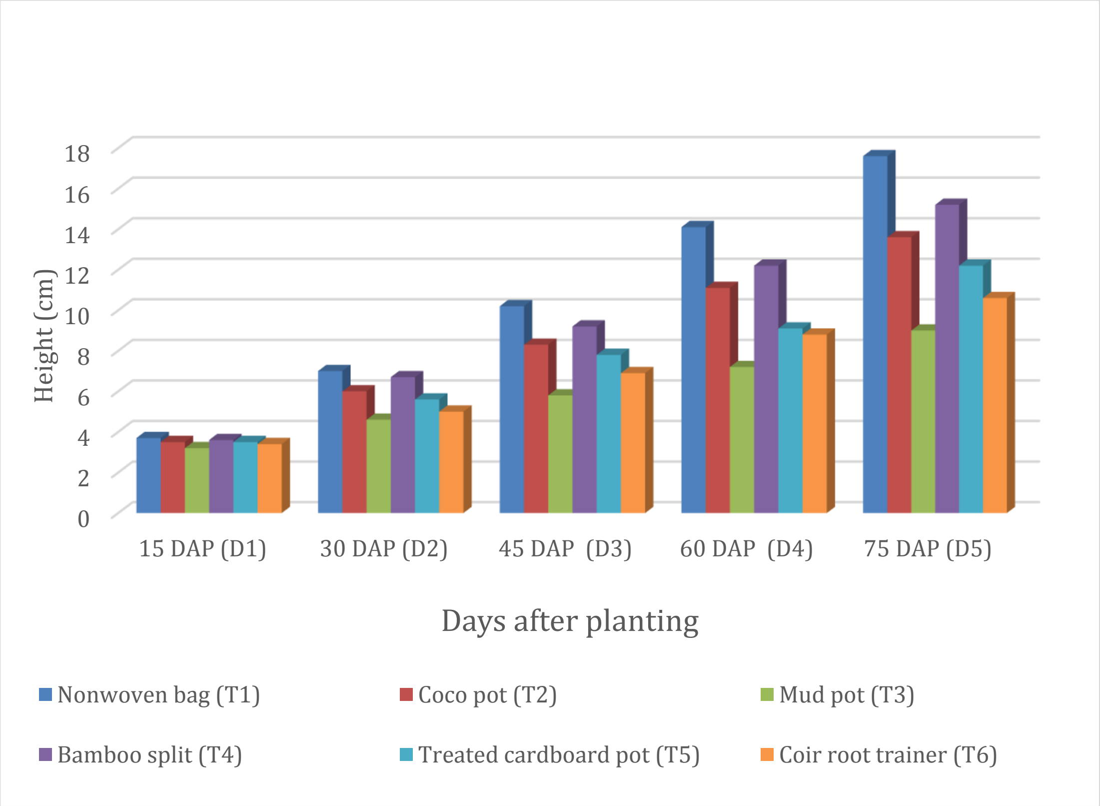

Fig 5. Height growth of teak seedlings in different biodegradable containers

growth within 2-3 months while the moderate growers such as teak takes longer times for optimal height growth. In the present study significance variation has been observed in teak seedling height for different container types despite the uniformity on potting mixture composition and container size. Except for the initial 15 days after planting this variability was discernible during all the sampling periods. For instance, the variation in height ranged in the order 4.6-7.0 cm at 30 DAP, 5.8-10.2 cm at 45 DAP, 7.2 -14.1 cm at 60 DAP and 9.0 to 17.6 cm at 75 DAP. Invariably seedlings in Non-woven bag and bamboo splits registered better heights followed by coco pots. Seedling height in the containers often strongly influenced by the container type especially the shape and cubic content (Tian *et al*., 2017; Aghai and Davis 2014; Nambuthiri and Ingram 2014; Omari 2010; Tsakaldimi *et al*., 2005 and Dominguez-Leren *et al*.,2006). Such factors again influence the root development especially root elongation and spread (Tsakaldimi *et al*. 2005 and Campbell and Hawkins, 2004). Ideally tree seedling containers with reasonably larger size (height) and moderate diameter are preferred which ensure deep root production and training of roots by the side walls. Non-woven bags are similar to polythene bags in terms of durability and physical sturdiness to hold soil. They also withstood continuous irrigation. The possible reason is that the non-woven container is permeable and allows water and soluble nutrients to move laterally, which could affect the water and nutrient availability for each seedling and thus impact the seedling growth (Tian *et al*., 2017). The container walls are strong enough to train the roots to the deeper soil. Bamboo splits also had high durability and better length to diameter ratio which permit the faster growth of the root system. This could be reason for the better height growth of teak seedlings in these two types of containers. Furthermore, better soil aeration, ability to hold water and minerals may also have contributed to the better height growth.

Interestingly height growth of teak seedlings in the mud pot was the lowest despite its physical soundness. Probably, the short stature and broad base of the mud pots may have adversely affected the root and shoot growth. Many studies illustrate such differences in seedling height growth consequent to size and shape of the containers. The positive effect of increasing container size on seedling growth was reported for many plant species. For *Pinus pinea* (Dominguez-Lerena *et al.,* 2006), *Eucalyptus citriodora* Hook. (Vaknin *et al.,* 2009), and *A. koa* (Dumroese *et al*., 2011) it was observed that seedling height, root-collar diameter, leaf production, and biomass increased with an increase in container size.

In a study conducted by Tsakldmi *et al*. (2005) found that *Quercus ilex* and *Quercus coccifera* seedlings grown in paper pot FS 615 had significantly greater height than those grown in plastic containers (Quick pot T18, Plantek 35F). All these containers were of different shape and sizes. In case of paper pot the volume of the container was 482 × 10^3 mm^3,150 mm depth and each cavity was hexagonally shaped where as in case of quick pot each cavity was square shaped with volume of 650×10^3 mm^3 ,180 mm depth and having interior vertical anti-spiralling ribs and open cross base. In case of plantek 35F the design was similar to that of quick pot, but these containers had additional benefit of air root pruning from sides and from base. The volume of the container was 275×10^3 mm^3 and130 mm in depth.

Attempts to relate seedling height growth with other growth parameters indicated high positive correlation (>0.95) among the tested variables such as collar diameter, shoot dry weight, root dry weight, total dry weight and root length. The high correlation obtained for seedling height and root length (>0.98) for non-woven bag indicate its importance in overall seedling growth (Table 18). It can be seen that the height had better correlation with root weight and root length as compared to collar diameter. This reveals the strong association between the aboveground and belowground growth variables. Similar observation has been observed for seedlings grown in bamboo splits reiterating the robust relation between seedling height and other growth variable especially those in the belowground (Table 19). Many studies established such positive correlation of seedling height with root growth (Binotto, 2010 and Ritchie *et al*., 1993).

Collar diameter: The seedling collar diameter is yet another prominent growth attribute that influence the quality of the seedlings. In general, the bigger the better. Stem diameter has been considered the best predictor of field survival and growth. Optimal collar diameter is inevitable for healthy growth of the plants which should be proportional to the height growth ((Nayak *et al*., 2017 and Mohapatra *et al*., 2008). A larger collar diameter also indicates a larger root system and a larger stem volume (Haase, 2008). Poor collar diameter and faster height growth often lead to weaker seedlings which may eventually topple with increase in biomass. As discussed before, the balanced plant growth warrants proportional growth in collar diameter compared to height growth. Among many biophysical factors, the congenial growth conditions provided by the plant containers ensure optimal availability of the resources and their allocation to the plant components. For instance, the present study demonstrated such appreciable variation of collar diameter of teak seedlings among containers (Table 5 and Fig 6) at various stages if seedling growth (days after planting). As observed earlier for height growth, the nonwoven bag (T_1) dominated in seedling collar diameter over others followed by bamboo splits while mud pot (T_3) performed least.

Significantly higher positive correlation has been observed between collar diameter and other growth variables such as height, shoot and root dry weight and total plant biomass (correlation coefficient >0.95) indicating the strong correspondence between the variables.

In a recent study on *Cyclocarya paliurus* it was demonstrated that the root-collar diameter and height of the seedlings were positively and significantly correlated with the biomass variables and root morphological variables, and could be considered essential attributes for evaluating seedling quality (Tian *et al*., 2017 and Binotto *et al*., 2009). Interestingly collar diameter was more closely correlated with root dry weight and root length. These clearly demonstrate the significance of collar diameter for balanced root growth.

Another study conducted by Apko *et al*., (2013) with oil palm (*Elaeis guineensis Jacq*.) grown in polythene bag observed that the relations between biomass and height and root-collar diameter variables were curvilinear. Correlation of biomass was highest with seedling height (R^2 = 0.85 and 0.91 in 2011 and 2012, respectively). The lowest correlation, which was still significant ($p < 0.001$), was observed with root-collar diameter (R^2 = 0.74 in 2011 and R^2 = 0.71 in 2012).

The better radial growth of teak seedlings in the nonwoven bag and bamboo splits suggest their ability to maintain better soil biophysical conditions especially for optimal root growth in addition to their enhanced physical suitability and durability. Most of the remaining container types exhibited varying levels of degradation due to infestation by fungi and termites. This may have further influenced the general health of the seedlings. Despite the moderate increment in collar diameter during the early phases of growth, treated cardboard pot showed significant increase in collar diameter (69%) between the final sampling periods (60 -75 days after planting). This observation suggests that the possible improvement in rhizosphere conditions in certain container types with advancement in growth. Yet another finding is that CNS treated cardboard containers exhibited fair stability and durability after non-woven bag and bamboo splits.

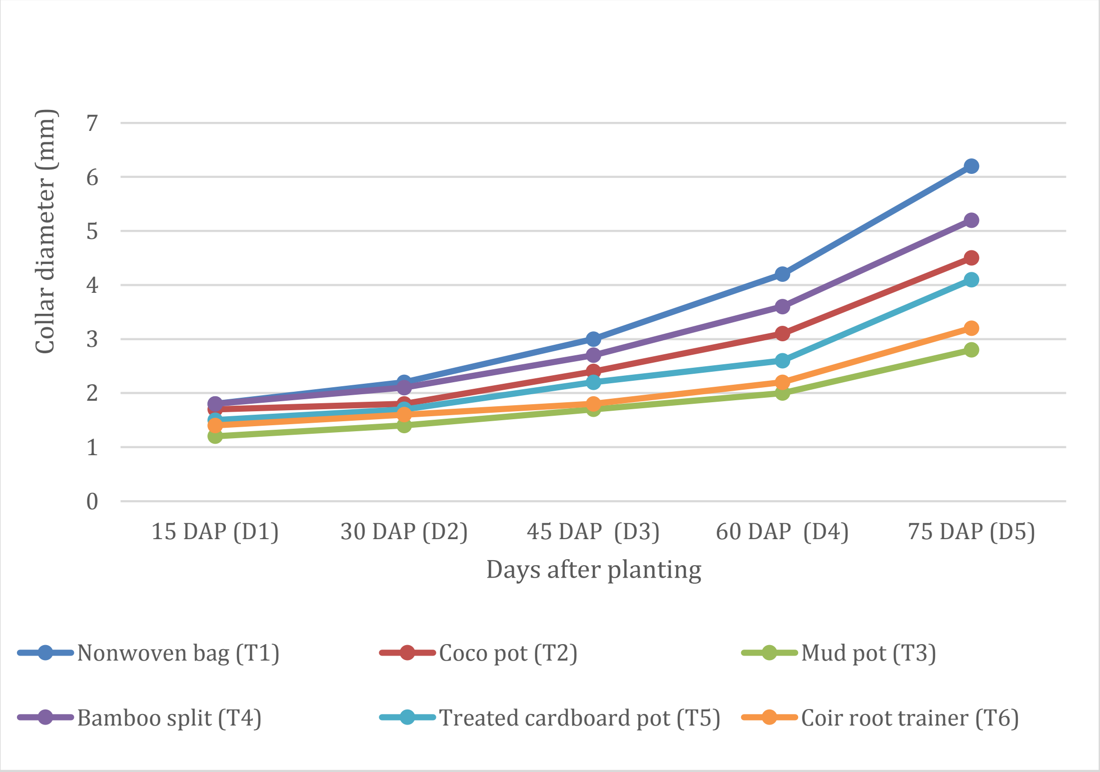

Fig 6. Collar diameter growth of teak seedlings in different biodegradeable containers

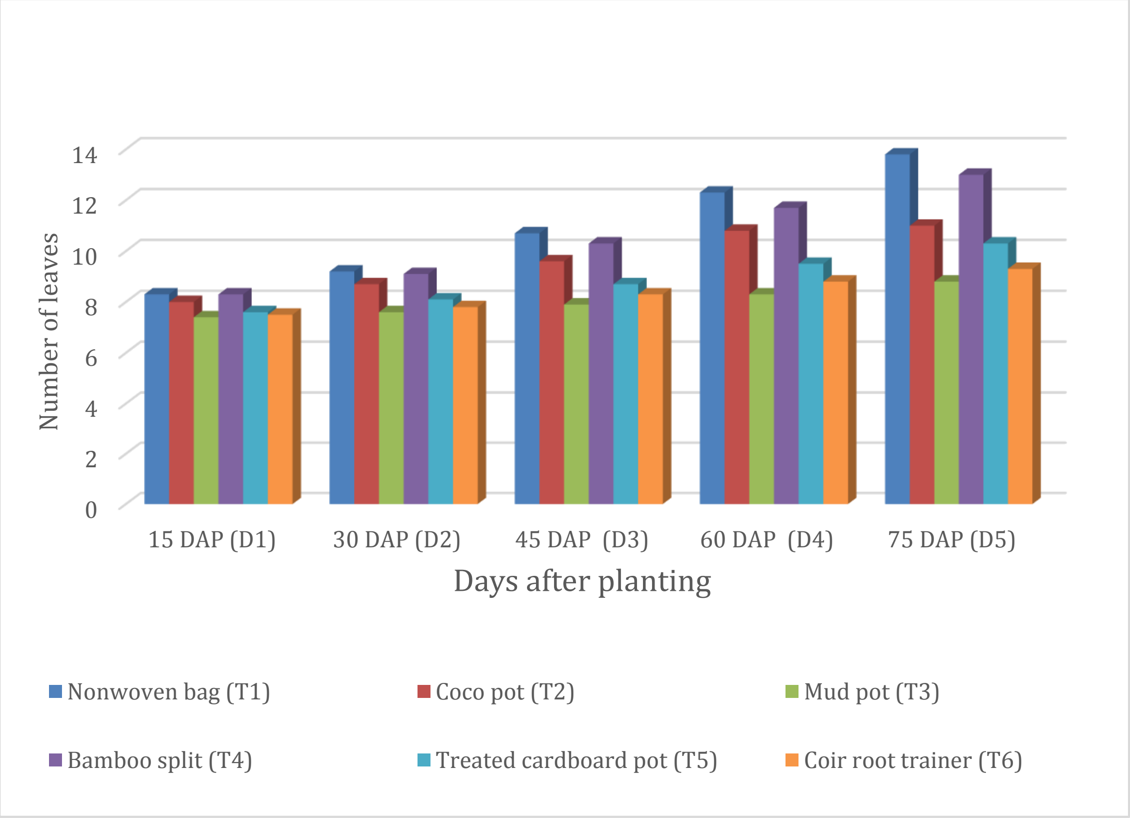

Fig 7. Number of leaves of teak seedlings in different biodegradeable containers

Number of leaves and leaf area: A significant variation in number of leaves was found during different stages of evaluation among various containers (Table 6 and Fig 7) except for the early two periods. Throughout the evaluation period nonwoven bag (T_1) maintained higher number of leaves closely followed by bamboo split (T_4) whereas Mud pot (T_3) continued to be maintain lower leaf numbers. A similar trend was discernible for leaf area as well, though it showed significant variation among the container types right from the first observation onwards.

The Table 7 and Fig 8 clearly demonstrate that the leaf area of teak seedling varied considerably among containers at different stages of sampling. This is also evident from the conspicuously lower p values (<0.0001). Leaves being the component responsible for photosynthesis, their number and leaf area plays pronounced effect on the overall seedling growth. Optimal growth of plants demands such high number of leave especially during the early growth phase. The relationship between leaf area growth and growth in terms of mass will depend on how carbon is partitioned among new leaf area, leaf mass, root mass, reproduction, and respiration (Weraduwage *et al.*, 2015). Hence leaf production and area of solar interception assume considerable importance in the production and allocation of carbon among the plant components. Obviously, seedlings with high leaf number register higher leaf area especially for big leaved trees like teak. The pronounced effect of container types on leaf number and leaf area conforms to the understanding that containers play larger role in providing optimal growth conditions for the seedling growth (Tian *et al.*, 2017). A cumulative effect of the container stability, potential to hold the seedling, proper drainage and soil aeration may have contributed for this trend.

5.2.3. Root growth

Primary root length: The roots play vital role in seedling growth. The balanced growth of the seedlings requires healthy root system to absorb water and minerals. The present study on the suitability of the container types for quality seedling production for teak clearly showed that nonwoven bag (T_1) manifested the highest primary root length which was at par with bamboo split (T_4). Mud pot (T_3) produced the shortest primary root among the containers tried. Seedlings in all the remaining containers showed moderate root development. The containers which resulted higher growth of primary root may ascribe to their better aeration and temperature regulation. This is in agreement with the report of Nandakumar (1996).

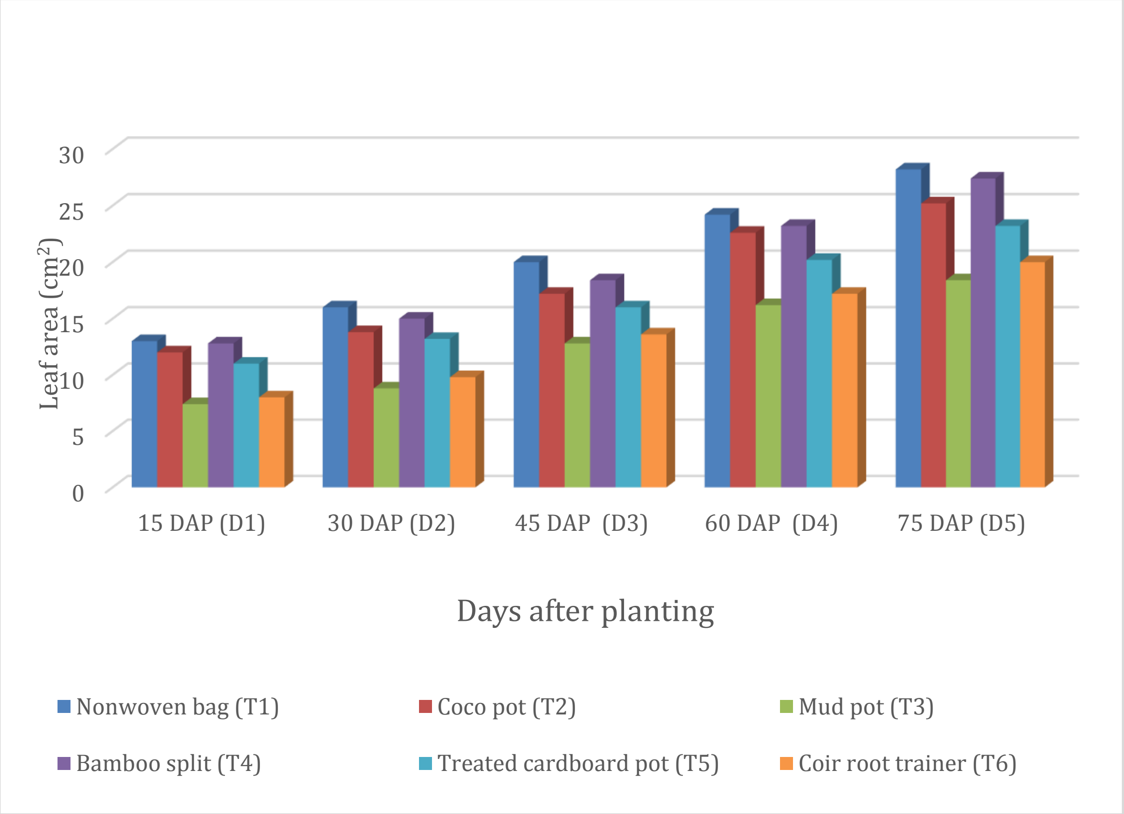

Fig 8. Leaf area of teak seedlings in different biodegradeable containers

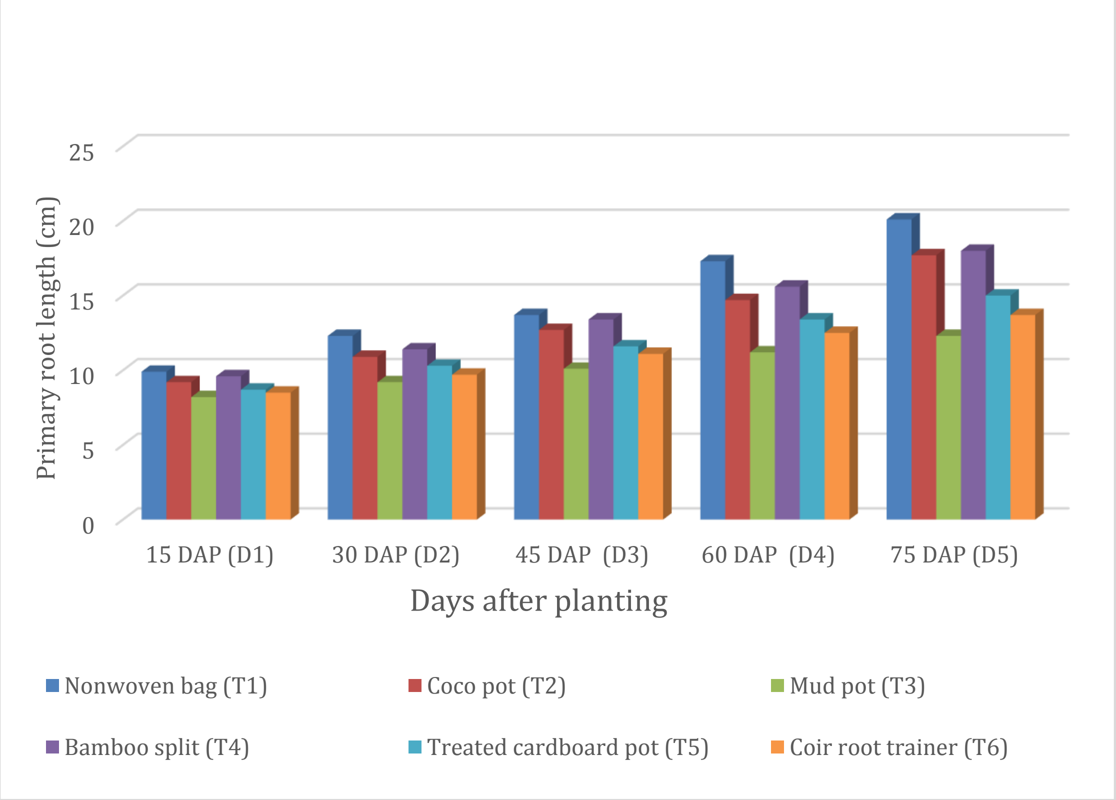

Fig 9. Primary root length of teak seedlings in different biodegradeable containers

Furthermore, one of the most serious problems in containers (especially for the seedlings with tap roots) is the tendency of root spiraling around the inside of the container when round, smooth-walled plastic containers were used, which can seriously reduce seedling quality and field performance after planting (Tian *et al*., 2017). The primary reason for the poor performance of tree seedlings in the field condition is the poor quality of the planting stock (de Oliveira and Miglioranza 2015; Tsakaldimi *et al*., 2005 and Stape *et al*., 2001). Apart from the overall poor seedling health, root coiling play adverse impacts on early establishment of seedlings in the field (Perello *et al*., 2013; Tsakaldimi *et al.*, 2005; Wightman 1998). In the present study too considerable variation in the tendency to root coiling has been observed with various container types. In general, the extent of root coiling was not discernible among the container types during the first three stages of sampling (15, 30 and 45 days after planting (Table 9 and Fig 10). Invariably very little coiling of primary roots was noticed because plants were in small stage and their roots were lesser than the container height. However, there was marginal variation in root coiling among the containers on 60 and 75 DAP.

Interestingly the containers with faster root growth such as nonwoven bag and bamboo showed marginally higher root coiling compared with other container types. This could be probably due the faster root growth shown by these container types where the root growth was higher than the container height as reflected in Table 9. However, the other containers recorded lower root length, hence the lower tendency to root coiling. The lesser root coiling associated with most of the container types under present study clearly demonstrate the role of container types in optimal root development. All these containers are stronger than conventional poly bag containers and hence the better physical strength to train the roots towards the deeper soil in the container. Generally, the type, volume and shape of the containers are the most important characteristics facilitating root growth which has major and direct impacts on seedling quality (Poorter *et al*., 2012; de Oliveira and Miglioranza, 2015; Tsakaldimi *et al*., 2005 and NeSmith and Duval, 1998).

The root length: shoot length ratio: The seedling root length: shoot length ratio often cited as an index of seedling health (Agathokleous *et al*., 2019; Binotto *et al*., 2010). Many factors contribute to this ratio which include the type, shape and volume of containers. In the present study, the various container types tested showed only marginal difference in root length: shoot length ratio during all the

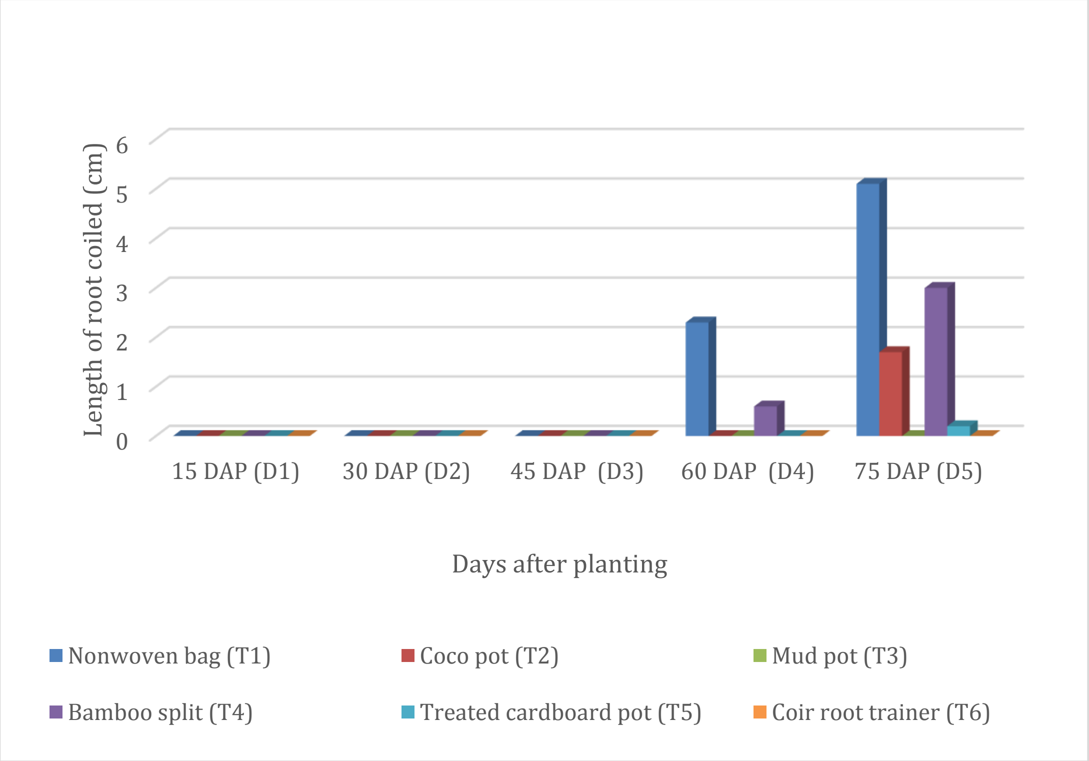

Fig 10. Length of primary root coiled in different biodegradeable containers

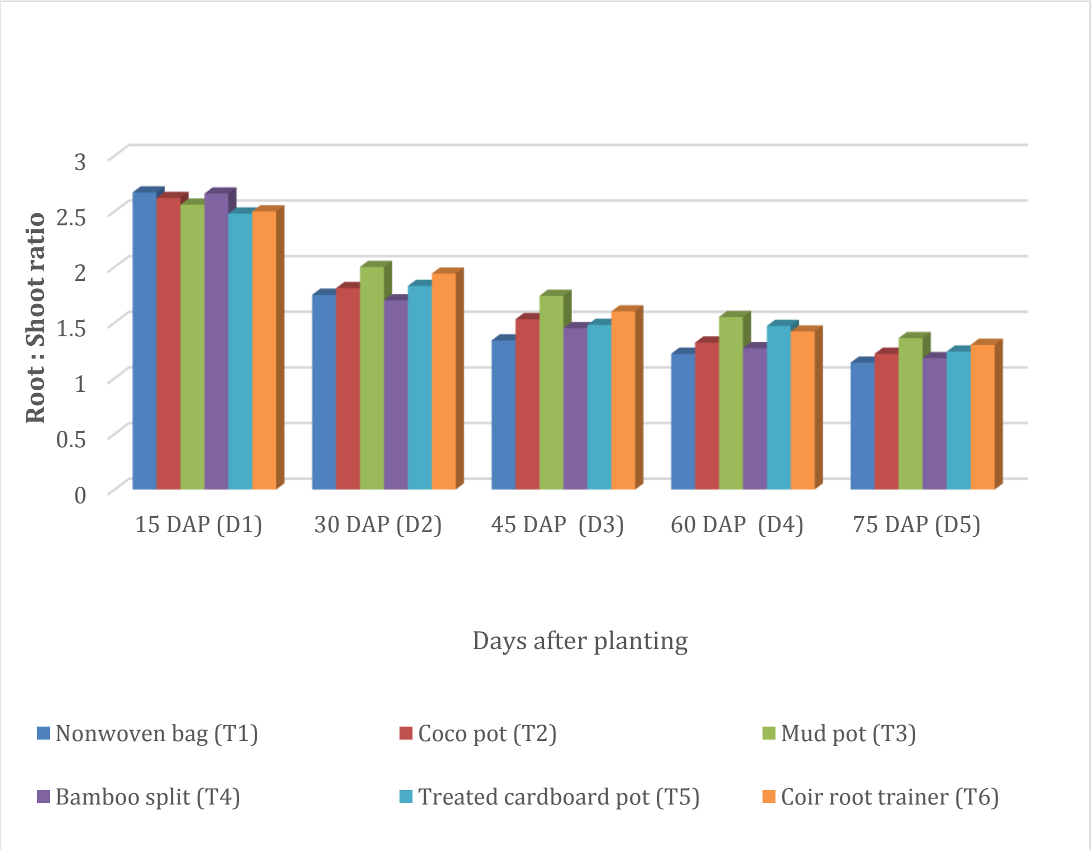

Fig 11. Root : Shoot ratio of teak seedlings in different biodegradable containers

This leads to the conclusion that the overall seedling performance remained balanced irrespective of the container types. Interestingly the ratio decreased with increase of age of the seedling for all container types. This could be on account of the faster shoot growth in the advance stages of seedling growth as contributed by the limited volume for root development in the containers (Maskova, and Herben, 2018).

Secondary, lateral and tertiary root growth: As observed for the primary root growth pattern, the secondary, lateral and tertiary roots also exhibited significant variation for teak seedlings grown in different containers. As expected, the non-woven bag and bamboo splits grown seedlings out performed all the remaining containers in this respect while mud pot recorded lowest value. For instance, the order of secondary root number was nonwoven bag (T_1)> bamboo split pot (T_4) > coco pot(T_2) > treated cardboard pot (T_5)> Coir root trainer (CRT)(T_6) > mud pot (Table 11 and Fig 12). With advancement of age, the number of secondary roots increased. The difference in number of secondary roots among container types may be due to variation in primary root length and growing atmosphere in rhizosphere. The number of secondary roots increased with age in all containers which could be due to the fact that the secondary root development often forms a function of the primary root development (Ortega *et al*., 2006; Gilman *et al*., 2010).

Similar observations were discernible for lateral root growth as well with significant variation among the container types (Table 12 and Fig 13). At 75 DAP, non-woven bag and bamboo splits dominated in terms of lateral root growth followed by coco pot, treated cardboard pot, Coir root trainer (CRT) and lowest by mud pot. The strong relation between lateral root spread and container wall type has been observed in many studies (Gilman et al. 2010). They observed that smooth-sided plastic containers were associated with the most defects. Smooth walled containers often offer limited training of the lateral roots leading to restrictions in root development.

The Tertiary root development also followed the predictable pattern with that of other root types (Table 13 and 14). Throughout the period of assessment, nonwoven bag maintained highest number of tertiary roots and remained at par with bamboo splits. Mud pot (T_3) found to continue with least number of tertiary roots. Interestingly, despite the lowest number of tertiary roots in mud pots, they showed

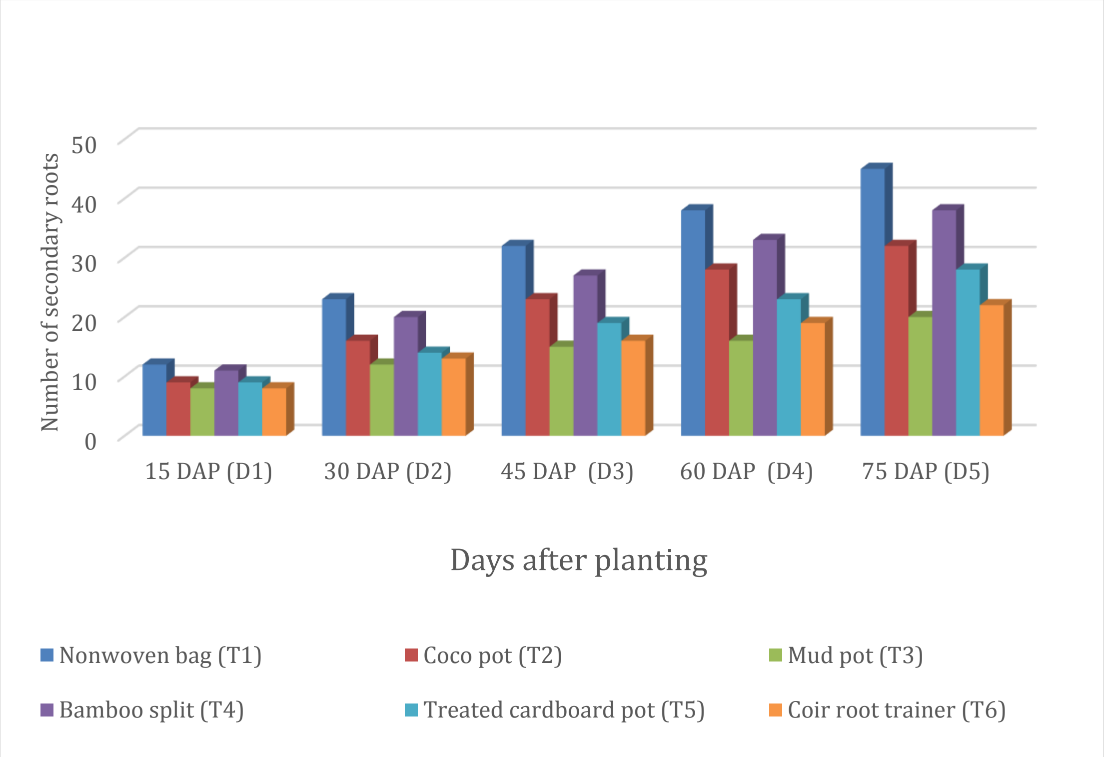

Fig 12. Number of secondary roots of teak seedlings in different biodegradeable containers

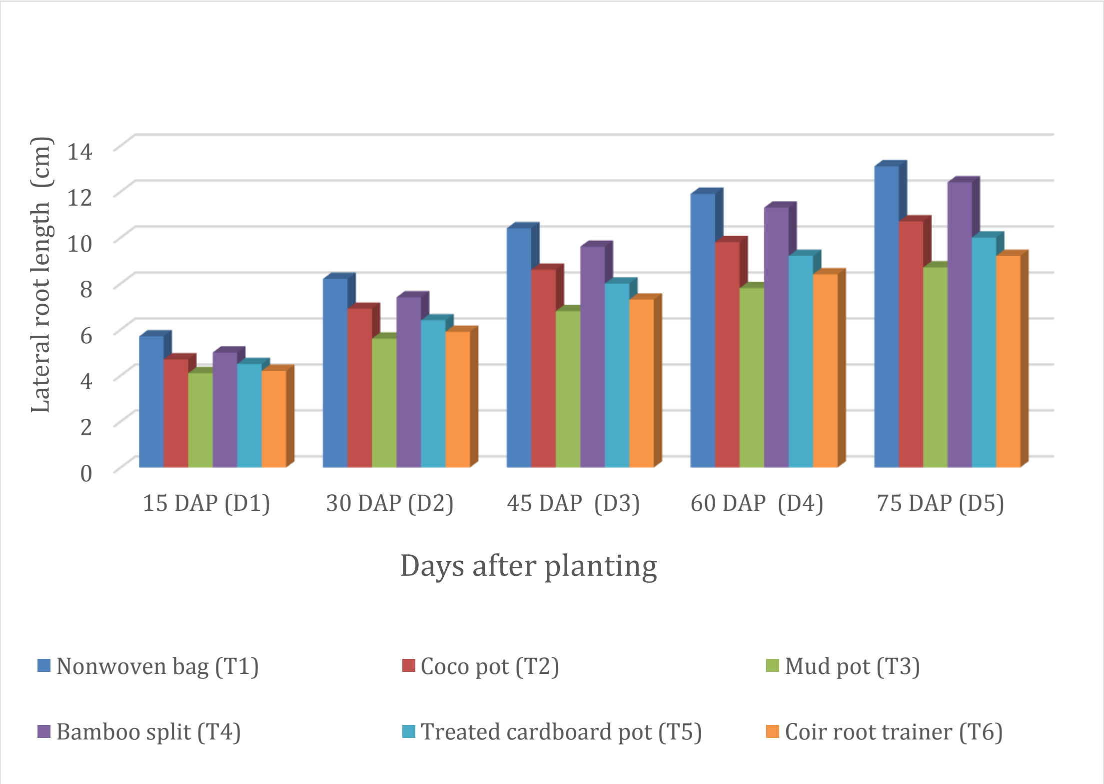

Fig 13. Lateral root length of teak seedlings in different biodegradeable containers

higher percentage increase (20.8%) during the last fortnight period (60 to 75 DAP) while all the remaining containers registered around 12-17% increase in seedling height during the corresponding period. Furthermore, the tertiary root production registered steady increase with advancement of age. Tertiary roots play prominent role in seedling nutrition as they form the fine roots responsible for water and mineral uptake. Hence, the rate of development of tertiary roots has significant influence on healthy seedling production. Being a function of primary and secondary root growth, they often follow the similar pattern as that of the other root types.

5.2.4. Shoot and Root Biomass

Shoot dry weight: The teak seedlings in various container types in general showed fair shoot dry weight during the two and half month study period. The study also demonstrated good variation in shoot dry weight of teak seedlings grown in different containers (Table 14 and Fig 15). The range of shoot weight per seedling among the containers was 0.13 to 0.20 g at 15 DAP, 0.28 to 0.72 g at 30 DAP, 0.46 to 1.26 g at 45 DAP, 0.68 to 1.85 g at 60 DAP and 0.90 to 2.34 g at 75 DAP. In consistent with the general trends observed so far, the non-woven bag and bamboo splits grown seedlings had higher shoot weight while the mud potted seedlings had the lowest value. Shoot weigh often reflect the total aboveground biomass allocation potential by plants with progressive time. The rate of shoot weight accumulation may vary with advancement in time for variable container types consequent to the changes in biophysical conditions. For instance, the better performed non-woven bags showed the lowest percentage (26.4%) increase in the shoot dry weight during the final sampling period (60 DAP to 75 DAP) whereas coco pot seedlings showed highest percentage increase 33.8% during the same period. The variation in shoot dry weight under different container types may be attributed to difference in shoot growth terms of height, diameter, number of leaves and leaf area.

The seedlings with a larger shoot mass have a greater photosynthetic capacity and potential for growth (Haase, 2008). However, a greater transpirational area may lead to moisture stress on dry sites prior to root establishment. Shoot mass must be in balance with root mass for optimum seedling quality.

Root dry weight: The seedlings with larger root dry weight tend to grow more and survive better than those with smaller root mass. Container types excreted good amount of variability in seedling root dry weight during different stages of the study.

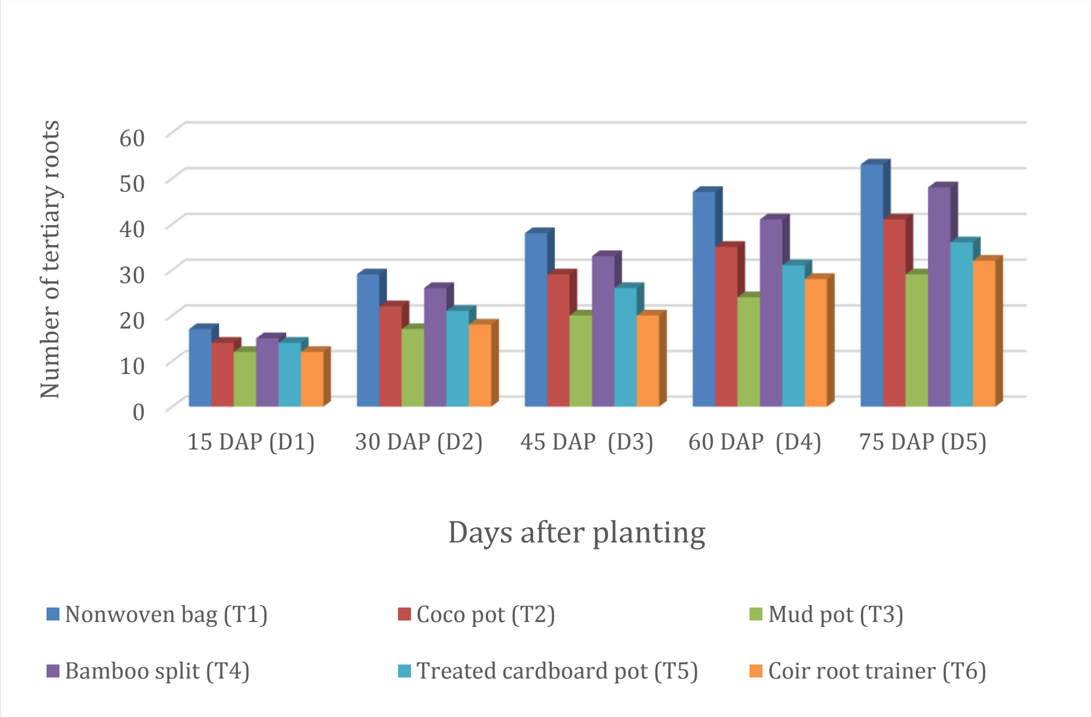

Fig 14. Number of tertiary roots of teak seedlings in different biodegradeable containers

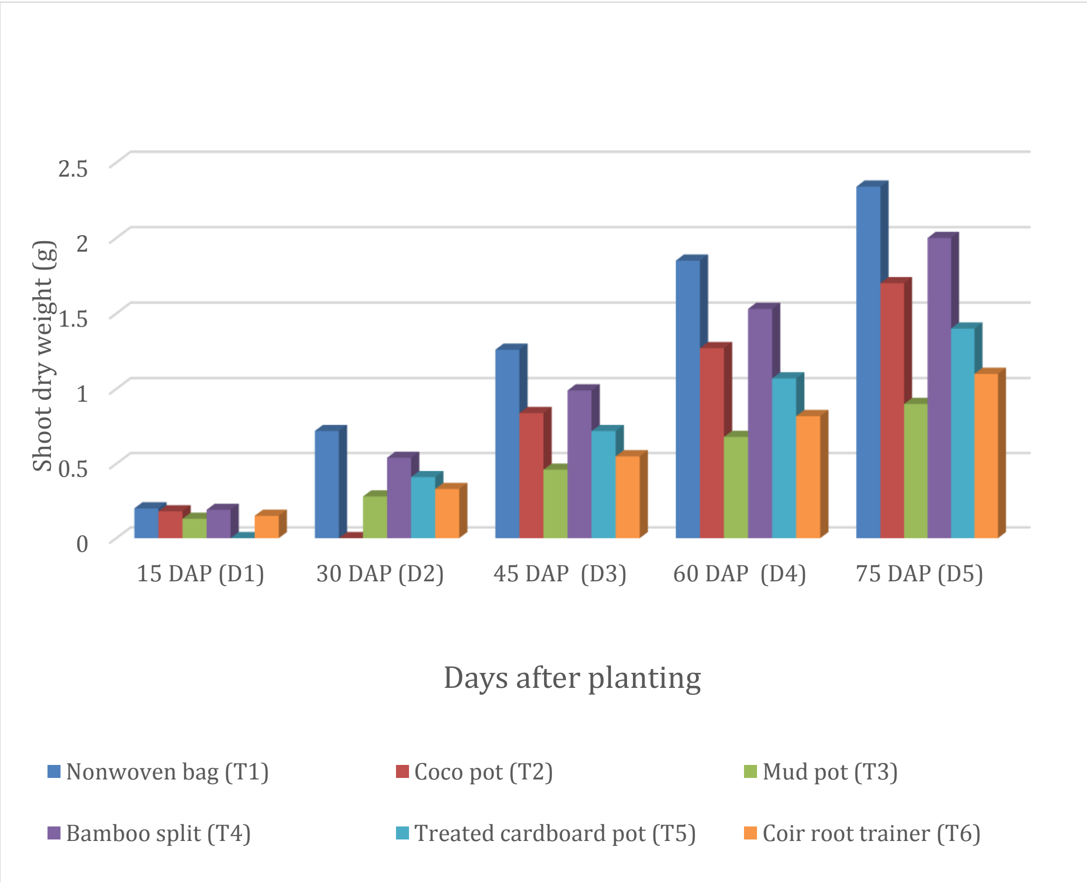

Fig 15. Shoot dry weight of teak seedlings in different biodegradeable containers

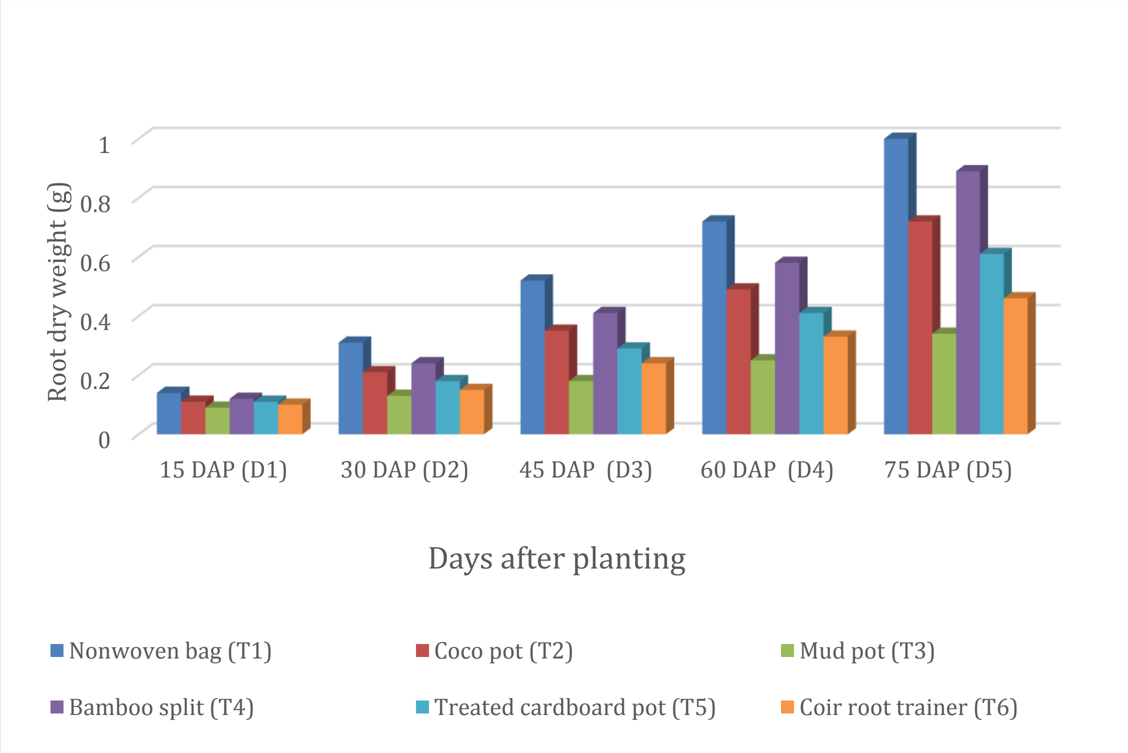

Fig 16. Root dry weight of teak seedlings in different biodegradeable containers

The higher root biomass associated with seedlings grown in non-woven bag and bamboo splits suggest physical suitability of the container material to facilitate root growth. Also considerable variation in root dry weight accumulation has been observed with increase in growing period. For instance, Bamboo split pot showed 53.4% increase in the root dry weight from 60 DAP to 75 DAP while mud pot showed 36% increase in the root dry weight in the same period of time. Such variations in root biomass with container types have been reported before (Kuehny *et al.*, 2011; de Oliveira and Milioranza, 2015 and Beeks and Evans, 2013a).

Faster root production is often a continuation of the better aboveground biomass accumulation. However, the size, shape and wall flexibility of the containers may limit the root growth considerably despite the better soil properties and moisture regimes (Moriwaki, 2013 and Gruber, 1978). Probably such physical barriers contributed by the container type could be the reason for their lower root dry weight. Despite the significance of root dry weight as a determinant of seedling growth, it may not always reflect root fibrosity since a seedling with many fine roots can have the same mass as a seedling with a large tap root (Haase, 2008).

Total dry weight: The totality of the growth potential of seedlings are often decided by the total plant dry weight. It reflects the capacity of the soil medium and the container bio-physical condition to support biomass. For instance, the biomass per seedling varied from 0.22 to 0.34 g at 15 DAP, 0.41 to 1.03g at 30 DAP, 0.64 -1.78 g at 45 DAP, 0.93 to 2.57 g at 60 DAP and 1.24 to 3.34 g at 75 DAP ((Table 16 and Fig 17). The composition and volume of the soil medium remains the same, this observed variability in total dry weight in the present study could be attributed to the container characteristics.

The highest total biomass production in the non-woven bagged seedlings in on account of the cumulative higher shoot and root biomass production. The variation of dry weight under different container types have also been reported by Tsakaldimi *et al.* (2005), Kuehny *et al.* (2011), Koeser *et al*. (2013), Beeks and Evans (2013a), de Oliveira and Milioranza (2015) and Castronuovo *et al.* (2015).

5.2.5. Quality Index of seedling

The scrutiny of data in Table 17 and Fig 18 denotes that the quality index of seedling varied significantly among the containers studied at various stages. The values of quality index differed from 0.05 to 1.00 at 15 DAP, 0.07 to 0.19 at 30 DAP, 0.10 to 0.30 at 45 DAP, 0.15 to 0.43 at 60 DAP and 0.22 to 0.64 at 75 DAP. Nonwoven bag (T_1) maintained its supremacy over others followed by bamboo split (T_4). Mud pot (T_3) continued to be the least performer.

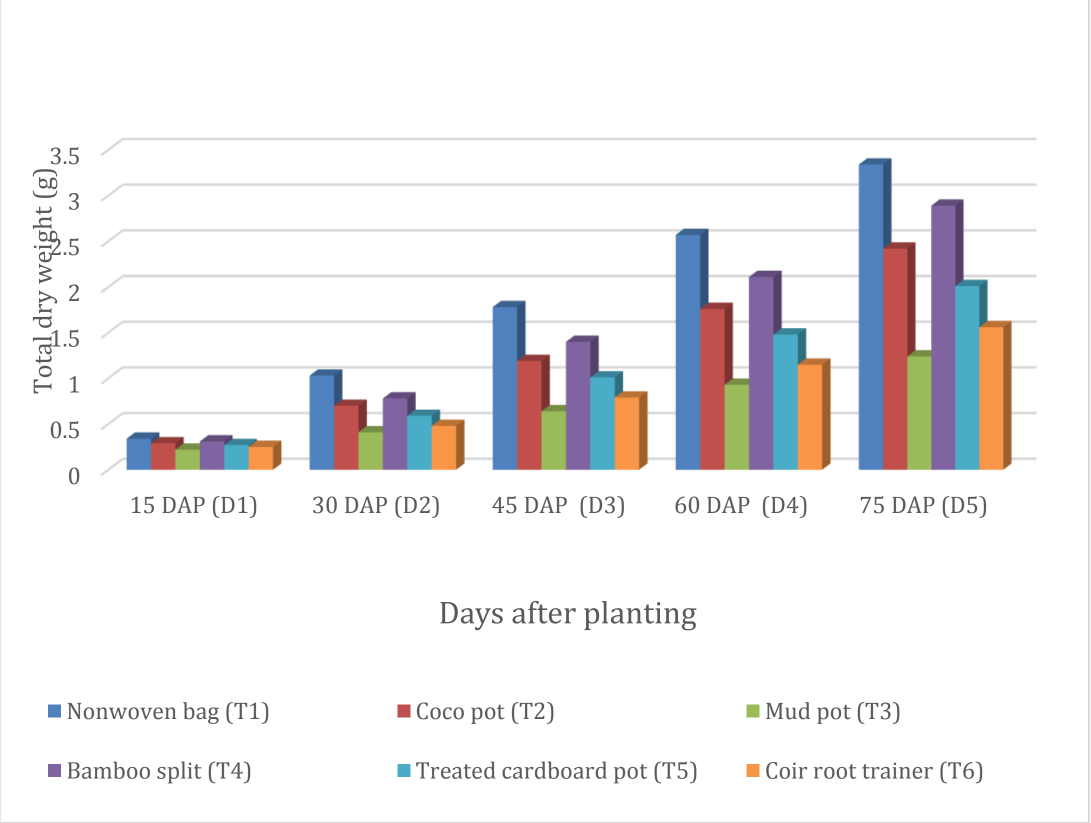

Fig 17. Total dry weight of teak seedlings in different biodegradeable containers

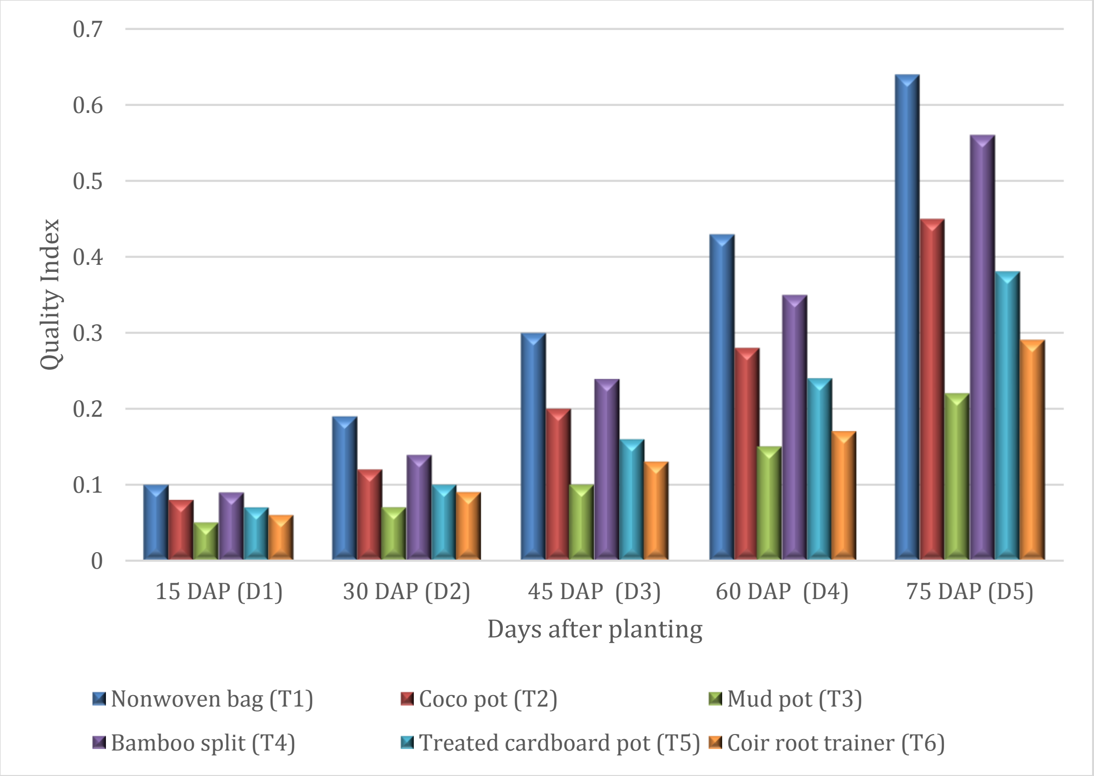

Fig 18. Quality Index of teak seedlings in different biodegradeable containers

The seedling quality is often considered as the net effect of growth potential and the effective allocation of biomass to the aboveground and belowground. For instance, the observed better quality index of seedlings grown in non-woven bag and bamboo splits could be linked with their high growth potential and the optimal distribution to the aboveground and belowground components in comparison to other container types. This is quite obvious from the root: shoot ratio attached to these two container types. Variation of seedling quality index in different container types has also been reported by de Oliveira and Milioranza (2015) for coffee seedlings. The quality of seedling improved in all containers with age. This is because of development of below ground and above ground parts of seedling in balanced way. The increase of quality of teak seedling with age has also been reported by Nayak *et al.* (2017) and for sandalwood seedling by Mohapatra *et al.* (2008).

5.3. Economics of raising teak seedling in different containers

The economics of raising teak seedlings (3-month old i.e. 15-day transplant plus 75 DAP) in different biodegradable containers has been presented in Table 18 and Fig 19-20. The total cost of raising one seedling which survived was calculated as Rs 8.3 for nonwoven bag (T_1), Rs 60.2 for coco pot (T_2), Rs 62.0 for mud pot (T_3), Rs 11.0 for bamboo splits (T_4), Rs 12.8 for treated cardboard (T_5), Rs 25.8 for Coir root trainer (CRT) (T_6). The sale price for 3- month old teak seedling have been considered Rs 20 for T_1, T_2, T_3, T_5 and T_6 and Rs 27 for T_4 (Bamboo split pot). In case of seedlings grown in bamboo split pot sale price has been considered Rs 7 more because the container can be used for another season whose price is Rs.7. The conventional container 'polythene bag' has also been included as check for comparison for which cost of raising seedling was Rs 5.0 and it was lowest among containers tried.

The benefit: cost ratio of raising 3- month old teak seedlings varied appreciably among different biodegradable containers ranging from 0.32 to 2.45. The value was highest in case of seedlings raised in bamboo split pot followed by nonwoven bag, treated cardboard (T_5), coir root trainer (T_6), coco pot (T_2), mud pot (T_3). The higher B:C ratio in case of bamboo split pot and nonwoven bag may be ascribed to their higher plant survival percent and low cost of containers. These two containers also produced better quality plants. The benefit: cost ratio for polythene bag was found 4.0 in the nursery trial of College of forestry, which is very high as compared to the containers tried in the above experiment. This is because of lowest cost of container in comparison to others.

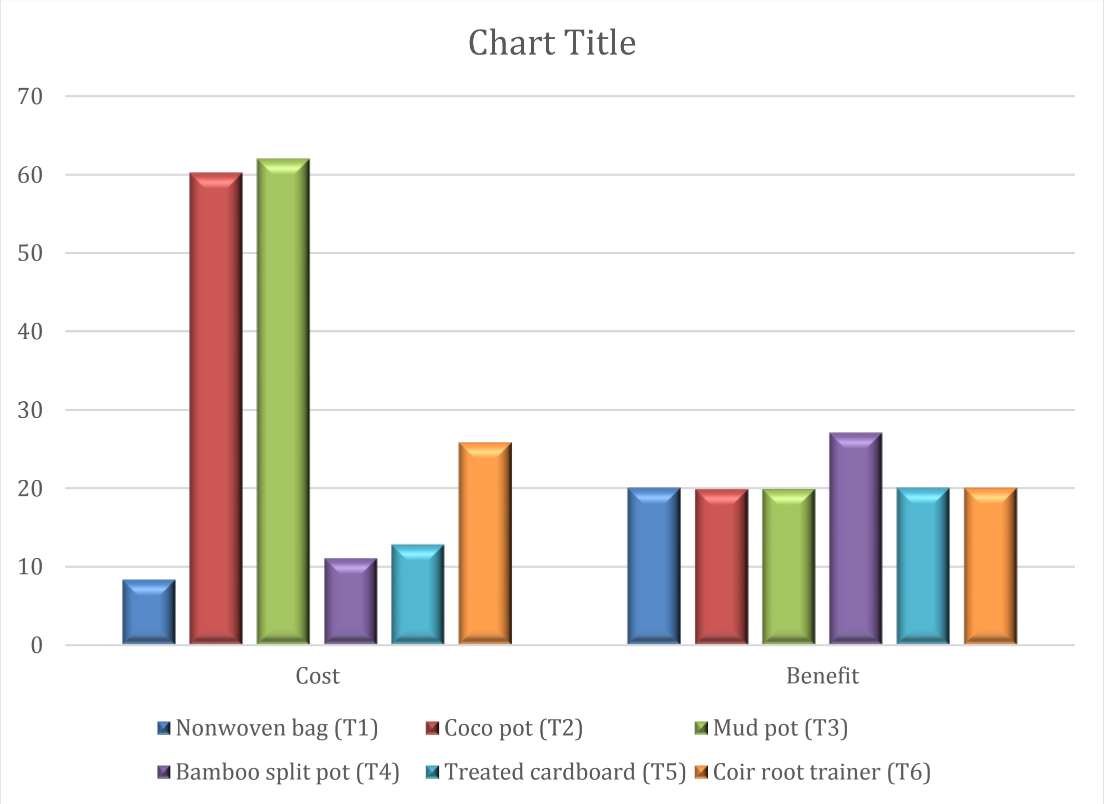

Fig 19. Economics of raising teak seedlings in different containers

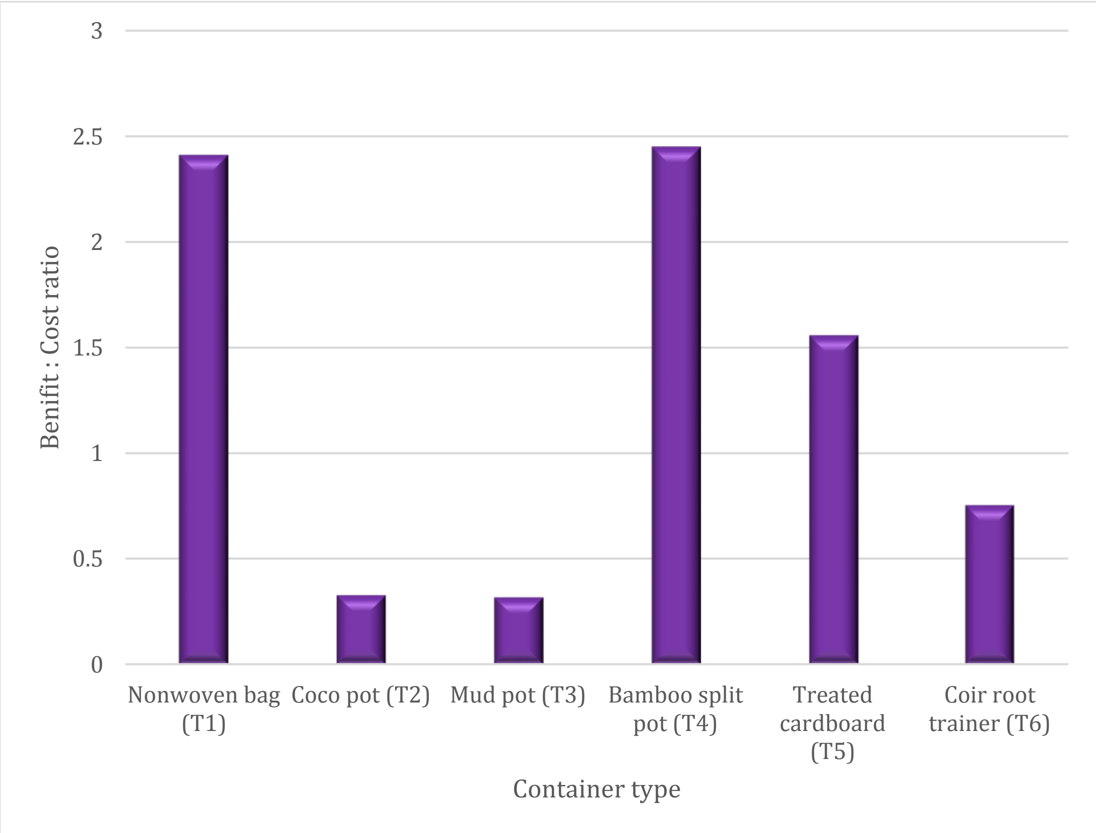

Fig 20. Benefit: Cost ratio of raising teak seedlings in different containers

5.4. Additional observation

The data of 3-month old teak seedlings (15 day-old transplants grown for 75 days after transplanting) were analyzed statically, presented and discussed above. However, the seedlings are still growing in different containers. The photographs of 4-month old seedlings are presented in Plate 4. While the growth of seedlings grown in bamboo splits, nonwoven bag, coco pot and treated card board was compared with seedling grown in polythene bag, a remarkable higher growth was observed in biodegradable containers. Even the growth of seedlings in bamboo splits and nonwoven bags was at par with 1-year old seedling grown in polythene bag. This indicates that with advancement of age of seedlings, the better growth environment of biodegradable containers accelerates the growth rate in comparison to polythene bag. However, it needs detailed study further to draw conclusion.

5.5. Managerial implications of the study

The primary objective of the study was to develop cost effective container types for mass production of teak seedlings. Our observations reveal that non-woven bag and bamboo splits are the superior among all the tested containers in terms of seedling quality and cost. Despite the better performance of non-woven bag as container, they are partly non-bio-degradable in composition. Bamboo splits are a better option though non-availability of uniform and optimal sized bamboos is a limitation. The fundamental issue with all bio-degradable containers is the low durability and amenability to degradation by fungi, termites and other decaying agents. Furthermore, most of the durable bio-degradable containers are costly and not suggestive for mass production of teak seedlings. A better bio-degradable container as a substitute for polythene bags is still a challenge though which can be partly addressed by employing the non-woven bags and bamboo splits for the purpose.

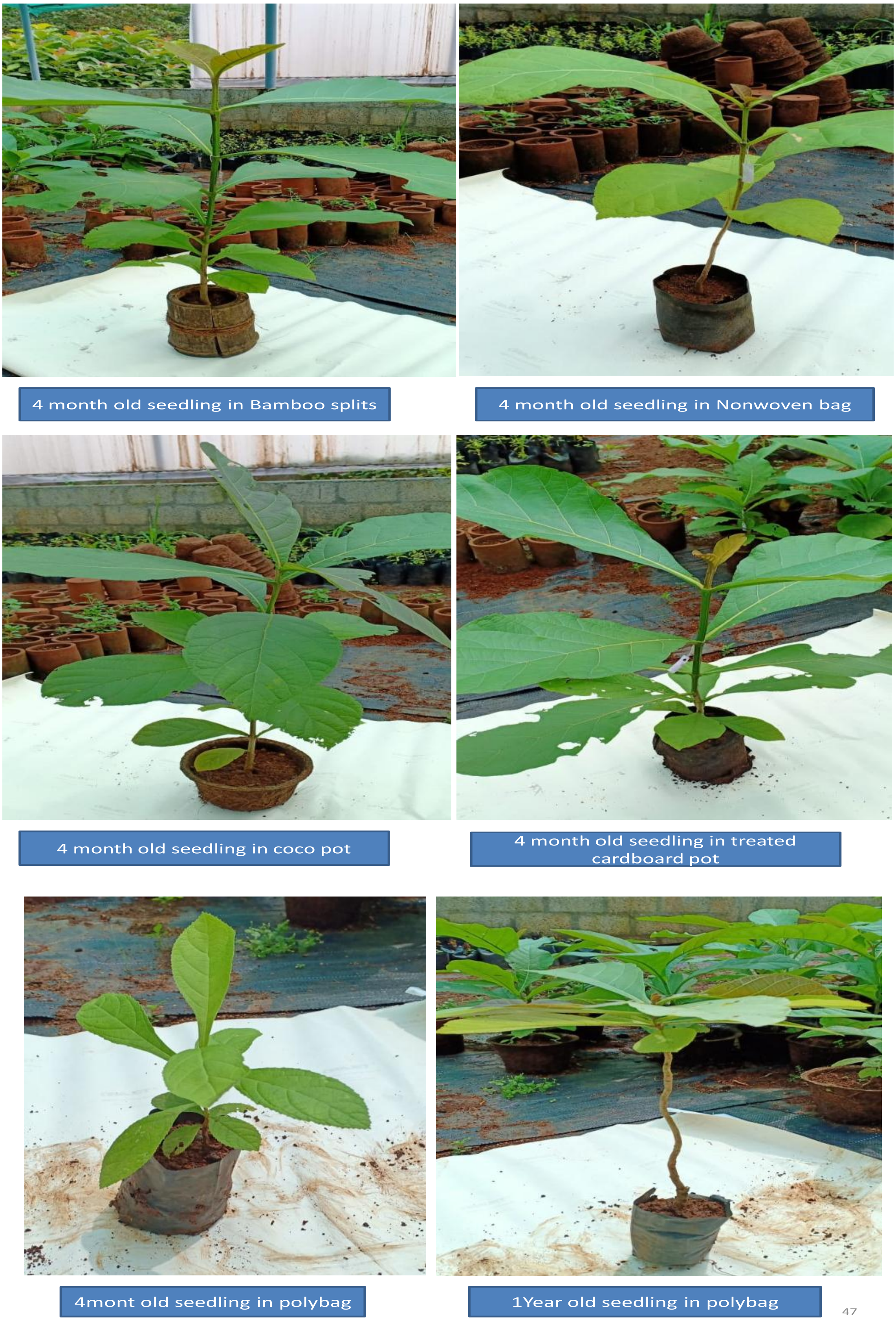

Plate 6. Teak seedlings of 4-month old in biodegradable containers and 1-year old in polythene bag

6. SUMMARY

The plastic container-based nursery production has been the major approach by virtue of its multitude of managerial and economic benefits. However, considering the possible environmental concerns on the use of plastic in the forest nurseries, it is imminent to evolve effective biodegradable containers to replace polythene bags. The present study was conducted in the nursery of College of Forestry, Kerala Agricultural University, Vellanikkara to develop alternate eco-friendly plant container as substitute for conventional polythene bag based containers in forest nurseries. The salient features of the study are summarized below:

6.1. Preliminary trial

An attempt was made to develop bio-degradable plant containers specifically suitable for tree species using locally available cheaper materials such as coir root trainer, cow dung, sugarcane bagasse, arecanut sheath, mud pots, bamboo splits, etc. Also the efficacy of biodegradable materials available in the market such as jiffy pots, nonwoven bag, reinforced cloth bag, bioplastics and treated cardboards were tested for their utility for growing teak seedlings was tested in the preliminary trial for 3 months.

1. The durability of different containers evinced considerable variation from one another in the preliminary trial. It varied from one month to twenty-four months among the containers. Bamboo split pot demonstrated highest longevity in nursery (24 months) while the containers such as arecanut sheath pot, cow dung pot, sugarcane bagasee pot, bamboo basket, bioplastic bag and cloth bag could be retained one month only. The other pots lasted for 12-15 months.

2. The pot made by bamboo splits was found to be used for two seasons while containers such as arecanut sheath pot, cow dung pot, sugarcane bagasee pot, bamboo basket, bioplastic bag and cloth bag could not be used even for one full season. The other pots can be used comfortable for one season.

3. Seedling survival in the preliminary showed that containers such as non-woven bag, coco pot, mud pot, bamboo splits recorded more than 24 weeks of survival. The survival of seedlings in containers like arecanut sheath pot, cowdung pot, bamboo basket and cloth bag was for 2- 4 weeks only.

4. The survival percent of seedlings at 3 months after planting exhibited good variation in different containers. It ranged from 0 – 100%. The container made by bamboo splits registered maximum survival of 100%. On the other hand, containers such as arecanut sheath pot, cow dung pot, sugarcane bagasee pot, bamboo basket, bioplastic bag, cloth bag resulted zero survival. The survival of nonwoven bag, coco pot, CNSL treated card board pot ranged from 92 – 97% while and mud pot resulted 71%.

5. Containers like arecanut sheath pot, cow dung pot, sugarcane bagasse pot, bioplastic bag and cloth bag were found very susceptible to water and degrade within a month in nursery after application of irrigation water. Those could not support the teak seedlings for more than one month.

6. Also most of these containers have high cost factor. Bamboo basket had additional problem of attack by termites. In case of coco pot and mud pot, cost of containers is very high. In mud pot poor growth was noticed. In sugarcane bagasee pot and cloth bag growth of fungi was found which could affect growth of seedlings.

7. The cost of production was maximum per container in case of coco pot (Rs. 55) whereas minimum per container in nonwoven bag (Rs. 4). Also arecanut sheath pot, cow dung pot, sugarcane bagasse pot, bamboo splits, bioplastic bag and cloth bag had high cost factor.

6.2. Main trial

Among the various locally available bio-dgradable container types subjected to the preliminary trial, six best performed containers viz mud pots, bamboo splits, treated card board, coco pot, coir root trainer and non-woven bag were selected for detailed investigation. The salient findings are summarized below.

1. The height growth of teak seedlings varied in the order 4.6-7.0 cm at 30 DAP, 5.8-10.2 cm at 45 DAP, 7.2 -14.1 cm at 60 DAP and 9.0 to 17.6 cm at 75 DAP. Invariably, seedlings in nonwoven bag and bamboo splits registered better heights followed by coco pots. The height growth of teak seedlings in the mud pot was the lowest despite its physical soundness.

2. Height growth showed high positive correlation (r^2 >0.95) with collar diameter, shoot dry weight, root dry weight, total dry weight and root. Length. Highest correlation was obtained for seedling height and root length (r^2 >0.98) for nonwoven bag.

3. The nonwoven bag dominated in seedling collar diameter over others followed by bamboo splits while mud pot performed least. Collar diameter also showed higher positive correlation with height, shoot and root dry weight and total biomass (correlation coefficient > 0.95).

4. The container types did not show perceptible change in number of leaves during the first two sampling periods (15 and 30 DAP) while the changes were significant during the remaining sampling periods. At 75 DAP, the highest number of leaves was produced by non-woven bagged seedlings (13.8) followed by bamboo split containers (13) and coco pot (11).

5. There was significant difference in seedling leaf area among the container types at the end of the study (p = 0.002). The highest leaf area was observed for nonwoven bag. The order of leaf area production with respect to container type was: nonwoven bag > bamboo split > coco pot > treated cardboard > Coir root trainer (CRT) > mud pot.

6. The seedling primary root length among different among container types differed considerably. Throughout the period of study nonwoven bag registered the longest primary root which was at par with bamboo split. Mud pot produced the shortest primary root among the containers tried.

7. The root length: shoot length ratio of teak seedlings revealed no appreciable variation among containers at 15, 30 and 75 days after planting. However, at 45 DAP and 60 DAP, the variation was 1.34 to 1.74 and 1.22 to 1.55, respectively.

The ratio decreased with increase of age of plant. Mud pot (T_3) registered maximum ratio whereas nonwoven bag (T_1) recorded minimum.

8. The lateral root length of teak seedlings demonstrated significant difference among different containers during the study period. Nonwoven bag, bamboo splits and coco pots recorded longest lateral root length during all stages of seedling growth. At 75 DAP, nonwoven bag produced longest lateral root (13.1 cm) closely followed by bamboo split containers (12.4 cm) and coco pot (10.7 cm). However, seedlings in mud pots registered the lowest root length (8.7cm) among the containers

9. The number of tertiary roots was widely different under container types. Throughout the period of assessment nonwoven bag maintained highest number of tertiary roots and remained at par with bamboo splits. Again, mud pot grown seedlings found to continue with least number of tertiary roots.

10. Seedling shoot dry weight showed appreciable variation among the container types during all stages of observation (< 0.001). The non-woven bag (2.34g) and bamboo splits (2.0 g) grown seedlings had higher shoot dry weight while the mud potted seedlings had the lowest value (0.90g). The importance of containers in seedling shoot growth is explicit from the study.

11. Significant variation in root dry weight was reported among the container types (< 0.001). At the end of the study period the non-woven bag represented dry root biomass of one g followed by bamboo splits (0.89g). The order of root dry weight was nonwoven bag > bamboo split > coco pot > treated cardboard > Coir root trainer (CRT) > mud pot (T_3). Bamboo splits recorded 7.4 times increase in shoot biomass at 75DAP as compared to 15DAP while mud pot registering moderate increase in shoot biomass.

12. In general, the root: Shoot length data varied from 1.34 - 1.74 with Mud pot (T_3) registering maximum ratio (1.74) while nonwoven bag (T_1) recorded minimum ratio (1.34). Only modest variation in root: shoot length ratio was discernible during various periods of observation. However, it was interesting to observe that there was consistent decline in root: shoot length with increasing seedling age for all the container types.

13. Seedling quality index which is a measure of the overall fitness of a seedling varied among the containers types in the expected lines with non-woven bag recording the highest value (0.64). Quality index improved consistently for all the container types with increase in seedling residence time in the containers. This was followed by bamboo splits (0.56) while the mud potted seedlings recorded the lowest quality index (0.22).

14. The seedling production cost showed considerable variation among the container types. Total cost of raising one seedling was calculated as Rs 8.3 for nonwoven bag (T_1), Rs 60.2 for coco pot (T_2), Rs 62.0 for mud pot (T_3), Rs 11.0 for bamboo split (T_4), Rs 12.8 for treated cardboard (T_5) and Rs 25.8 for Coir root trainer (CRT) (T_6). But it was Rs 5.00 for conventional container – polythene bag.

15. The Benefit: Cost ratio of raising 3-month old teak seedling varied considerably among different biodegradable containers. It ranged from 0.32 – 2.45 for biodegradable containers and 4.0 for polythene bag. Among biodegradable containers the value was highest in case of seedlings raised in bamboo split pot (2.45) followed by nonwoven bag (2.41), treated cardboard (1.56), Coir root trainer (CRT) (0.76), coco pot (0.33), mud pot (0.32). It could be concluded that among the container types tested, only bamboo splits and non-woven bags are economically viable for large scale production of teak seedlings in nursery.

7. CONCLUSION

The performance of different biodegradable containers tested for raising teak seedlings varied remarkably with respect to height, diameter, shoot dry weight, root dry weight, total dry weight, seedling quality, etc. Also economics of raising teak seedling considerably differed between different biodegradable containers. Nonwoven bag closely followed by bamboo split pot performed appreciably better over others with regard to growth and quality of seedling. The economics of raising 3-month old teak seedling was much better in these two types of biodegradable containers among the containers tested. However, while the economics was compared with conventional polythene bagged plant, it was not appreciable in the present scenario. Hence, further research should be done to improve the economics of raising seedlings in biodegradable containers particularly in better performing containers such as nonwoven bag and bamboo splits so that those will be adoptable by the growers.

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EVALUATION OF BIODEGRADABLE CONTAINERS FOR SEEDLING PRODUCTION IN TREE NURSERIES

BY

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ABSTRACT OF THE THESIS

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ABSTRACT

A nursery trial titled 'Evaluation of biodegradable containers for seedling production in tree nurseries' was conducted to develop alternate eco-friendly plant container as substitute for conventional polythene bag based containers at College of Forestry, Kerala Agricultural University, Thrissur. The study involved a three month long preliminary trial to explore the efficacy of various locally available materials for use as container for tree species. Based on the preliminary trial, five better performing container types were screened for detailed nursery trial to further examine their efficiency as containers for tree seedling production. Teak (*Tectona grandis*) being the widely produced forest planation species in Kerala, the nursery trials were performed with teak as test crop.

The locally available materials used as containers for the preliminary trial included cow dung pot, sugarcane bagasse, arecanut sheath, mud pots, bamboo splits, bamboo basket, coco pot, cloth bag, nonwoven bag, bioplastic bag and treated card board. The containers were evaluated for their durability, physical stability to management practices such as irrigation and manuring, survival percent, height and collar diameter of the teak seedlings. It was observed that the bamboo splits based containers had the highest durability and can be used for two seasons while containers made from arecanut sheath, cow dung pot, sugarcane bagasee pot, bamboo basket, bioplastic bag and cloth bag totally degraded within two months suggesting their unsuitability for tree seedling production. In general, the better container types in terms of overall seedling growth performance and physical soundness were nonwoven bag, bamboo split, coco pot, treated cardboard pot and mud pot. These five container types along with coir root trainer (CRT) supplied by Kerala Forest Department were subjected to detailed nursery trial.

It was observed that considerable variability existed in seedling growth characters such as height, collar diameter, number of leaves, leaf area, number of secondary and tertiary roots, lateral root length, root length: shoot length ratio, root and shoot dry and total dry weight. Among all container types studied, nonwoven bag grown seedlings showed better growth performance followed by seedlings grown in bamboo split containers while mud pot raised seedlings showed the lowest performance during all the stages of seedling growth. The overall performance of the container types followed the order: nonwoven bag > bamboo split > coco pot > treated cardboard > Coir root trainer (CRT) > mud pot. The cost of production per seedling was Rs 8.3 for non-woven bag, Rs 60.2 for coco pot, Rs 62.0 for mud pot, Rs 11.0 for bamboo split, Rs 12.8 for treated cardboard pot and Rs 25.8 for Coir root trainer (CRT). The Benefit: Cost ratio of raising 3- month old teak seedling ranged from 0.32 – 2.45. The value was highest for seedlings raised in bamboo split pot (2.45) followed by nonwoven bag (2.41) and cardboard (1.56) while it was less than one for all the remaining container types. The trial suggest that further studies are required to develop protocols for the reinforcement of biodegradable containers for increased phys ical strength and durability.