GROWTH AND BIOMASS PRODUCTION IN DIFFERENT BAMBOO SPECIES IN PUNJAB

Thesis

Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE
in
FORESTRY
(Minor Subject: Fruit Science)

By

Jasveer Singh
(L-2014-A-75-M)

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LUDHIANA - 141004

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CERTIFICATE - I

This is to certify that the [illegible]led **“GROWTH AND BIOMASS PRODUCTION IN DIFFERENT BAMBOO SPECIES IN PUNJAB”** submitted for the degree of **Master of Science** in the subject of **Forestry** (Minor subject: **Fruit Science**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Jasveer Singh** (**L-2014-A-75-M**) under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE - II

This is to certify that the thesis entitled, **"GROWTH AND BIOMASS PRODUCTION IN DIFFERENT BAMBOO SPECIES IN PUNJAB"** submitted by **Jasveer Singh** (Admission No. **L-2014-A-75-M**) to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **M.Sc.,** in the subject of **Forestry** (Minor subject: **Fruit Science**) has been approved by the Student's Advisory Committee after an oral examination on the same.

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ABSTRACT

The present study was carried out at University Seed Farm Ladhowal, Punjab Agricultural University Ludhiana, Punjab during 2015-16. Different bamboo species *viz.*, *Bambusa balcooa*, *Bambusa bambos*, *Bambusa nutans*, *Bambusa tulda*, *Bambusa vulgaris and Dendrocalamus strictus* were selected and culms of these species were collected from FRI Dehradun. Different growth parameters *viz*., plant height (m), clump diameter (cm), number of culms per clump, culm diameter (cm) and inter-node length (cm), and biomass parameter *viz*., culms fresh weight and culms dry weight (t/ha), and quality parameters *viz*., hollowness (cm), fiber length (µm) and specific gravity were recorded during study period. *Bambusa nutans* was found best for clump diameter, culm diameter and inter-node length, whereas, *Bambusa bambus* for clump height and *Bambusa balcooa* for number of culms per clump. The highest biomass production was recorded in *Bambusa nutans* and the lowest in *Bambusa balcooa*. The *Bambusa balcooa* was found best for hollowness characters. This revealed that elasticity was best in *Bambusa balcooa*. Maximum fibre length was recorded in *Dandrocalamus strictus* that is good for pulp, whereas, specific gravity was highest in *Bambusa tulda*.

Key words: Bamboo species, growth, biomass, hollowness, fibre length, specific gravity etc.

Signature of Major Advisor **Signature of the student**

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ਸਾਰ-ਅੰਸ਼

ਮੌਜੂਦਾ ਅਧਿਐਨ ਯੂਨੀਵਰਸਿਟੀ ਸੀਡ ਫਾਰਮ ਲਾਡੋਵਾਲ, ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ ਲੁਧਿਆਣਾ ਪੰਜਾਬ ਉੱਤੇ ਸਾਲ 2015-16 ਦੌਰਾਨ ਕੀਤਾ ਗਿਆ ਸੀ। ਜਿਸ ਵਿੱਚ ਵੱਖ-ਵੱਖ ਬਾਂਸ ਦੀਆਂ ਪ੍ਰਜਾਤੀਆਂ ਚੁਣੀਆਂ ਗਈਆਂ ਸਨ। ਜਿਵੇਂ ਕਿ *ਬੰਬੂਸਾ ਬਾਲਕੋਹਾ, ਬੰਬੂਸਾ ਬੈਂਮਬਸ, ਬੰਬੂਸਾ ਨਟੇਨਜ਼, ਬੰਬੂਸਾ ਟੂਲਡਾ, ਬੰਬੂਸਾ ਵਲਗੇਰਸ* ਅਤੇ *ਡੈਂਡਰੋਕੈਲੇਮਸ ਸਟਿਕਟਸ* ਅਤੇ ਇਹਨਾਂ ਪ੍ਰਜਾਤੀਆਂ ਦੀਆਂ ਕਲਮਾ ਐਫ. ਆਰ. ਆਈ. ਦੇਹਰਾਦੂਨ ਤੋਂ ਮੰਗਵਾਈਆਂ ਗਈਆਂ ਸਨ। ਵੱਖ-ਵੱਖ ਵਿਕਾਸ ਮਾਤਦੰਡ ਜਿਵੇਂ ਕਿ ਪੌਦੇ ਦੀ ਉਚਾਈ (ਮੀਟਰ) ਕਲਮ ਕਲੰਪ ਵਿਕਾਸ (ਸੈਂਟੀਮੀਟਰ) ਕਲਮਾਂ ਪ੍ਰਤੀ ਕਲੰਪ, ਕਲਮ ਵਿਕਾਸ (ਸੈਂਟੀਮੀਟਰ) ਅਤੇ ਅੰਦਰੂਨੀ ਲੰਬਾਈ (ਸੈਂਟੀਮੀਟਰ) ਅਤੇ ਬਾਇਓਮਾਸ ਮਾਪਦੰਡ ਜਿਵੇਂ ਕਿ ਕਲਮਾਂ ਦਾ ਤਾਜ਼ਾ ਭਾਰ ਅਤੇ ਕਲਮਾਂ ਦਾ ਸੁੱਕਾ ਭਾਰ (ਟਨ/ਹੈਕ:) ਅਤੇ ਗੁਣਵੱਤਾ ਮਾਪਦੰਡ ਜਿਵੇਂ ਕਿ ਹੌਲੋਨੈੱਸ, ਫਾਈਬਰ ਦੀ ਲੰਬਾਈ ਅਤੇ ਸਪੈਸੀਫ਼ਿਕ ਗਰੈਵਿਟੀ ਅਧਿਐਨ ਦੀ ਮਿਆਦ ਦੇ ਦੌਰਾਨ ਰਿਕਾਰਡ ਕੀਤੇ ਗਏ ਸਨ। ਕਲੰਪ ਵਿਕਾਸ, ਕਲਮ ਵਿਕਾਸ ਅਤੇ ਅੰਦਰੂਨੀ ਲੰਬਾਈ ਦੇ ਲਈ *ਬੰਬੂਸਾ ਨਟੇਨਜ਼* ਸਭ ਤੋਂ ਵਧੀਆ ਸਾਬਿਤ ਹੋਇਆ ਜਦੋਂ ਕਿ *ਬੰਬੂਸਾ ਬੈਂਮਬਸ* ਕਲੰਪ ਦੀ ਉਚਾਈ ਅਤੇ *ਬੰਬੂਸਾ ਬਾਲਕੋਆ* ਕਲਮਾਂ ਪ੍ਰਤੀ ਕਲੰਪ ਲਈ ਸਭ ਤੋਂ ਵਧੀਆ ਸਨ। ਬਾਇਓਮਾਸ ਉਤਪਾਦਨ ਸਭ ਤੋਂ ਜ਼ਿਆਦਾ *ਬੰਬੂਸਾ ਨਟੇਨਜ਼* ਵਿੱਚ ਰਿਕਾਰਡ ਕੀਤਾ ਗਿਆ ਅਤੇ ਸਭ ਤੋਂ ਘੱਟ *ਬੰਬੂਸਾ ਬਾਲਕੋਆ* ਵਿੱਚ ਦੇਖਿਆ ਗਿਆ । *ਬੰਬੂਸਾ ਬਾਲਕੋਆ* ਹੋਲੋਨੈੱਸ ਦੇ ਲਈ ਸਭ ਤੋਂ ਵਧੀਆ ਰਿਕਾਰਡ ਕੀਤਾ ਗਿਆ । ਇਸ ਤੋਂ ਪਤਾ ਚੱਲਦਾ ਹੈ ਕਿ ਸਭ ਤੋਂ ਜ਼ਿਆਂਦਾ ਇਲਾਸਟੀਸਿਟੀ *ਬੰਬੂਸਾ ਬਾਲਕੋਆ* ਵਿੱਚ ਸੀ। ਸਭ ਤੋਂ ਜ਼ਿਆਦਾ ਫਾਈਬਰ ਦੀ ਲੰਬਾਈ ਡੈਂਡਰੋਕੈਲੇਮਸ ਸਟਿਕਟਸ ਵਿੱਚ ਰਿਕਾਰਡ ਕੀਤੀ ਗਈ ਜੋ ਕਿ ਪਲਪ ਦੇ ਲਈ ਵਧੀਆ ਹੈ ਜਦੋਂ ਕਿ ਸਪੈਸੀਫਿੱਕ ਗਰੈਵਿਟੀ ਸਭ ਤੋਂ ਜ਼ਿਆਦਾ *ਬੰਬੂਸਾ ਟੂਲਡਾ* ਵਿੱਚ ਪਾਈ ਗਈ ।

ਮੁੱਖ ਸ਼ਬਦ: ਬਾਂਸ ਦੀਆਂ ਪ੍ਰਜਾਤੀਆਂ, ਵਿਕਾਸ, ਬਾਇਓਮਾਸ, ਹੌਲੋਨੈੱਸ, ਫਾਇਬਰ ਦੀ ਲੰਬਾਈ, ਸਪੈਸੀਫ਼ਿਕ ਗਰੈਵਿਟੀ ਆਦਿ

ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ **ਵਿੱਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ**

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(Jasveer Singh)

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INTRODUCTION

Bamboo belongs to grass family Poaceae and it is a flowering perennial evergreen plant in the subfamily Bambusoideae. In recent times it achieved worldwide attention as a resource of quickly renewable biomass and a possible alternative to paper and pulp wood. It has the rapid growth rate after four to five years to mature before they are ready for harvesting and utilization. It can attain heights up to four feet in a day and its stalk can be cut leaving only the roots intact to grow. Each plant can reside up to 75 years and it attains harvesting maturity in three to six years (Okwori and Chad 2013). There are many bamboo species, but no precise estimates are updated because taxonomic revisions continue and new species are often recognized.

Indicative estimates vary from 111 genera and 1400-1575 species (Ohrnberger 1999) belonging to 100-111 genera in Bambusoideae (Clark 2006). Of the later estimate, 1290 are woody bamboos (Bambuseae) and the rest are herbaceous bamboos (Olyreae, Parianeae and Buergersiochloeae). Bamboo is grown in tropical, subtropical and temperate regions between 46^0N and 47^0S latitudes, in all continents except Europe and western Asia, up to 4000 m altitude (Dransfield and Widjaja 1995). Bamboo is a natural resource in most of the Asian countries, however, approximately 30% of the total area under bamboo is planted (FAO 2007).

Bamboos have been cultivated in villages, by farmers to satisfy their social, ecological and economical needs. A rough estimate of worldwide coverage is 36.8 million ha, of which 23.6 million ha (65%) is in Asia, 10.4 million ha (28%) in America and 2.8 million ha (7%) in Africa (FAO 2007). In Asia, India leads the bamboo producing countries with an estimated source area of 11.4 million hectares and is followed by China with 5.4 million hectares. China has the highest bamboo diversity in Asia with over 500 species, followed by India, Indonesia, Myanmar and Malaysia, each with more than a hundred species. Other major bamboo producing countries in the region include Indonesia (2 million hectares) and Lao PDR (1.6 million hectares).

Growing stock wise, China (total - 164 million tonnes, average - 30 tonnes/ha) is ahead of India (total - 122 million tonnes, average - 11 tonnes/ha). When combined together, these two countries contribute over 80% of the total growing stock in Asia. Although India has a larger area of bamboo than China its total and unit growing stock per hectare is relatively low. India’s present requirement for bamboo is expected to 27 million tons per year to meet all the industrial and domestic requirements. As there is a gap between demand and supply in the country, the National Bamboo Mission in India has recognized 18 economically important species for mass scale cultivation.

In India, 145 species of 23 genera are available, including both exotic and indigenous (Anon 2005). North-east India accounts nearly 50 percent of the total bamboo resource of the country (Sharma 1987). The variety of bamboo species present within the Indian subcontinent and the capability for this group of woody grasses to make it appropriate for cultivating in several regions all over the country. With 23 genera and over one hundred species, bamboo is one of India's most important forest resources.

Bamboos of diverse kinds provide food, shelter and raw material for numerous other uses for a good part of its population, and are vital to the rural economy of the country. Bamboo is a natural resource that plays a vital role in the livelihood of rural/tribal people and small-scale industry. Although bamboos have been associated with human civilization since time immemorial, their true potential is being realized only recently. This green-gold is sufficiently cheap and plentiful to meet the vast needs of human populace from the "child's cradle to the dead man's bier". That is why sometimes it is known as "*Poor man's timber,"* "green gold," "bamboo friend of people," "cradle to coffin timber" etc. Bamboos have versatile end-uses as a building material, paper pulp resource, scaffolding, food, agricultural implements, fishing rods, weaving material, substitute for rattan, plywood and particleboard manufacture. Pickled or stewed bamboo shoots are regarded as delicacies in many parts of the country. Bamboo is an ideal renewable resource for biomass. It is useful for wood and paper industry. At one time, the supply of bamboo was thought to be perpetual. Bamboo was often viewed as a weed species and a nuisance due to its rapid growth, therefore its mass utilization in paper industries was welcome.

The multifarious uses of bamboo have resulted in an indiscriminate extraction of the bamboo resource. Due to the human interventions, poor regeneration and the peculiar nature of gregarious flowering and death of bamboo clumps after seed setting, there has been a steady decline in the species diversity and the extent of bamboo resources. Overexploitation coupled with the absence or inadequate replanting, shifting cultivation practices and extensive forest fires have further resulted in dwindling resources (Shanmughavel *et al* 2001). One of the potential alternative energy sources, which actively cater to the mitigation and adaptation of climate change and rehabilitation of marginal land is bamboo based agroforestry system. Bamboo has a great potential for biomass production and could be a significant net sink for carbon dioxide sequestration (Kumar and Kumari 2010).

Bamboo cultivation, harvesting, and processing are continuing to provide a means of livelihood for millions of people across these continents. The international trade in bamboo currently amounts to about $2.5 billion (INBAR 2005). The national and local trades are likely to be even more economical but reliable statistics are lacking (FAO 2001). China, Indonesia, and Vietnam were the major bamboo exporters of Asia in 2000, while the European Union, Hong Kong, Japan and the United States were the major markets for the bamboo products. Export statistics for bamboo products from India are not available but the total value of raw bamboo and finished products in 2005 in India have been estimated to be $409 million (FAO 2007).

Bamboo is promising alternative raw material for the timber and supports agro-industries worldwide for manufacturing handicraft items, packaging materials, raw materials for paper industries etc. The potential of bamboo cultivation for biomass is significant since it can be cultivated for fuelwood or other biomass needs. The mass utilization of bamboo by the paper and pulp industry is increasing thus it is going out of reach of the common man. It has no longer remained the poor man's timber. On the other hand, it is fast becoming a high-value crop. This is in itself would serve to bring a new focus on the bamboo and help their conservation and replantation with the mission to harness the potential of bamboo crop, National Bamboo mission was implemented by Govt. of India, under this mission bamboo nurseries are supported in all the states to increase the availability of quality planting material of bamboo having fast growth, higher number of culms per clump, more intermodal length etc.

India is one of the major bamboo producing country of Asia (11.4m ha), which accounts about half the total area of bamboo in Asia. It occurs although in all the states of India extended from the tropical and temperate region and alluvial planes to the high mountains. It is successfully planted in the agro-forestry system, mono-cropping and in the restoration of marginal lands. One of the plants that display promise in the condition is bamboo. Bamboo which prefers slightly acidic soils are generally found in areas with high rainfall, though check in region with very acidic soils. More than 80 % of rainfall is reported to be absorbed in bamboo plantation based interventions in ravines and nutrient deficit by 50-67%. The National Bamboo Mission promotes bamboo plantations in the ravine landscapes of the country.

Bamboo is an important part of the socio-cultural and religious life of Indian communities. Bamboo is part of traditional socio-economical system but also economically sound fulfilling the needs of growing population of these tribal communities. The development and enhancement of bamboo cultivation can promote economic and environmental growth, mitigate deforestation and illegal logging, prevent soil degradation and restore degraded lands in both village as well as urban area of India. Bamboo fiber-based panels and boards are hard, durable and prove to be a promising substitute for hard woods in merchandise production. Moreover, bamboo fibers yield paper with a high tear index and almost the same strain strength as paper made from wood (FAO 1997).

In this regard, a study was conducted at School of Forestry & Environment, Sam Higginbottom University of Agriculture, Technology and Sciences, Allahabad (India) and center of bamboo and rattan of ICFRE in North-East India to analyze the performance of different species of bamboo under central India climate change mitigation initiative. The previous study showed that production system has a significant influence on performance among the different bamboo species. Therefore, systematic bamboo cultivation with sufficient management practices will be more beneficial towards the extra income generation.

Keeping in view the importance of mass scale propagation of superior genotypes through macro and micro-propagation to meet the ever-increasing demands, it was proposed to collect superior clumps of bamboo species from different sources, evaluate them and use the available variability and introduce superior genotype of different species of bamboo at Ludhiana (Chauhan *et al* 2006). In the present scenario in the state, the bamboo has huge potential for biomass production for pulp. Different species of bamboos were introduced in Punjab to widen the genetic base of the species. The present study entitled “Growth and biomass production in different bamboo species in Punjab” had been designed to record information on the growth and biomass production of different bamboo species at "University Seed Farm” Ladhowal, PAU with following objectives:

Objectives

1. To assess the growth and quality of different bamboo species.
2. To study the biomass production of different bamboo species.

CHAPTER II

REVIEW OF LITERATURE

The review of literature provides basis for preparing the research proposal and conceptualization of different ideas given by different researchers. In the present case, the relevant literature with particular focus on bamboo improvement aspects has been reviewed under the following heads:

2.1 Growth parameters

2.2 Biomass parameters

2.3 Quality parameters

2.1 Growth parameters

Sturkie *et al* (1968) stated that seven or eight years are required after establishing a stand of tall bamboo before the culms are large enough and sufficiently “woody” to be harvested. Some weaker shoots may die back before reaching maturity. Adamson *et al* (1978) agree that up to the period of 8 years of initial establishment, yields are low. The idea of bamboos competing with pioneer woody species contrasts strongly with the hypothesis that there is a sort of gap partitioning among plants, which maintains extraordinarily high species diversity in tropical forests (Denslow 1980, Brandani *et al* 1988 and Brown 1993, 1996).

Das (1988) found the bamboos, which are perennial woody grasses, are one of the most important forest resources of Nepal, These are also cultivated by farmers. The bamboos are extensively used by the rural people and are distributed from the terai (flat plains) to the high regions. The bamboos are conventionally propagated by vegetative means in which culms more than 2 m high with rhizomes are planted vertically. Investigation is now in progress at the Forest Research and Information Centre, Department of Forests (Negpal), to search another propagation method. Effort on the tissue culture of bamboo is being carried out by the Department of Medicinal Plants, Nepal, and also in cooperation, by the Department of Forestry, University of Aberdeen in Scotland. For propagating *Bambusa balcoa, Bambusa sp.* (Tharu bans), *Dendrocalamus humiltonii, D. hookerii, and Dendrocalamus sp.* (Dhungre bans), the node culm cutting method has verified successfuly. A course on this technique have been carrying on in different districts of the country, because of the importance of bamboos in forestry.

Bamboo has the ‘nutrient pumping’ action, slow decomposition of its silica rich litter, and the extremely high biomass of bamboo fine roots (Christanty *et al* 1996). Bamboos are an important woody part of many old land use systems and/or its new variants in India too, which is home to many species of bamboo. Fast growing solid bamboo [*Dendrocalamus strictus* (Roxb.) Nees] in particular has different types of uses and is suitable for agroforestry, plantation forestry and social forestry (John and Nadagouda 1995).

The bamboo resource in natural habitats is dwindling, due to overexploitation, gregarious flowering, shifting cultivation and extensive forest fires. Sustained availability and utilisation can be ensured by proactive bamboo cultivation (Shanmughavel *et al* 1996). Patterns of plant growth and other ecological processes are considered to vary as a function of gap area, as it directly alters microclimatic conditions (Denslow *et al* 1998).

Arya *et al* (1999) revealed that an effective and reproducible method for the huge-scale propagation of *Dendrocalamus asper* is defined. High-frequency direct shoot proliferation was tempted in sterilized seed cultures of *D. asper* on improved medium augmented with 1.0–10.0 mg/l benzyl adenine (BA). Numerous shoots (1–25) developed within 5 weeks of seed culture lacking of root formation. The shoot-developing capability of seeds was influenced by the BA strength in the medium. Proliferating shoot cultures were showed by frequently sub culturing shoots in propagules of 3 shoots each. A reproduction rate of 15–16 folds was attained on MS medium +3.0 mg/l BA. Roots were founded on eliminated propagules of 3 –5 shoots as soon as transferred to MS medium having 10.0 mg/l indole-3-butyric acid or 3.0 mg/l 1-naphthaleneacetic acid (NAA). Sprouts were stabilized, adjusted and established in soil, where they showed average growth.

Scurlock *et al* (2000) revealed the Bamboo is the term used for a wide group of huge woody grasses, extending from 10 cm to 40m in height. Bamboo play a vital role in everyday life of about 2.5 billion people within Asia. Bamboo productivity is uncommon, with most reports coming from different parts of Asia. There are few evidence overall that bamboo is significantly more productive than many other candidate bio-energy crops, but it shares a number of required fuel features with certain other bio-energy feed stocks. Its warming value is lower than many woody biomass feed stocks but higher than maximum agricultural residues, grasses and straws. Though non-fuel uses of bamboo biomass may be really more profitable than energy retrieval, there may also be possible for co-production of bio-energy together with other bamboo processing. A substantial problem is the difficulty of selective breeding, given the shortage of knowledge of lowering physiology.

A study conducted by Tabarelli and Mantovani (2000) tried to find the effect of gap structure and bamboo species on the re-growth of Montane Atlantic forest.

They found that colonization by plants was characterized in 30 tree fall gaps (30.3-500.5 m^2). The experiment was conducted at Santa Virgínia (45°300 W, 23°170 S), a 4970-ha reserve of the Atlantic montane forest in southeastern Brazil. Area covered by bamboos ranged from 0% to 100% of gap area. Average height of surrounding canopies ranged from 12 to 30 m. As gap are covered by bamboo and average height of surrounding canopies increased, both density and richness of pioneer woody species decreased. Density and richness of shade-tolerant species were negatively influenced by gap area. Low-light-demanding species of *Miconia*, *Leandra* and *Rapanea* accounted for the majority of both pioneer species and individuals sampled, whereas, high-light demanding pioneers of *Cecropia*, *Alchornea* and *Tibouchina* were poorly represented. They suggested that in the Atlantic montane forest bamboo species compete for gaps, excluding other light-demanding pioneers. Divakara *et al* (2001) studied the distribution of roots at the periphery of bamboo plant and also evaluated root competition with nearby trees in two binary associations.

According to the study of Qing *et al* (2004) growth and biomass of the bamboo (*Pleioblastus maculate)* is directly affected by moisture availability at early growth period. Increased in total above-ground biomass as well as dry weight of biomass parts with DBH and height of the stems contributed significant share to the total biomass. Above-ground biomass improved with ageing, which accumulated to highest at age 6 year. Shanmughavel *et al* (2001) said that the percentage contribution of culms (81%), branches (14%) and leaves (1%) was total 96 per cent, whereas, in the below-ground rhizome the contribution was 4 per cent. The total above ground biomass ranged from 2.3t dry matter (DM) ha^{-1} to 297.9t dry matter (DM) ha^{-1} for the growth period of 1 year to 6 year). The mean yearly biomass production was 49.6t dry matter (DM) ha^{-1} after the 6 year period.

Gratzer *et al* (2004) studied the responses of radial and height growth, plant architecture, and the possibility of mortality of sprouts to variable light levels were computed for six tree species in temperate conifer forests of the Bhutan Himalayas. Improves in growth with rising light were equivalent with those of elevated latitude tree species but lesser than those of tropical tree species and temperate species in North America. The shade-tolerant species *Tsuga dumosa* (D Don) Eichler revealed the effective rise in radial growth at short light and attained asymptotic growth initially. It had the deepest crowns in short light and a little decline of head growth with reducing light. It denotes a nonstop growth type, which spends in height rather than adjacent growth in low light situations. *Betula utilis* D. Don. Revealed bigger rises in radial growth and a upper death at low light than the more shade-tolerant *Abies densa* Griff, in possession with the trade-off between survivorship and growth at low light. Differences in the possibility of mortality at dissimilar light levels were more noticeable than differences in the light–growth reaction, emphasizing the importance of survivorship at low light for succession dynamics.

Muthukumar and Udaiyan (2006) performed an experiment to measure the effect of bioinoculants (*Glomus aggregatum*, *Bacillus polymixa*, *Azospirillum brasilense*) on seedling growth improvement of bamboo (*Dendrocalamus strictus* (Roxb.) Nees.) in alfisol, vertisol, with or without fertilizer use. Bamboo seedlings were developed in the existence or nonexistence of bioinoculants either independently or in all combinations for 180 days in field soil in tropical nursery situation. Shoot, rhizome and dry masses, root length, nutrient applications and arbuscular mycorrhizal (AM) root lengths were measured at harvest stage. Under the research condition combined inoculation of PSB, AM fungi and *A. brasilense* resulted in highest growth response both under fertilized and unfertilized situation in both soil types. Fertilizer application improved the effectiveness of N, P and K uptake, while decreased the treatment efficiencies. Although soil type did not influence microbial inoculation response, fertilizer application extensively influence plant response to microbial inoculation.

Misra *et al* (2007) study defines standardization of an effective in vitro propagation and hardening procedure for gaining plantlets from field grown culms of *Bambusa tulda*. Administration for 10 min of 0.05 and 0.1% mercuric chloride to explants accumulated in winter and summer periods, respectively accelerated optimum culture establishment and bud break. 0.1–0.2% mercuric chloride in rainy season improved sterile culture formation but prevented bud break due to toxicity to explants. MS liquid medium supplemented with 100 mM glutamine, 0.1 mMindole-3-acetic acid and 12 mM 6-benzylaminopurine supported highest in vitro shoot reproduction rate of two-fold. The shoots were effectively rooted on MS liquid medium enhanced with 40 mM coumarin resulting in 98% rooting. The procedure needs 45 days cycle for the in vitro clonal propagation and 80 days for acclimatized plantlet production.

Gratani *et al* (2008) evaluated the growth pattern and physiological activity i.e photosynthetic rate of different bamboo species (*Bambusa ventricosa* McClure, *Phyllostachys bambusoides* Siebold et Zucc., *Phyllostachys pubescens* Mazel ex Lehaie, and *Phyllostachys viridi-glaucescens*. Riviere). Among the considered species, *P. pubescens* had the largest mean stem height (14.3±0.6 m) and diameter

(10.771.5 cm), while *B. ventricosa* had the least mean stem height (6.0±0.2 m) and internodes count (3571). The greatest net photosynthetic rates (NP) of the considered species were determined in early summer, while the lowest was in spring (30% of the maximum in the genus Phyllostachys), in the period of vegetative activity, and in winter (10% of the maximum in *B. ventricosa*).

Wahab *et al* (2010) examine the *Bambusa vulgaris* at early stage were harvested and examined for their anatomy and physical properties. This revealed that the bamboo anatomy structure was strongly correlated to age. The frequency of vascular bundles was higher at bottom and top portion rather than in core portion for both age-groups. There was no significant difference in vessel diameter among the two and four-year old culms at the middle of the culms wall thickness. The cell's wall thickness of both parenchyma and fibre were higher in the 4 year-old than in the 2 year-old culms.

Darabant *et al* (2014) studied the bamboo plantations in different sites in eastern Thailand which differentiated in their biomass yield, may be because of location productivity and plantation management. The biomass yield of two species *Bambusa beecheyana* and *Dendrocalamus membranaceus* were at par with each other, but the moisture content of stems of *B. beecheyana* was significantly higher as compared to *D. membranaceus*. The moisture content reduced with increasing height of culms in both species, but this gradient was more in *D. membranaceus*. The moisture content of culms of *B. beecheyana* decreased with increase in culms age, indicating that older culms are more useful for energy production.

Seven bamboo species (*Dendrocalamus strictus*, *Thyrsostachys siamensis*, *Bambusa tuldoides*, *Gigantochloa wrayi*, *Bamibusaold hiamii*, *Bambusa multiplex* and *Bambusa vulgaris)* were grown to find the impact of two nutrient rates in a one year experiment (Piouceau *et al* 2014). Fertilizers ratio 20:20:20 NPK was applied with 13.2 t/ha yr^{-1} NPK to three-year-old bamboo planted in 70 containers. Nutrient (NPK) content in bamboo as well as morphology and physiology was studied and it was seen that under high nutrient supply rate, culms height increased but culms diameters decreased. For the seven species, with high-nutrient rate there was an increase in the aboveground biomass.

Onuorah *et al* (2014) had studied the potentials of *Bambusa vulgaris* which was planted in Nigeria for the manufacture of wood-cement composite panels. Component solubility of 3.09, 5.60 and 19.8 % for cold water soaking for 24 hrs; hot water soaking at 80˚C for 1 hr, and 1% NaOH soaking for 24 hrs, respectively and ratio of fiber slenderness was 160.95:1,. Properties ranged from a low of 25.00

to 75.45 N/mm^2 for MOR; 4128 to 15,065 N/mm^2 for Modulus of Elasticity (MOE) 15.01 to 36.11 per cent for water absorption (WA) and 3.04 to 12.72 % for TA. Effect of production mix on properties was determined using factorial analysis. Except for composite density whose effect was not significant at 0.05% level, all production mix was found significant at 0.01% level at the second order level of interactions.

Alemayehu *et al* (2015) reported that introduction and evaluation of their growth performance of different species of bamboo is required in different agro-climatic zones. Four potential bamboo species, *Bambusa vulgaris*, *Dendrocalamus hamiltonii*, *Dendrocalamus membranaceus* and *Guadua amplexifolia* were introduced and evaluated for their growth and biomass performance at Jimma Agricultural Research Centre Ethiopia. *Dendrocalamus hamiltonii* showed best performance with average DBH, height and basal area respectively. *B. vulgaris* had the greatest number of culms+clump (66+5) and showed lower performance in diameter of culms and basal area. *D. membranaceus* performed well in average number of nodes per clump and *G. amplexifolia* showed lower performance in culm number, height and number of nodes, respectively. Among the four species, the highest total biomass accumulation was reported in *D. hamiltonii* i.e. 82.16+0.94 kg/clump of which leaf, branch, culm and rhizome parts contributed about 12.66%, 16.77%, 50.32%, 20.25%, respectively. Among the four species, *D. hamiltonii* showed faster growth performance followed by *D. membranaceus*. The results indicated that *D. hamiltonii* and *D. membranaceus* are good potential bamboo species for cultivation in Ethiopia.

Kittur (2016) reported that the agroforestry based on bamboo is best option for management of land in India. He recorded the performance of turmeric under 7-year old bamboo [*Dendrocalamus strictus* (Roxb.) Nees] at spacing (4x4, 6x6, 8x8, 10x10 and 12x12 m) at University Campus, Kerala. Results showed that spacing had influence on bamboo growth. The clump height decreased (19%) in the wider spacing (12x12 m) of bamboo compared to that (4x4 m) spacing. It was seen that wide spaced bamboo had better clump diameter, crown coverage and turmeric rhizome yield, whereas, less (4x4 m) spacing least rhizome yield of 8 Mg/ha; this was 58 % less compared to widest spacing of 12x12 m (19.32 Mg/ha).

2.2 Biomass parameters

The biomass studies are very crucial parameter to judge the performances of the bamboo in terms of biological production and cycling of nutrient status during the harvest (Negi 1984). Above-ground net primary productivity (ANPP) and leaf turnover was found 24.6 t/ha/year after the age of 6-year in *Phyllostachys bambusoides* as the study was conducted in Japan (Isagi *et al* 1993).

Christanty *et al* (1996) found that with an increase in age of bamboo, there was an increase in biomass upto 76.6 Mg ha^{-1} after 6 years. The distribution of total bamboo biomass between above- and below-ground components also changes with age. Above-ground biomass was up to 6 per cent of the bamboo total mass at 16 months. The above ground contribution was 59 per cent at the end of 6 years. Shanmughave and Francis (1996) calculated the total biomass (t/ha) of bamboo on the basis of the number of culms in the 6th year. The dry matter production of above ground biomass was found to be increasing progressively and recorded up to 286 t/ha in the 6 years. There was greater height of bamboo up to 30 cm and the total above ground biomass increased linearly for all components with including culms, branches and leaves and found that diameter and height was significantly correlated with total above ground biomass. The total biomass can be predicted by using these variables.

Ravikumar *et al* (1997) revealed the function of vesicular-arbuscular mycorrhizae (VAM) fungi symbiosis with bamboo seedling was examined. Species of VAM like *Glomus aggregatum*, *G. fasciculatum* and *G. mosseae* were inoculated independently and in grouping with the bamboo seedlings. The proportion of infection and different growth parameters such as the number of shoots, number of rhizome, inter-nodal distance, leaf length and breadth and total biomass production were considered in myocorrhizal and non-mycorrhizal plants. The above study indicated a substantial enhance in the growth rate and biomass productivity in seedling treated with VAM.

Based on their origin, the species of the genus *Phyllostachys*, found in a cold climate had a greater sensibility to high air temperatures than *B. ventricosa*, originating in a tropical and subtropical climate, and having a less sensibility to low air temperatures. Bamboos could be a significant net sink for CO_2 carbon due to higher potential for biomass production. The highest complete culm photosynthetic rate (WNP ¼ 2727 7.2 m mol CO_2 s^{-1}) was calculated by the total leaf surface area per culm (28.671.1m^2) and it was found that the mean maximum yearly assimilation rate was (9.574.5 mmolm^2 s^{-1}), *P. pubescens* and it contributed in major role to carbon sequestration (1470.6 kg CO_2 $year^1$ per culm) compared with the other species (on the average 3.071.6 kg CO_2 $year^1$, mean value). The phenological trend examined in Rome was in the same trend as that examined by Li *et al* (1998) for the genus *Phyllostachys* in China and by Nath *et al* (2004) for the genus *Bambusa* in

India.

A study was conducted to determine the growth and effect of *Dendrocalamus strictus* plantation on mine soil in a dry tropical region at ages 3, 4 and 5 years. The total primary production was found to be between 20.7 t/ha yr^{-1} for 3-year old and 32.0 t/ha yr^{-1} for 5-year old, of which aboveground production was 17.0 to 24.7 t/ha yr^{-1} (Singh and Singh 1999). Bektas *et al* (1999) stated that if the slenderness ratio of bamboo is lesser than 70, it is not valuable for pulp and paper production.

Riano *et al* (2002) studied the complete *Guadua angustifolia* clumps, with different ages, located on the southeastern flank of the Cauca River valley. Estimates of the accumulated biomass and its reorganization into various organs were attained. The shoot portions accumulated 80.1% of the total biomass and CO2 fixation, and the rhizome 19.9% of these. Mathematical functions defining its growth as a function of chronological time on quantity of organs, fresh and dry weight and leaf area measurements, were established.

Nath *et al* (2004) reported that the response surface methodology (RSM) was practical to optimize culture situations for the growth of *Candida utilis* with bamboo wastewater. A substantial impact of initial pH, fermentation time and yeast extract on biomass of *C. utilis* was estimated by Plackett–Burman design (PBD). These factors were optimized using a central composite design (CCD) and response surface methodology. A combination of pH 6.1, fermentation time 69 h and yeast extract 1.17 g/L was best for maximum biomass of *C. utilis*. A 1.7-fold of biomass of *C. utilis* was increased after optimization in shake-flask cultivation. The biomass of *C. utilis* reached 19.17 g/L in 3 L fermentor.

An experiment on biomass and nutrient distribution in a highland bamboo forest in southwest Ethiopia was conducted by Embaye *et al* (2005). The Masha natural bamboo forest was planted with 8840 trees ha^{-1}, uniformly arranged with a height of 16.8 m, diameter of 7.6 cm and leaf area index of 9.7. Age-structure was 13 per cent of <1 year, 24 per cent of 1–3 years and 63 per cent of >3 years. Culm had 82 per cent, branch 13 per cent and leaf 5 per cent contribution in total above ground biomass. Annual shoot production was 8t ha^{-1} and had 44 kg ha^{-1} of N, 6 kg ha^{-1} of P, 122 kg ha^{-1} of K and 1 kg ha^{-1} of Ca. The plant sub-samples were dried to uniform weight at 85.8^0C and mean values ratios of the dry to fresh weight sub-samples were computed. These ratios were utilized to find the dry biomass of the plant parts in each age-class category. The mean biomass parts were multiplied by the mean tree number per plot to obtain mean plant biomass of each age-class per plot, another changed to per hectare.

Kumar *et al* (2005) revealed that above ground biomass of *Bambusa bambos* clumps from Kerala in hedge rows average 2417 kg per clump with average per ha aggregation of 241.7 $Mgha^{-1}$. The maximum biomass aggregation was examined in the live culms (82 %), followed by thorn + leaves (13%); dead culms accounted for only nearly 5 per cent of the biomass aggregation.

Biomass model of *Bambusa tulda* was prepared by Oli (2005) at Belbari, Morang district of Eastern Nepal. A total of 153 culms were selected from 59 clumps. Above base diameter 15 cm (*D*15*)*, height of culms, weight of green culms, branches and leaves were measured. The samples were taken and oven dried in laboratory at Kathmandu. The biomass was estimated with regression model by using of oven dry and green weight. The model used was $W = a + b \times (D^2 L)$. The R^2 values were obtained for culms, branch and leaves based on the oven dry weight which were 92, 81 and 83 per cent, respectively. Similarly, R^2 values for culms and leaves on the basis of green weight were 92 and 82 per cent, respectively. The R^2 values obtained for branch and leaves were lower than culms. In similar site conditions, bamboo biomass of managed natural stands or plantations can be estimated using this equation.

An experiment on above ground standing biomass and carbon storage in village bamboos in North East India was conducted by Nath *et al* (2009) for biomass estimation, Allometric relationships were formed by harvest method which described leaf, branch and culm biomass with DBH as an independent variable by use of a log linear model. The density of culm of the stand was 8950 culms ha^{-1} during 2005 and 67 per cent of the growing stock was represented by *Bambusa cacharensis*, 17.88 per cent by *Bambusa vulgaris* and 15.12 per cent by *Bambusa balcooa*. From the biomass for the different parts between the different culms age classes for the three species it was found that the highest proportion was shared by culm (80–95%), lower by branch (1–14%) and lowest by leaf (0.13–7%). Above ground biomass was 121.51t ha^{-1} and of this 86 per cent was made of culm. 10 per cent of above ground biomass was contributed by culm and 4 per cent by leaves. With respect to species, *B. cacharensis* contributed up to 46 per cent of total stand biomass followed by *B. vulgaris* (28%) and *B. balcooa* (26%).

Wu *et al* (2009) studied the effect of stem density on biomass in China and reported that branch, leaf, root and total biomass of bamboo enhanced with the increase in of stem density.

The above ground biomass of five bamboo species in Uttarakhand, India viz *Dendrocalamus strictus*, *B. vulgaris*, *B. multiplex*, *B. bambos* and *PhylIlostachys* *nigra*, differed in size and growth pattern. Linear regression model revealed that above ground biomass is dependent on the height of pole, girth to height ratio at 1.0 m and 1.5 m by 107, 67, 98, 125 and 99 per cent on dry weight basis, and 104, 65, 107, 168, and 100 per cent on fresh weight basis in *D. strictus*, B. vulgaris, *B. multiplex*, *B. bambos* and *P. nigra*, respectively. Biomass obtained was 30 per cent greater on fresh weight basis as compared to dry weight in all the species. Average biomass produced was *D. strictus* –581.8 kg ha^{-1} $pole^{-1}$, *B. vulgaris* – 832.4 kg ha^{-1} $pole^{-1}$, *B. multiplex*-15.9 kg ha^{-1} $clump^{-1}$, *B. bambos* – 703.1 kg ha^{-1} $pole^{-1}$, and *P. nigra*- 72.5kg ha^{-1} $pole^{-1}$ on dry weight basis (Agarwal and Purwar 2010).

In southeast and south Asia, moso bamboo is found in a huge extent. It plays a crucial role in carbon budget of the earth as reported by Du *et al* (2010). The research used geo-statistics theory to determine the heterogeneity in space of above ground biomass (AGB) of moso bamboo. He used a point kriging interpolation method to find and draw maps of its distribution space. The total above ground biomass (AGB) of moso bamboo was found to be 16.97 per cent of the total biomass as forest-stand in Zhejiang province.

Hong *et al* (2011) reported that the bamboo species are low-input plants which are excellent for bio-energy feedstock production. Biological characteristics, dry matter yields and fuel properties of the bamboo were estimated. Genotype growth characteristics governed by measurements of plant height, tillering and shoot diameter. Bamboo species were gathered. Genotypes varied in plant height, tillering and shoot diameter. Nitrogen, temperature, water and plant density have influences on mature stands biomass production, from 5.9 to 49.5 tonnes/ha/yr .With such biomass yields, bamboo should be considered as very promising plants for biomass production in Zhejiang, China in the near future.

Singh and Rai (2012) studied the biomass production of 30 bamboo species at ICAR Research Complex for North East hilly region, Arunachal Pradesh which falls in the humid sub-tropical region. On the basis of mean annual aboveground biomass as well as annual culms production, all the species were categorized into five distinct clusters at average linkage distance of 0.6. Bamboo species grouped in cluster III viz. *B. bambos*, *B. balcooa*, *D. giganteus*, *B. cacharensis*, *B. pallida* type I, *B. nutans*, *B. tulda*, *D. sikkimensis*, *D. hookeri* were the largest annual biomass producers (494.67 ± 260.36 t/ha). More than 90% of total biomass was contributed by culms in *Arundinaria hirsuta*, *A. mannii*, *B. bambos* and *B. balcooa*. Leaves and branches contributed 45 per cent of the total biomass in *Schizostachyum polymorphum*.

2.3 Quality parameter

Dinwoodie (1965) stated that Runkel ratio must be less than one for the suitability of raw material for pulp and paper making. Volkomer (1969), in agreement stated that, if the Runkel ratio is less than one, such fibre source is suitable for paper production. Bektas *et al* (1999) stated lesser paper strength properties especially lower burst and tensile indexes were obtained when Runkel ratio is high. This was corroborated by Oluwadare and Egbewole (2008) who stated that Runkel ratio is closely associated with cell wall thickness and it influences paper strength properties. In the early 1960s, the USDA examined the paper pulping traits of 21 bamboo species, which also included 5 tropical sympodial (clumped) bamboos from Puerto Rico (latitude 18° N). All were suitable for making paper by use of either the Kraft or the Raitt processes, with long fibers (1.4-2.3 mm) (Adamson *et al* 1978).

Some of researchers revealed that the fiber length is positive and strongly correlated with fiber diameter, cell wall thickness and internode diameter, but not with lumen diameter and internodes length. The fiber diameter varies between 11 and 19µm, the lumen diameter between 2 - 4 µm and the cell wall thickness between 4 - 6 µm of *Bambusa blumeana, bambusa vulgarius* and Gigantochloa scortechinii located at Forest Research Institute Malaysia (Liese 1985). Latif and Tarmizi (1990) studied the anatomical properties of three Malaysian bamboo species, and fiber length between species was significantly different. Age did not significantly affect fiber length, which reflected its strong genetic control.

Alvin and Murphy (1988) studied the mid-inter-nodal composition of three culms estimated to be less than one, one to two and more than two years old respectively, has been examined revealing significant increases in normal cell wall thickness of the fiber and ground tissue parenchyma. The density of the culms also increased. Cortical parenchyma, in comparison, showed no obvious change. Both fibers and parenchyma emerge to maintain living protoplasts. Progressive thickening of the cell walls over a phase of perhaps several years would have significant implications for harvesting and utilization of bamboo culms and would modify certain mechanical properties with time.

The chemical composition and fiber characteristics of two sympodial bamboos were studied by Feng *et al* (2003). The results revealed that the Whangee bamboo is far better as compared to that of Yunnanicus bamboo in common use because of it has higher specific gravity, better fiber length and its distribution in the plant, higher wall/lumen ratio as compared to those of Yunnanicus bamboo. For the paper making and panel processing which is used in house construction, Whangee bamboo is more suitable. The higher benzene-ethanol extractives of the Whangee bamboo can be used for anti-decay in architecture processing and use when comparing with the yunnanicus bamboo.

Li (2004) study investigated observed the chemical, physical, and mechanical properties of the bamboo species *Phyllostachys pubescens* and its potential to manufacture medium density fiberboard (MDF). The result showed holocellulose and alpha-cellulose content rise from the base to the top portion. There was no significant difference in Klason lignin or ash content from the base to the top portion of the bamboo. The outer layer had the maximum holocellulose, alpha cellulose, and Klason lignin contents and the lowermost extractive and ash contents. The epidermis had the maximum extractive and ash substances and the lowest holocellulose and alpha-cellulose content. Specific gravity (SG) and bending properties of bamboo differed with age and vertical height site as well as horizontal layer. All mechanical properties parameters increased from one year old to five year old bamboo. The outside layer had significantly upper SG and bending properties than the inner layer. The SG differed along the culms height. The top portions had constantly higher SG than the base. Bending strength had a strong positive correlation with SG. In order to mechanically use bamboo strips effectively, it is advisable to eliminate marginal surface material to yield high strength bamboo composites. Compression properties parallel to the longitudinal way was significantly higher than perpendicular to the longitudinal direction. Age had a significant impact on panel properties. Fiberboard prepared with five year old bamboo at 8% resin level had the highest bonding strength.

High flexibility of bamboo may be suitable to produce paper with greater burst and tensile. Bamboo fibers are well suited for tissue, corrugating medium, news print, and writing paper as stated by Kellomäki (1998) and Covey *et al* (2006). In the whole world attention has been focused on the search of alternative fiber resources because of the potential role of these fibers in climate and forest restoration. Among bamboos, *Bambusa balcooa* is generally recommended for industrial use due to its faster growth, good flexibility and tensile strength. A non-invasive and efficient method of screening superior fiber quality from the wild gene pool of *B. balcooa* was established Bhattacharya *et al* (2010).

Sathitsuksanoh *et al* (2010) found that the modified cellulose solvent- (concentrated phosphoric acid) and organic solvent- (95% ethanol) based lingo cellulose fractionation (COSLIF) was useful to a naturally-dry moso bamboo sample. The biomass dissolution were 50 °C, 1 atm for 60 min. Glucan digestibility was 88.2% at an ultra-low cellulase loading of one filter paper unit per gram of glucan. The complete glucose and xylose yields were 86.0% and 82.6%, respectively. COSLIF effectively destructed bamboo's fibril structure, resulting in a ∼33-fold enhanced in cellulose accessibility to cellulase (CAC) from 0.27 to 9.14 m^2 per gram of biomass. Cost analysis showed that a 15-fold reduce in use of costly cellulase would be of importance to reduce overall costs of biomass saccharification when cellulase costs are higher than $0.15 per gallon of cellulosic ethanol.

Escamilla and Habert (2014) showed bamboo-based construction objects have been recognized as a potential way of decreasing pressure on resources and on the environment. These materials have environmental and mechanical advantages over regular construction materials. The life cycle estimation of five bamboo-based construction materials was carried out: flattened bamboo, woven bamboo mat, bamboo pole, glued laminated bamboo and woven bamboo mat panels. The main purpose of the present study is to build up a sequence of life cycle estimation data that can signify the diversity establish in the overall production of bamboo-based construction materials. This study also aims to present a easy and cost effective method to developing this type of data while maintaining its quality. It was found out that the variety of bamboo and harvesting practices do not make a considerable contribution to the overall environmental effect of bamboo-based construction materials. It was also found out that, in general, the method contributing most to environmental influence are not always the most significant contributors to the changeability of the result. It was probable to create a relationship between the processes contributing to the changeability of the results and the results' uncertainty. In this way, it was showed that it is probable to categorize the main processes contributing to the variability of the results and that by recovering the quality of this data uncertainty of the results can be decreased. Therefore, the proposed approach can be successfully used to consider the environmental effect of non-conventional materials with a high degree of precision in a cost-effective way.

Sharma *et al* (2014) reported the traits of the fiber of the two bamboo species. They found that the fiber traits were ranging between 3.34 mm to 3.43 mm in case of length of fiber, 24.49 μm to 24.96 μm in case of width and 14.35 μm to 15.46 μm in case of diameter fiber lumen for *Dendrocalmus strictus*, while in *Bambusa bamboos* it ranged between 3.60 mm to 3.65 mm in case of length of fiber, 15.58 μm to 15.95 μm in case of width of fiber and 12.67 μm to 13.37 μm in case of diameter fiber lumen. No significant differences between the species were found at ($P<0.05$) level of probability in fiber traits. The result of Duncan Multiple Range Test carried out showed that not much variation occurred in fiber length, whereas, in fiber width *Dendrocalmus strictus* appears >*Bambusa bambos* and in lumen diameter, the value was higher in case of *Dendrocalmus strictus*>*Bambusa bambos.*

The investigations were carried out by Sharma *et al* (2015) to see the potential use of stalks of selected species of agrowaste materials as an alternative source for pulp and paper making by studying their anatomical characteristics, fibre morphology and their derived indices. Anatomically, fibres were thin walled, rectangular and hexagonal in cross section. The percentage of fibres was greater than other xylem elements and varied from 38% (*S. edule*) to 46% (*C. annumvar. accuminatum* and *S. melongena*). The fibre morphology of selected species showed that mean fibre length, fibre diameter, lumen diameter and fibre wall thickness varied from 522.08±61.96µm (*G. max*) to 1285.80±270.29µm (*C. sativus*), 18.87±3.56µm (*G. max*) to 30.16±5.69µm (*S. edule*), 15.25±3.50µm (*C. annum var. accuminatum*) to 25.09±5.58µm (*S. edule*) and 2.52±0.31µm (*S. lycopersicum*) to 2.81±0.57µm (*S. melongena*), respectively. All selected species had potential to be used in pulp and paper making in one way or the other but *C. annuum var. accuminatum*, *C. annum var. grossum*, *C. sativus* and *S. edule* had the most desirable fibre characteristics and their derived indices.

Egbewole *et al* (2015) determined the variation in the fiber properties of bamboo (*Bambusa vulgaris*), it also assessed the suitability of bamboo obtained from three locations in Nasarawa state, Nigeria for pulp and paper manufacturing. The study was laid out in a 3 x 4 x 10 factorial experiment in a completely randomized design (CRD). The experiment was conducted at the 3 sites. There were 10 stem samples and 4 disc levels and the following variables were measured as fibre length, lumen width, cell wall thickness, Runkel ratio, flexibility ratio and felting coefficient. Disc samples collected at individual axial axis were assessed after harvesting. Stock collected from Keffi had the highest mean fibre length of 3.14±0.71mm at 25% and 75% disk level followed by 2.85±0.76mm from Garaku. The physical properties of the disc samples collected at four axial levels (5%, 25%, 50% and 75%) along the individual axial axis. Stock collected from Keffi had the highest mean fibre length of 3.14±0.71mm at 25% and 75% disk level followed by 2.85±0.76mm from Garaku and least fibre length of 2.64±0.79mm from Lafia. Keffi had highest mean lumen width of 9.80±2.86µm, followed by Garaku with 9.56±3.19µm while the samples from Lafia had the least lumen width of

8.66±3.32µm. The runkel ratio (0.61±0.12) was highest in samples from Lafia, followed by 0.54±0.05 in Keffi and 0.51±0.00 in Garaku. The ANOVA revealed that significant differences were found in the fibre length, lumen width and cell wall thickness both within and between sample stems. Bamboo (*Bambusa vulgaris*) fibre characteristics as reported in this study, showed that, they are well suited for tissue, corrugating medium, newsprint, and writing paper.

Bamboo is a distinctive plant, which have enormous application. Among plants, bamboo is a structurally smart plant and functionally gradient materials, which resembles a long cylindrical fiber-reinforced composite with several internodes and nodes along its length. There are approximately over thousand species of bamboo .The resource of bamboo can be abundantly availed in various aspects by (Sreeremya 2017).

CHAPTER III

MATERIALS AND METHODS

The present study entitled **"Growth and biomass production in different bamboo species in Punjab"** was carried out during 2015-16. The details of site area, experimental procedures and methodology adopted are described in this chapter as follow:

3.1 Materials

The experimental material for the present study consisted of six bamboo species *viz.*, *Bambusa nutans, Bambusa vulgaris, Bambusa bambos, Bambusa tulda, Bambusa balcooa* and *Dendrocalamus strictus.* These species were collected from Forest Research Institute Dehradun, (Table 3.1). From each clump of selected bamboo species of different age gradations viz., third, fourth, fifth, sixth, seventh and eighth, culms were felled at the stump height of 15cm above the ground level.

The evaluation trial of different bamboo species was laid out at the field of University Seed Farm Ladhowal, Ludhiana during July 2010. The field layout of experimental plot is given table 3.2.

The healthy clones and seedlings were planted in a randomized block design with 3 replications. The spacing adopted was 6 x 6m with plot size of five plants per replication.

Table 3.1: Details of bamboo species

Code	Species common name	Characteristics feature	Photograph from experiment
T1	*Bambusa nutans*	It is an evergreen or deciduous, clump-forming bamboo with fairly thick-walled culms reaching a height of 6 - 15 meters, with culms 5 - 10cm in diameter.	

T2	*Bambusa vulgaris* (Green bamboo)	The culms are up to 20 m tall. Inter-node are 30 to 45 cm long, 5 to 10 cm diameter with wall thickness of 0.7 to 1.5 cm. Clump flower rarely, if at all after 80 years), and then die.	
T3	*Bambusa bambos* (Thorny bamboo, spiny bamboo)	Thorny bamboo densely tufted, with curving branches, graceful upright, shining culms 10-15m, inter-node 20-40cm long, diameter 5-10cm, leaves lanceolate, inflorescence is compound panicle.	
T4	*Bambusa tulda* (Bengal bamboo)	Occurs at altitude up to1500 m. The culms are up to 25 m tall. It is greyish-green when older. Internodes are 40-70cm long. 5 to 10 cm in diameter. The flowering cycle is 30 to 60 year. Flowers are green.	

T5	*Bambusa balcooa* (Plain bamboo)	Tall bamboo, forming distinct tufts, groups or clumps, culms 20-40 m long, 8-15 cm diameter, grayish green to light white, thick walled, leaf blade oblong lanceolate, inflorescence is compound panicle.	
T6	*Dendrocalamus strictus* (Solid bamboo)	The culms are up to 50 m tall. Internodes are 30 to 45 cm long, 6 to 10 cm in diameter. Reported flowering cycle in south India is 24 to 28 years, in the north east and central India 40 to 45 years, in Western India 65 year.	

Table 3.2: Field layout of Bamboo species evaluation trial at University seed farm Ladhowal, PAU Ludhiana

R1			R2			R3		
T1	T3	T5	T3	T4	T2	T6	T2	T4
T1	T3	T5	T3	T4	T2	T6	T2	T4
T1	T3	T5	T3	T4	T2	T6	T2	T4
T1	T3	T5	T3	T4	T2	T6	T2	T4
T1	T3	T5	T3	T4	T2	T6	T2	T4
T2	T4	T6	T5	T6	T1	T3	T5	T1
T2	T4	T6	T5	T6	T1	T3	T5	T1
T2	T4	T6	T5	T6	T1	T3	T5	T1
T2	T4	T6	T5	T6	T1	T3	T5	T1
T2	T4	T6	T5	T6	T1	T3	T5	T1

- No. of species : 6
- Spacing: 6m x 6m Design : RBD
- Replication : 3
- No. of plants/Replication : 5

3.2 Methodology of experiment

- Date of planting : July 17, 2010
- Species six- (*Bambusa vulgaris, Bambusa nutans, Bambusa bambos, Bambusa tulda, Bambusa balcooa* and *Dendrocalamus strictus)*
- Replications : 3 (Five plant per replication)
- Spacing : 6m x 6m

3.3 Geographical information

Site (University Seed Farm, Ladhowal, Ludhiana) is located in the central plain zone of Punjab. It lies at 30^{0}58' N latitude and 75^{0}45'E longitude, and 230 m above mean sea level.

3.4 Climate

Punjab state comes under subtropical climate. It experience severe summer during May- June and during winter Dec- Jan. The average annual rainfall ranges from 300-500 mm in the central plain zone of Punjab. Plantation sites soil status is depicted in Table 3.3.

Table 3.3: Physio-chemical properties of soil

Depth (cm)	**Texture**	**N (kg/ha)**	**P (kg/ha)**	**K (kg/ha)**	**Ph**
0-15	Loamy sand	151.5	8.32	220.1	8.4
15-30	Loamy sand	146.3	8.50	215.2	8.2
30-60	Loamy sand	150.4	6.50	195.3	8.4
60-90	Loamy sand	147.4	7.25	212.0	8.4

3.5 Observation

a) **Plant height (m):** three random clumps were selected and harvest from each plot at the time of maturity. The height of this randomly selected clump was measured from the base level of plant to tip of plant with the help of tape. The plant height was recorded in meters.

b) **Clump diameter (cm):** Clump diameter of the plant was recorded at the base with the help of measuring tape.

c) **Number of culms per clump:** Number of culms per clump was counted numerically. Some of the Culms were young.

d) **Culm diameter (cm):** Culm diameter was measured in cm at three places (base, middle and top) with the help of vernier calliper.

e) **Internode length (cm):** Internode length was measured with the help of measuring tape in cm**.**

f) **Culms weight (kg/plant):** Three clumps from each replication were selected randomly and uprooted. The shoot portion was separated from the root and it was weighed on an electronic balance to get fresh shoot weight. The shoots were dried in hot air oven at $70+2^0$C and weighed to get dry shoot weight.

g) **Hollowness (cm):** Hollowness of bamboo plants was measured by using vernier calliper in cm. Three observations (one from base second from middle and third from top) were recorded to represent the whole culm.

h) **Fibres length (µm):** Small sliver of wood were placed in test tubes and nitric acid (30% HNO_3) and a few crystals of potassium chloride (KCl) were added. Test tubes were heated in oven at 75^0C for approximately 24 hours till the slivers turned into white colour. Slivers were washed 2 to 3 times and shaken so the fibres get separated. Fibres were further stained with safranin and mounting on slide then observed under microscope at the power of 10X. Straightened and undamaged fibres were selected and measured with ocular micrometer. Twenty measurements were made for each sample then average was calculated. Same process was replicated 4 times. Calibrations were made by stage micrometer for width and values were interpreted accordingly.

i) **Specific gravity:** The samples selected from branches **(**without pith) for specific gravity were suitably numbered with copying pencil. They were then soaked in water till they sunk to the bottom. Saturated samples were then taken out and weighed on an electric balance after removing the surface water with filter paper. The samples were then oven dried at $103+-2^0$C until there was no further loss of moisture. Oven dry weight was determined and specific gravity calculated by the formula given by Smith (1954) on the basis of three samples per plant.

$$\text{Specific gravity of wood sample} = \frac{1}{\frac{(Mm - Mo)}{Mo}} + \frac{1}{Gs}$$

Where,

Mm = weight of sample having maximum moisture

Mo = oven dry weight

GS = constant = 1.53

3.6 Statistical analysis

Statistical analysis was done as per the procedure laid down for Completely

Randomized Block design (CRBD). Analysis of variance, critical difference (CD) and variance components was calculated for the interpretation of results of the study following Panse and Sukhatme (1978). The various data were statistically analyzed using Proc GLM (SAS Software 9.1, SAS Institute Ltd. U.S.A.).

3.6.1 Mean

The mean value of each character was worked out by dividing the sum by corresponding number of observations:

$$\bar{X} = \Sigma \frac{Xij}{N}$$

Where, Xij = any observation in i^{th} genotype j^{th} replication

$\bar{X}$ = Mean of character X

N = Total number of observations

3.6.2 Range

The lowest and the highest values for each character were recorded for determining range of that character.

The data for different parameters were subjected to statistical analysis using randomized block design in CPCS1 and MVM computer package.

Randomized Block Design

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F_{cal}
Replications	(r – 1)	$\frac{1}{g}\sum_k Y^2{}_k - \frac{Y2..}{gr}$	M_1	$(\sigma^2_e + g\ \sigma^2_r)$ or (M_1/M_3)
Genotype	(g – 1)	$\frac{1}{r}\sum_i Y^2{}_i - \frac{Y2..}{gr}$	M_2	$(\sigma^2_e + r\ \sigma^2_g)$ or (M_2/M_3)
Total	rg -1	$\sum_i\sum_j Y^2{}_{ik} - \frac{Y2..}{gr}$		

g = number of genotypes

r = number of replications

3.6.3 Critical difference (CD)

In order to compare mean of various parameters, the critical differences (CD) were calculated at 5 per cent level of significance by formula:

$$CD = S.Ed \times t_{0.05}$$

Here S.Ed is the standard error of the difference of the treatment means to be compared and is equal to:

$$SE_d = \sqrt{2MSe/R}$$

With MSe as error means sum of square and R as number of replications and ‘t’ is the tabulated value of ‘t’ at 5 per cent level of significance for the degree of freedom of error mean square.

3.6.4 Index score analysis

Index score analysis was carried out by for growth characters i.e. plant height, clump diameter, number of culms per plant, culms diameter, inter-node length, culms fresh weight and culms dry weight. The class intervals used for different character are given in Table 3.4.

Table 3.4: Class intervals for index scoring for different bamboo species:

Characters	1	2	3
Plant height (m)	<6.3	6.3-7.7	>7.7
Clump diameter (cm)	<378	378-483	>483
Numbers of culms per clump	>144	144-85	<85
Culm diameter (cm)	<2.2	2.2-2.9	>2.9
Inter -node length (cm)	>30	30-25	<25
Culms fresh weight (t/ha)	<78	78-116	>116
Culms dry weight (t/ha)	<46	46-68	>68

Index score analysis was carried out by using data for quality characters i.e. hollowness, fiber length and specific gravity (Anderson 1957). The class intervals used for different characters are given in Table 3.5.

Table: 3.5 Index score quality parameter of different bamboo species:

Characters	1	2	3
Hollowness(cm)	<0.8	0.8-1.1	>1.1
Fiber length (µm)	<18	18-21	>21
Specific gravity	<0.44	0.44-0.49	>0.49

CHAPTER IV

RESULTS AND DISCUSSON

The results of data collected for different parameters in different bamboo species on growth and biomass production and quality parameter as describes in the Chapter III carried out during 2015-2016 are presented and discussed with appropriate justification and with the support of available literature on the bamboo and other woody species in this chapter. In the present study, data were analyzed in randomized block design for different growth, biomass and quality characteristics collected at University Seed Farm, Ladhowal, PAU Ludhiana. Results obtained in the study are presented in the following headings.

4.1 Growth characteristics

4.2 Biomass characteristics

4.3 Quality characteristics

4.4 Correlation studies

4.5 General performance

4.1 Growth characteristics

Significant differences were observed for the different parameters of different bamboo species. *Bambusa nutans*, *Bambusa vulgaris*, *Bambusa bambos*, *Bambusa tulda*, *Bambusa balcooa* and *Dendrocalamus strictus* exhibited significant effect on plant height, clump diameter, number of culms per clump, culm diameter (Base, Middle and Top) and inter-node length. Culm diameter differences among different species at top were found non-significant (Table 4.1). Much variation was recorded among the different bamboo species for clump diameter, number of culms per clump, culm diameter, internode length and biomass characteristics.

Table 4.1 Distribution of growth parameter of different bamboo species

Treatments	Plant height (m)	Clump diameter (cm)	Number of culms per clump	Culm diameter (cm)			Internode length (cm)
				Base	Middle	Top	
Bambusa nutans	8.7	587	70	4.6	3.7	2.0	35
Bambusa vulgaris	8.7	423	35	4.9	3.7	1.8	27
Bambusa bambos	9.2	347	26	5.5	3.6	1.8	23
Bambusa tulda	8.5	320	27	4.9	3.2	1.6	22
Bambusa balcooa	4.9	273	204	2.1	1.6	0.8	32
Dendrocalamus strictus	9.0	365	39	4.8	3.4	2.1	20
Range	4.9-9.2	273-587	26-204	2.1-5.5	1.6-3.7	0.8-2.1	20-35
CD(0.05)	**1.7**	**75**	**30**	**0.8**	**0.7**	**NS**	**2.0**

4.1.1 Plant height

The datas recorded for plant height at USF, Ladhowal are present in Table 4.1 and fig.1, which showed that the plant height of different bamboo species ranged between 4.9 to 9.2m. *Bambusa bambos* registered the maximum culms height (9.2m) followed by *Dendrocalamus strictus* (9.0m) and *Bambusa nutans* (8.7m), *Bambusa vulgaris* (8.7m), where as the *Bambusa balcooa* had the minimum height (4.9m). Plant heights *of Bambusa bambos*, *Bambusa nutans*, *Bambusa vulgaris*, *Bambusa* tulda and *Dendrocalamus strictus* were at par with each other and significantly better than *Bambusa balcooa*. Pathak *et al* (2015) also recorded significant differences in culms height among seven bamboo species with maximum height in *Bambusa tulda* but contrary with our results, culms height of *Bambusa balcooa* was also comparable and at par to *Bambusa tulda*. Shanmughavel *et al* (2001) also reported the significant difference in the plant height of six species after 6 year in the Kallipatty near Sathyamangalam. The culms height increased from 1.4 to 28.5 m in 6 year concomitant with the expansion in diameter from 2.3 to 8.3 cm.

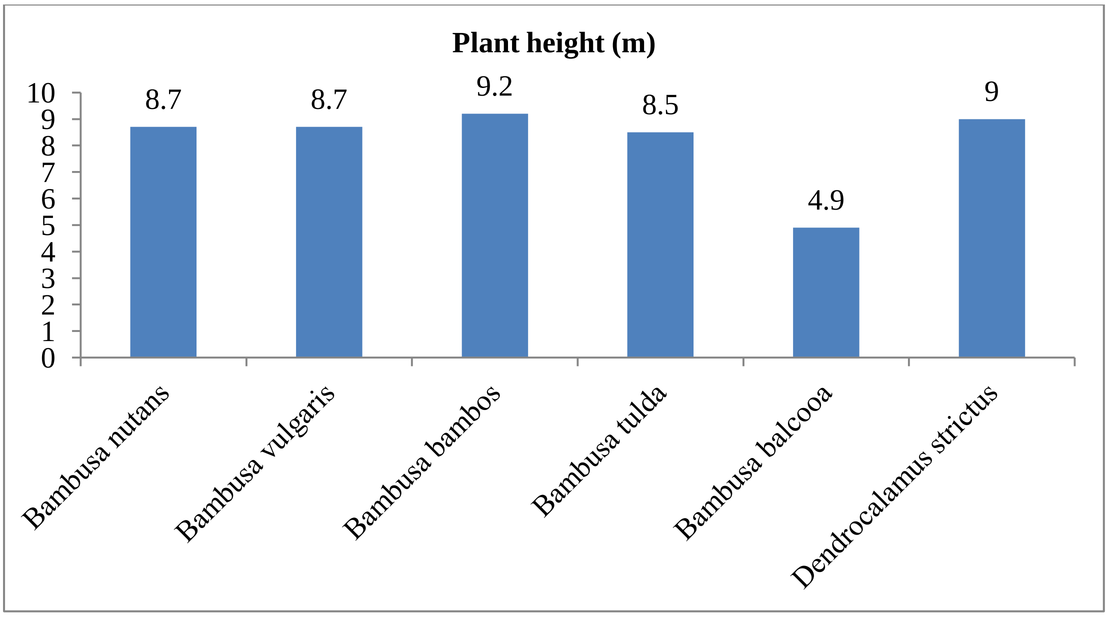


Fig.1 Variations among the different bamboo species for plant height

As per Pathak *et al* (2015) studies, it was reported that out of 7 bamboo species viz. *Dendrocalamus strictus*, *Bamboosa bamboos*, *Bambusa nutan*, *Bambusa asper*, *Bambusa bulgaris*, *Bambusa tulda* and *Bambusa balcooa*. Maximum culms height was recorded in *B. tulda* (15.84 m) followed by *B. balcooa* (15.62 m). The minimum culm height was observed in *B. asper* (5.34m). Culm height differed significantly from each other and had positive correlation with biomass production. The culm diameter of different bamboo species also differed significantly from each other and ranges from 4.1 cm to 10.1cm. The maximum culm diameter was found in *Bambusa vulgaris* (10.2cm) while minimum was in *Bambusa asper* (4.1cm).While in our study maximum culms height was recorded in *Bamboosa bamboos* (9.2m) and minimum culms height was recorded in *Bambusa balcooa* (4.9m).

4.1.2 Clump diameter

Data recorded for clump diameter at USF, Ladhowal provided in the table 4.1 and fig 2 showed that clump diameter of bamboos ranged from 273 to 587 cm. Maximum clump diameter (587 cm) was recorded in *Bambusa nutans* followed by *Bambusa vulgaris* and *Dendrocalamus strictus* and minimum clump diameter (273 cm) in *Bambusa balcooa* species. *Bambusa nutans* was significantly better than all other species. *Bambusa vulgaris* was significantly better than *Bambusa tulda, Bambusa balcooa* but significantly at par with *Dendrocalamus strictus and Bambusa bambos*.

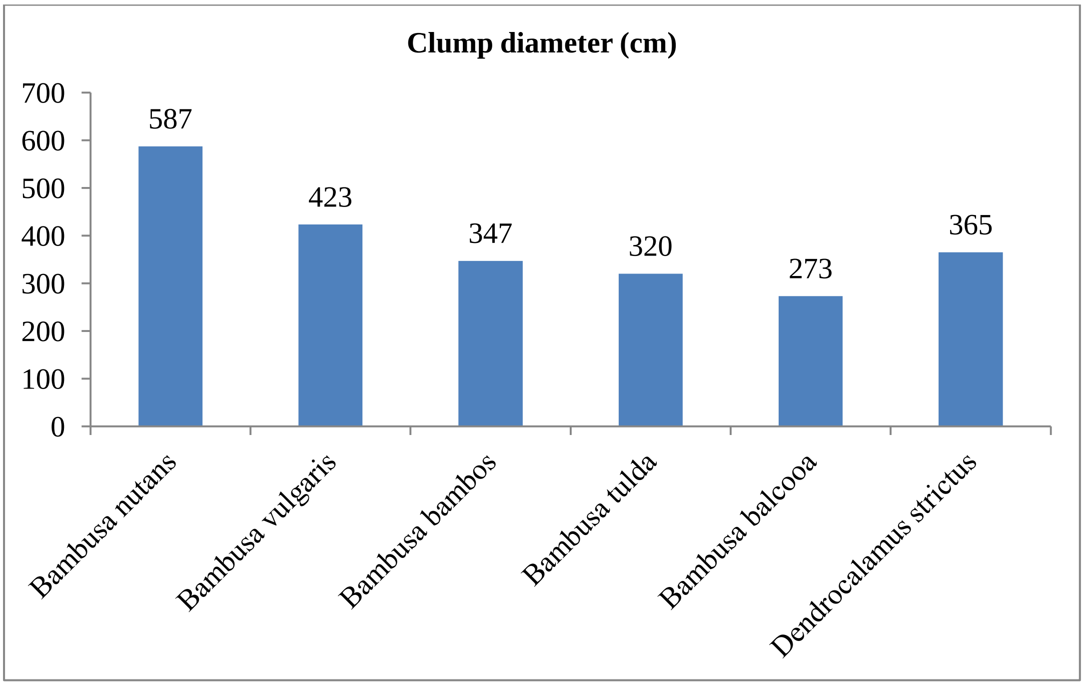
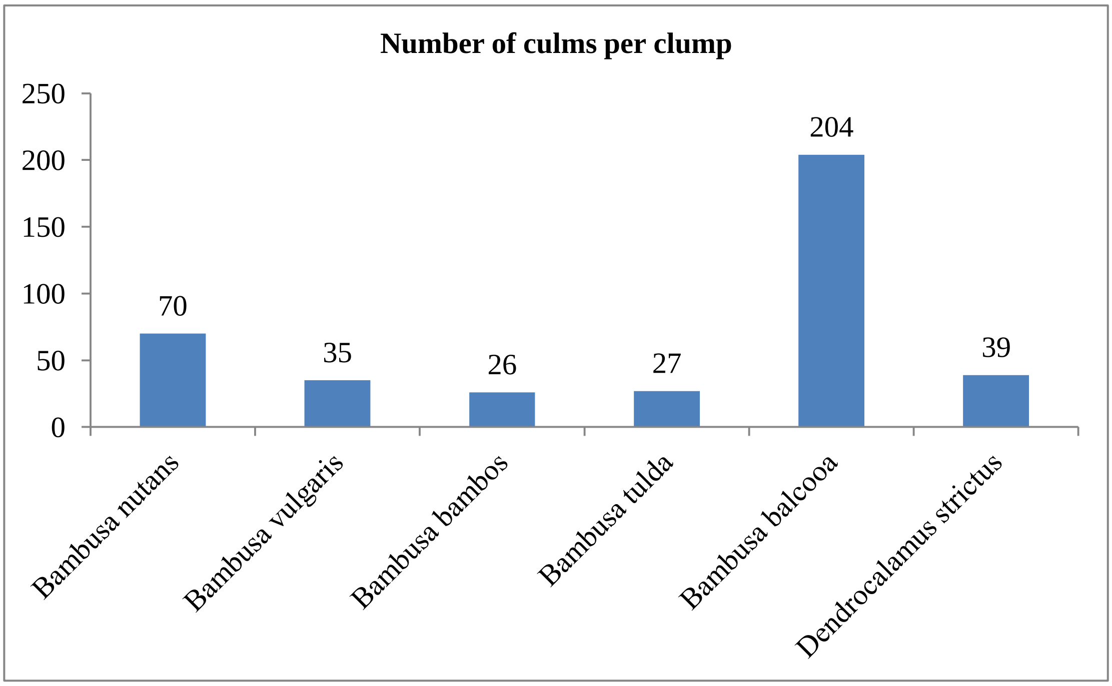


Fig.2 Variations among the different bamboo species for clump diameter

4.1.3 Number of culms per clump

Data recorded for the number of culms per clump of different bamboo species at USF, Ladhowal are present in table 4.1 and fig.3. The perusal of data showed that the number of culms per clump ranged from 26 to 204. Highest number of culms per clump was found in *Bambusa balcooa* (204), which was significantly better than all other species and was minimum number (26) was recorded in *Bambusa bambos*. *Bambusa nutans* had less number of culms per clump than *Bambusa balcooa* but it was significantly better than *Dendrocalamus strictus, Bambusa vulgaris, Bambusa tulda and Bambusa bambos. Dendrocalamus strictus,* *Bambusa vulgaris, Bambusa tulda* and *Bambusa bambos* were at par with each other. Ram *et al* (2010) had also noticed a same range variation in seven different bamboo species in North Bihar. Arunachalam and Arunachalam (2002) also observed that under natural regenerated forest on abandoned *jhum* land, total number of culms per



plant was 5 times more in *B. nutans* than in the *B. bambos*.

Fig.3 Variations among the different bamboo species for number of culms per clump

4.1.4 Culm diameter

Data recorded for culm diameter at base, middle and top of different species of bamboo at USF, Ladhowal were also depicted in table 4.1and fig.4, which showed that the culm diameter at base, middle and top ranged between 2.1 to 5.5 cm, 1.6 to 3.7 cm and 0.8 to 2.1 cm, respectively. Maximum culm diameter at base was recorded in *Bambusa bambos* (5.5cm), at middle (3.7 cm) in *Bambusa nutans* and *Bambusa vulgaris* and at top (2.1cm) in *Dendrocalamus strictus*. Minimum culm diameter at base, middle and top was recorded in the *Bambusa balcooa* (2.1cm, 1.6 cm and 0.8 cm). At the base, *Bambusa bambos* was at par with *Bambusa vulgaris, Bambusa tulda* and *Dendrocalamus strictus* but significantly better than *Bambusa balcooa* and *Bambusa nutans*. At middle, *Bambusa nutans*, *Bambusa vulgaris, Bambusa bambos, Dendrocalamus strictus* and *Bambusa tulda* were at par with each other and significantly better than *Bambusa balcooa*. At the top, all the species were at par with each other. Minimum values (base 2.1cm, 1.6 cm) and 0.8 cm) were recorded in the *Bambusa balcooa*.

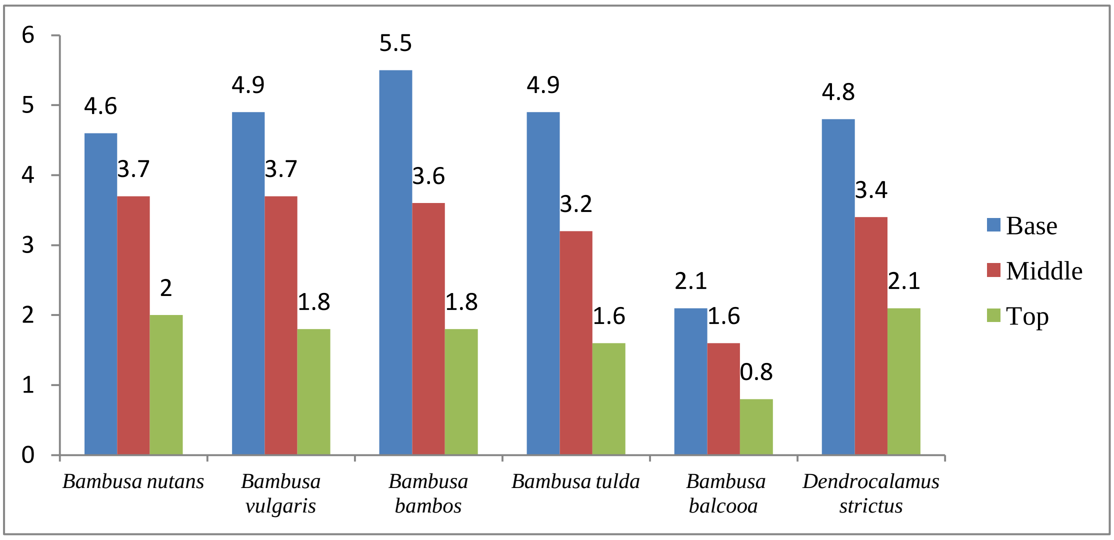


Fig.4 Variations among the different bamboo species for culm diameter

4.1.5 Inter-node length

Data recorded for the inter-node length of different bamboo species at USF, Ladhowal are provided in table 4.1 and fig.5, which shows that the internode length of different species ranged between 20 to 35 cm. Maximum internode length was recorded in *Bambusa nutans* (35 cm) and minimum (20 cm) was recorded in *Dendrocalamus strictus*. *Bambusa nutans* is significantly better than other all species. *Bambusa balcooa* was significantly better than *Bambusa vulgris, Bambusa bambos, Bambusa tulda* and *Dendrocalamus strictus*. Similarly, *Bambusa vulgaris* is significantly better than *Bambusa bambos*, *Bambusa tulda* and *Dendrocalamus strictus*. *Bambusa bambos* is at par with *Bambusa tulda* but significantly better than *Dendrocalamus strictus*. *Bambusa tulda* and *Dendrocalamus strictus* were at par with each other.

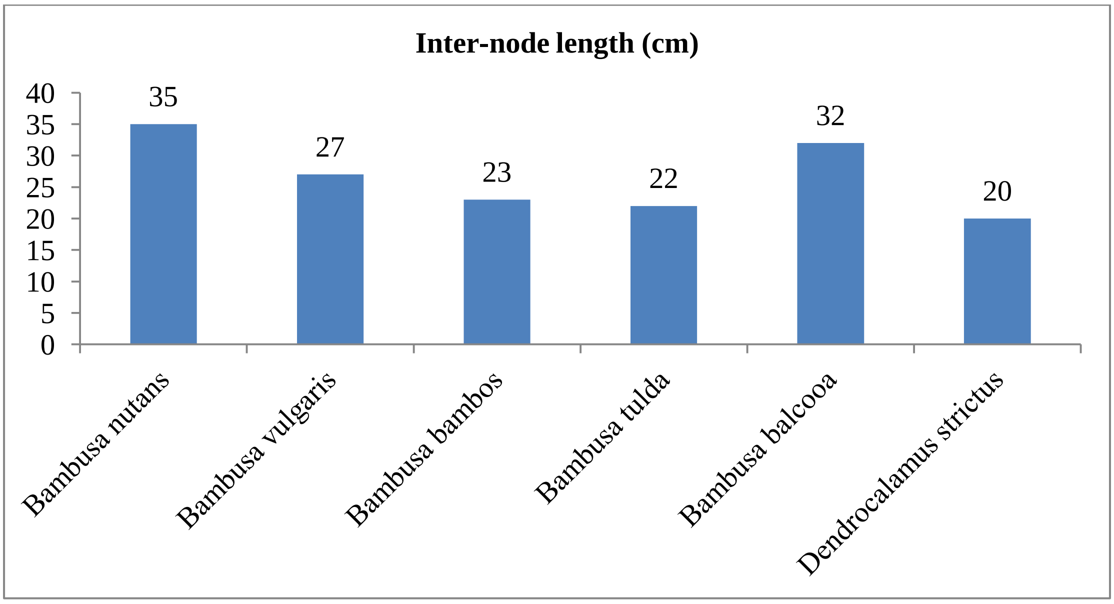


Fig.5 Variations among the different bamboo species for inter-node length

4.2 Biomass characteristics

Table 4.2 Biomass parameters of different bamboo species

Treatment	Culms weight (Kg/plant)		Culms weight (t/ha)	
	Culms fresh	Culms dry	Culms fresh	Culms dry
Bambusa nutans	553	326	154	91
Bambusa vulgaris	347	204	96.4	57
Bambusa bambos	380	224	106	62.2
Bambusa tulda	240	141	67	39.1
Bambusa balcooa	142	84	39.4	23.3
Dendrocalamus strictus	287	181	80	50.3
Range	142-553	84-326	39.4-154	23.3-91
CD (0.05)	207	119	207	119

4.2.1 Culms fresh weight

Three randomly selected samples from each replication have been tabulated in Table 4.2 and depicted in Figure 6. Data showed that the culms fresh weight of different species ranged from 39.4-154 (t/ha). Significant differences were observed among species for fresh weight. Maximum culms fresh weight (154 t/ha) was recorded in *Bambusa nutans* followed by *Bambusa bambos* (106 t/ha) and *Bambusa vulgaris* (96.4 t/ha) and minimum (39.4 t/ha) in *Bambusa balcooa*. *Bambusa nutans*, *Bambusa vulgaris* and *Bambusa bambos* were at par with each other but *Bambusa nutans* was significantly better than *Bambusa tulda, Bambusa balcooa* and *Dendrocalamus strictus*. *Bambusa bambos* was significantly better than *Bambusa balcooa* but at par with *Dendrocalamus strictus, Bambusa tulda* and *Bambusa vulgaris*. *Bambusa vulgaris, Bambusa tulda, Bambusa balcooa* and *Dendrocalamus strictus* were at par with each other. According to Shanmughavel and Francis (1996), Kumar *et al* (2005), the average biomass production of different bamboo species was found to be higher in comparison to the earlier reports for *Bambusa bambos*. Biomass production depends on the size of the culms and the number of culms production, which was maximum in *Bambusa nutans* in the current study.

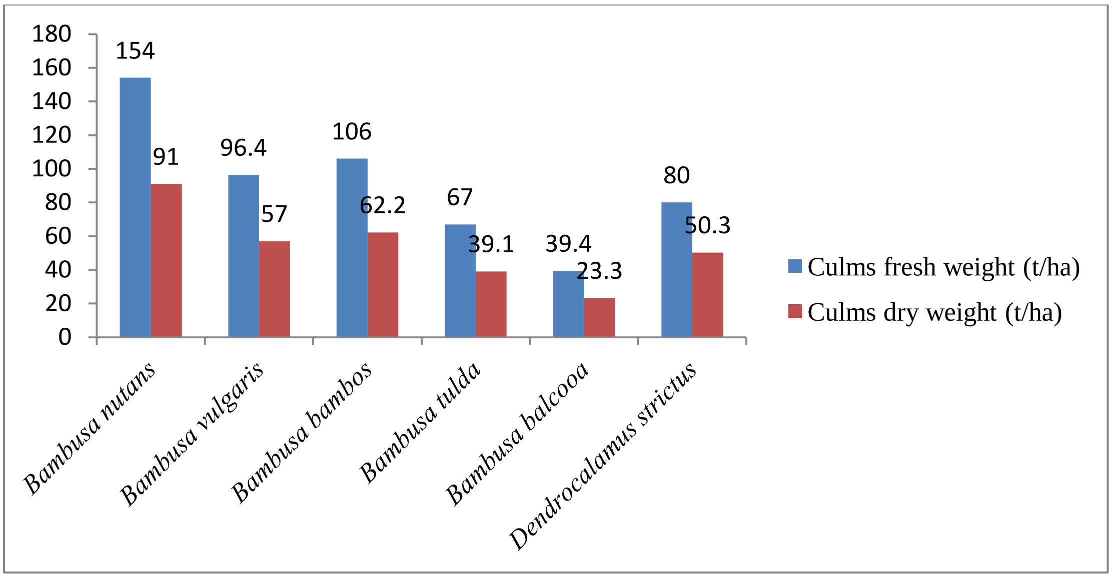


Fig. 6 Variations among the different bamboo species for culms fresh weight/dry weight

4.2.2 Culms dry weight

Culms dry weight exhibited the similar trend of culms fresh weight as presented in the table 4.2 and Figure 6. Culms dry weight was observed to be maximum (91 t/ha) in the *Bambusa nutans* and minimum (23.3 t/ha) in the *Bambusa balcooa*. *Bambusa nutans* was at par with *Bambusa bambos* but significantly better than all other species. *Bambusa bambos* and *Bambusa vulgaris* were significantly better than *Bambusa balcooa* but at par with *Bambusa tulda* and *Dendrocalamus strictus*. *Bambusa tulda*, *Bambusa bambos* and *Dendrocalamus strictus* were at par with each other. Christanty *et al* (1996) found that the total biomass of *Gigantochloa* bamboo species increased with increasing age and reached 76.6 Mg ha^{-1} after 6 years.

4.3 Quality characteristics

Data pertaining to the Table 4.3 revealed that quality characters viz., fiber traits and hollowness was significantly influenced by the species, while specific gravity had non-significant effect of the species.

Table 4.3 revealed that the hollowness, fiber length and specific gravity was measured for the *Bambusa nutans*, *Bambusa vulgaris*, *Bambusa bambos*, *Bambusa tulda*, *Bambusa balcooa* and *Dendrocalamus strictus*. Base hollowness was 1.0, 1.8, 1.2, 1.2, 0.5 and 0.7 for *Bambusa nutans*, *Bambusa vulgaris*, *Bambusa bambos*, *Bambusa tulda*, *Bambusa balcooa* and *Dendrocalamus strictus*, respectively. Middle hollowness was 2.0, 2.0, 1.1, 1.5, 0.8, 1.8 and top hollowness was 1.4, 1.0, 0.7, 0.8, 0.3, 0.6 for the 6 bamboo species individually. Maximum fiber length was found in *Dendrocalamus strictus* i.e. 25µm and minimum in *Bambusa balcooa* 15µm.

Specific gravity was maximum of *Bambusa tulda* i.e. 0.54 and was minimum in *Bambusa nutans* i.e. 0.39.

Table 4.3 Quality parameter of different bamboo species

Treatments	Hollowness (cm)			Fiber length (µm)	Specific gravity
	Base	Middle	Top		
Bambusa nutans	1.0	2.0	1.4	17	0.39
Bambusa vulgaris	1.8	2.0	1.0	16	0.46
Bambusa bambos	1.2	1.1	0.7	17	0.43
Bambusa tulda	1.2	1.5	0.8	17	0.54
Bambusa balcooa	0.5	0.8	0.3	15	0.42
Dendrocalamus strictus	0.7	1.8	0.6	25	0.45
Range	0.5-1.8	0.8-2.0	0.3-1.4	15-25	0.39-0.54
CD(0.05)	**0.5**	**0.6**	**0.3**	**4.6**	**NS**

4.3.1 Hollowness

Data recorded for hollowness at base, middle and top of different species of bamboo at USF, Ladhowal are provided in table 4.3 and figure 7, which shows that the hollowness at base, middle and top ranged between 0.5 to 1.8cm, 0.8 to 2.0 cm and 0.3 to 1.4 cm, respectively. Maximum hollowness at base was recorded for *Bambusa vulgaris* (1.8 cm), at middle for *Bambusa nutans* and *Bambusa vulgaris* (2.0 cm) and at top for *Bambusa nutans* (1.4 cm), whereas, minimum (base 0.5 cm, middle 0.8 cm and top 0.3 cm) was in the *Bambusa balcooa*. *Bambusa vulgaris* was significantly better than all the other species. *Bambusa nutans*, *Bambusa tulda*, *Bambusa bambos* and *Dendrocalamus strictus* were at par with each other but *Bambusa tulda* and *Bambusa bambos* were significantly better than *bambusa balcooa* which was at par with *Dendrocalamus strictus* and *Bambusa nutans*.

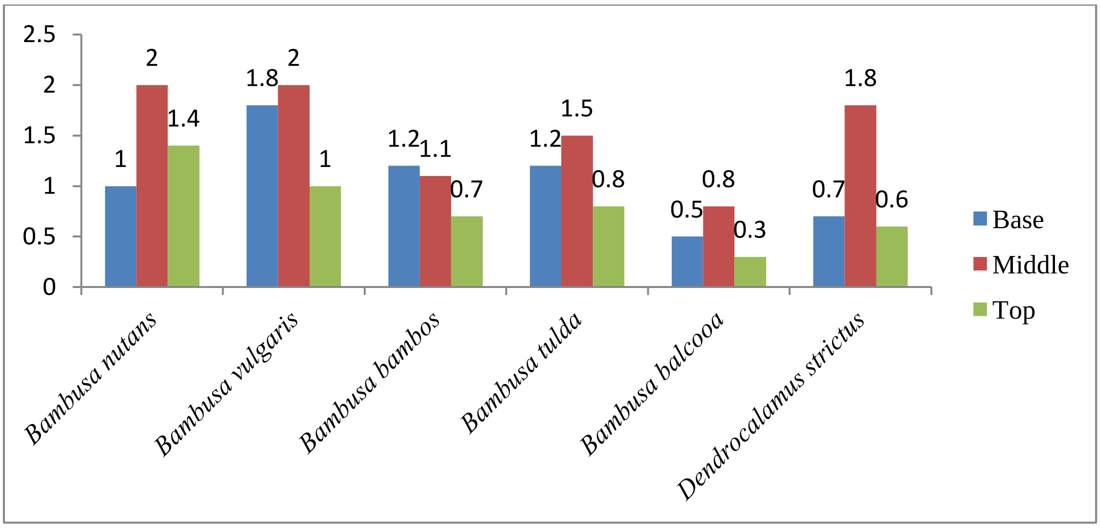


Fig.7 Variation in hollowness for different bamboo species

4.3.2 Fiber length (µm)

Data recorded for the fiber length of different bamboo species at USF, Ladhowal are provided in table 4.3 and fig.8, which shows that the fiber length of species ranged between 15 µm to 25µm. Maximum fiber length was recorded in the *Dendrocalamus strictus* (25µm) and minimum (15µm) was in *Bambusa balcooa. Dendrocalamus strictus* was significantly better than all other species and remaining five species were at par with each other. Sharma *et al* (2014) reported similar variation in fiber length of *Dendrocalamus strictus* (24.49 µm) greater than *Bambusa bambos*. Latif and Tarmizi (1990) studied the anatomical properties of three Malaysian bamboo species, and fiber length between species to species was significantly different. Age does not significantly affect fiber length, which shows that the character is under strong genetic control.

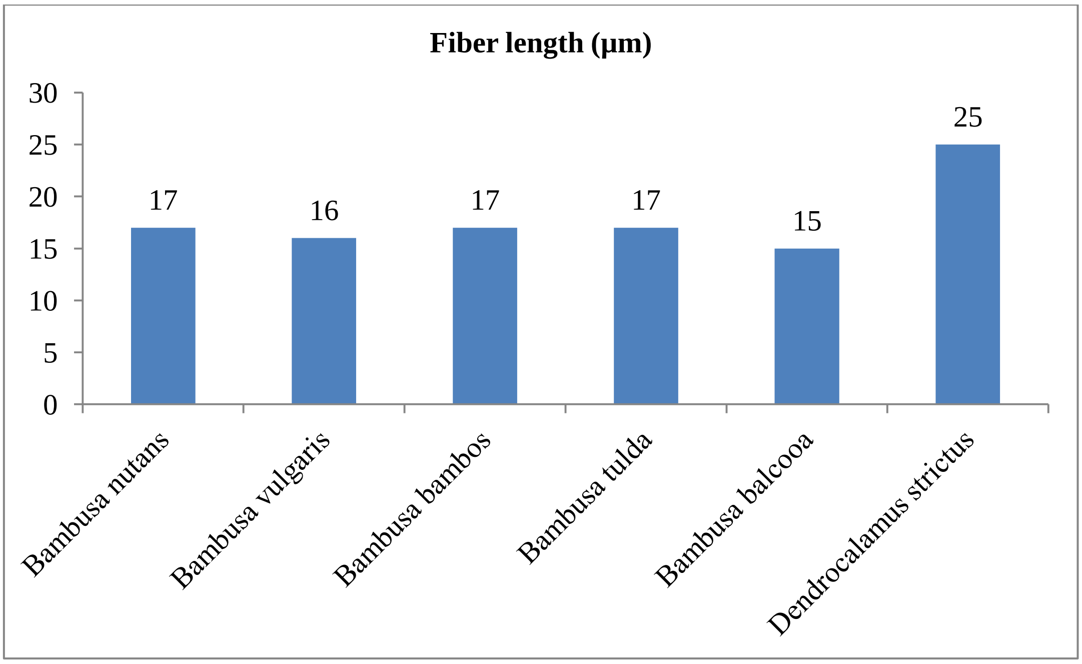


Fig.8 Variation in fiber length for different bamboo species

4.3.3 Specific gravity

Data recorded for the specific gravity of different bamboo species at USF, Ladhowal is present in table 4.3 and fig.9, which shows that the specific gravity of species ranged from 0.39 to 0.54. Maximum specific gravity was recorded in the *Bambusa tulda* (0.54) and was minimum (0.39) in *Bambusa nutans*. All species showed non-significant differences in value. Fujii (1985) reported that the specific gravity of one year old bamboo was significantly lower than that of either year three or five year old culms. But little difference was shown in specific gravity between year three and five. It is generally accepted that an increase in density of culms is mainly due to thickening of the cell wall. Average specific gravity increased about

58 per cent from one year to three, indicating cell wall thickening occurs mostly in the first two years.

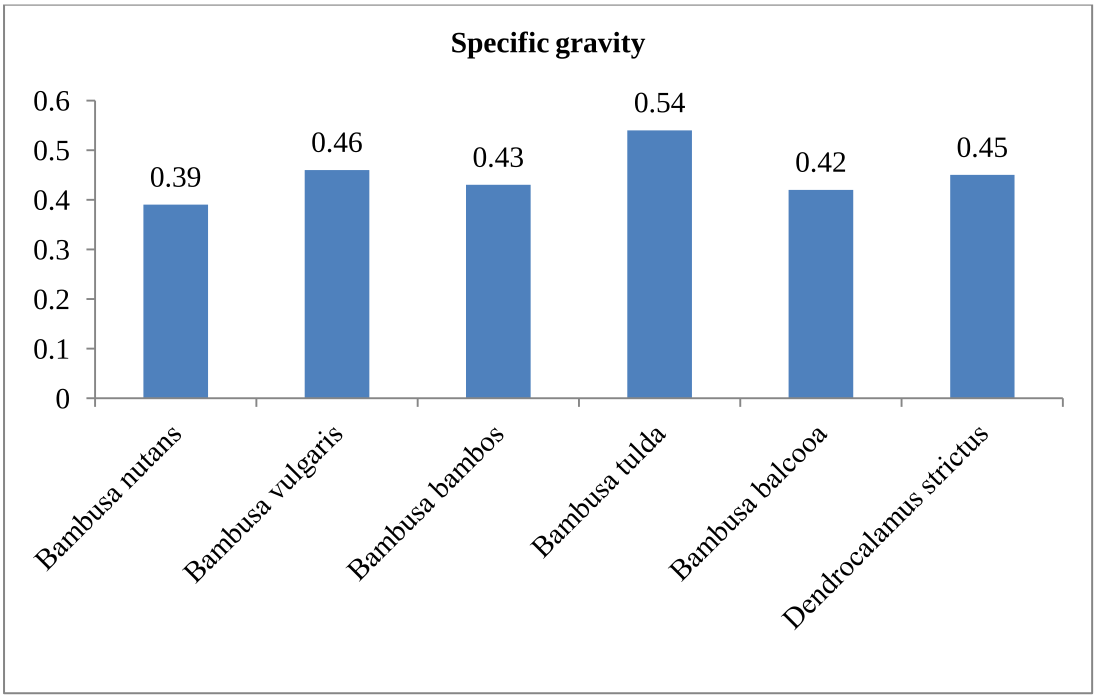


Fig.9 Variation in specific gravity for different bamboo species

4.4 Correlation studies

Correlation studies help us to reveal the degree of inter-relationship between different parameters. Some traits are strongly interlinked with each other as compared to others and it helps us to select species for particular trait on the basis of some other related traits. Even indirect selection can be facilitated through correlation coefficients, where easily measurably parameters can be used to select the plants for particular related parameters. The data pertaining to table 4.4 revealed that different parameter had positive and negative correlation among different character studied.

The table 4.4 shows that the plant height of different bamboo species was significantly ($P < 0.01$) correlated ($r > 0.9$) with culm diameter and inter-node length but inter-node length showed negative correlation. There was also significant ($P < 0.01$) positive correlation between clump diameter and culms fresh ($r > 0.9$) and dry weight ($r > 0.9$) and also significant ($P < 0.01$) correlation between number of culms per clump and culm diameter ($r > -0.9$) but it showed negative correlation. There was also significant ($P < 0.01$) positive correlation between culms fresh weight and culms dry weight ($r > 0.9$), but some characters like clump diameter and hollowness, culm diameter and hollowness had significant ($P < 0.1$) positive correlation ($r > 0.77$). The highly significant positive correlation was also observed between plant height and culm diameter (0.995), culms fresh weight and culms dry

Table 4.4 Correlation studies among different bamboo species

	Plant height (m)	Clump diameter (cm)	Number of culms per clump	Culm diameter (cm)	Inter-node length (cm)	Culms fresh weight (t/ha)	Culms dry weight (t/ha)	Hollowness (cm)	Fiber length (μm)	Specific gravity
Plant height (m)	1									
Clump diameter (cm)	0.466	1								
Number of culms per clump	-0.969**	-0.295	1							
Culm diameter (cm)	0.995**	0.509	-0.962**	1						
Inter-node length (cm)	-0.491	0.510	0.616	-0.433	1					
Culms fresh weight (t/ha)	0.643*	0.928**	-0.474	0.681*	0.331	1				
Culms dry weight (t/ha)	0.660*	0.929**	-0.486	0.694*	0.303	0.998**	1			
Hollowness (cm)	0.717*	0.770**	-0.684*	0.767*	0.075	0.738*	0.732	1		
Fiber length (μm)	0.434	0.010	-0.374	0.369	-0.592*	0.016	0.074	-0.002	1	
Specific gravity	0.195	-0.477	-0.418	0.163	-0.659*	-0.468	-0.473	0.066	0.063	1

*Significant at 5% ($P < 0.05$), **Significant at 1% ($P < 0.01$)

weight. Singh and Rai (2012) found the significant positive correlation observed between biomass production and clump circumference which was also in conformity with these findings. Biomass of the culms showed positive correlation with culms characteristics such as plant height, clump diameter, culm diameter, inter-node length and hollowness (Table 4.4).

Plant height had positive effect on clump diameter, culm diameter, culms fresh weight, culms dry weight, hollowness, fiber length and specific gravity but had negative effect on number of culms per clump and inter-node length. Clump diameter had positive effect on culm diameter, inter node length, culms fresh weight, culms dry weight, hollowness and fiber length but had negative effect on number of culms per clump and specific gravity. Number of culms per clump has positive effect on inter node length but culm diameter, culms fresh weight, culms dry weight, fiber length and specific gravity had negative effect. culm diameter had positive effect on culms fresh weight, culms dry weight, hollowness, fiber length and specific gravity but had negative effect on inter node length. Inter node length had positive effect on culms fresh weight, culms dry weight and hollowness but had negative effect on fiber length and specific gravity. Culms fresh weight had positive effect on culms dry weight, hollowness and fiber length but had negative effect on specific gravity. Culms dry weight had positive effect on hollowness and fiber length but had negative effect on specific gravity. Hollowness had positive effect on the specific gravity but had negative effect on fiber length. Fiber length had positive effect on specific gravity and but non significant. (Singh and Rai 2012) Variability in clump circumference (1.5 to 16.8m) and culms spacing (4-65) was 43 per cent. Considerable variations observed for various culms, clump and biomass variables were mainly due to inherent characteristics of different bamboo species.

4.5 General performance of species for growth and biomass characters

Index score analysis was carried out in 6 bamboo species. Superiority was given to the species on the basis of index scores as presented in Table 4.5. Index score ranged from 7 to 19 among different species. Highest index scores of 19 was observed for *Bambusa nutans* which indicated overall superiority in growth followed by the *Bambusa vulgaris*, *Bambusa bambos* and *Dendrocalamus strictus* got score 17. Minimum index score of 7 was recorded for *Bambusa balcooa*.

Table 4.5 Index scores for different characters recorded for growth characters in six bamboo spp.

Species	Plant height (m)	Clump diameter (cm)	Number of culms per clump	Culm diameter (cm)	Inter-node length (cm)	culms fresh weight (t/ha)	culms dry weight(t/ha)	Total score
Bambusa nutans	3	3	3	3	1	3	3	19
Bambusa vulgaris	3	2	3	3	2	2	2	17
Bambusa bambos	3	1	3	3	3	2	2	17
Bambusa tulda	2	1	3	3	3	1	1	13
Bambusa balcooa	1	1	1	1	1	1	1	7
Dendrocalamus strictus	3	1	3	3	3	2	2	17

4.6 General performance of species for quality characters

Index score analysis was carried out in 6 bamboo species. Classification of superior plant on the basis of index score analysis is presented in table 4.6. Index score ranged from 3 to 7 among different species. Highest index scores was observed 7 for *Dendrocalamus strictus* which indicated overall superiority in quality followed by the *Bambusa tulda, Bambusa nutans* and *Bambusa vulgaris* with score 5. Minimum index score of 3 was found in *Bambusa balcooa*.

Table 4.6 Index scores for different characters recorded for quality characters in six bamboo spp.

Species	Hollowness (cm)	Fiber length (µm)	Specific gravity	Total score
Bambusa nutans	3	1	1	5
Bambusa vulgaris	2	1	2	5
Bambusa bambos	2	1	1	4
Bambusa tulda	2	1	3	6
Bambusa balcooa	1	1	1	3
Dendrocalamus strictus	2	3	2	7

CHAPTER V

SUMMARY

The present study entitled "Growth and Biomass Production in Different Bamboo Species in Punjab" was carried out in the field of University Seed Farm Ladhowal, Ludhiana during 2015-2016. For this study, different bamboo species were selected *viz., Bambusa nutans, Bambusa vulgaris, Bambusa bambos, Bambusa tulda, Bambusa balcooa and Dendrocalamus strictus.* The culms of *B. vulgaris, B. nutans, B. balcooa, B. tulda, B. bambos* and *D. strictus* were collected from FRI Dehradun.

The different growth, biomass and quality parameters of above mentioned species were studied. Different growth parameters included plant height (m), clump diameter (cm), number of culms per clump, culm diameter (cm) and inter-node length (cm). Biomass parameter includes culms fresh weight and culms dry weight (t/ha), whereas, quality parameters included hollowness, fiber length (µm) and specific gravity. Plant height was measured as 8.7, 8.7, 9.2, 8.5, 4.9 and 9.0 m for *B. nutans*, *B. vulgaris*, *B. bambos*, *B. tulda*, *B. balcooa* and *D. strictus*, respectively. Maximum and minimum plant height was observed in *B. bambos* and *B. balcooa*. Total plant height ranged from 4.9 to 9.2 cm.

The clump diameter of *B. nutans*, *B. vulgaris*, *B. bambos*, *B. tulda*, *B. balcooa* and *D. strictus* was measured as 587, 423, 347, 320, 273 and 365 cm, respectively while on the respective species, the number of culms per plant was 70, 35, 26, 27, 204 and 39. Maximum and minimum clump diameter was seen in *B. nutans* and *B. balcooa*, whereas, clump diameter was ranged between 273 and 587. Maximum number of culms per clump was recorded in *B. balcooa* and minimum in *B. bambos*, also it ranged from 26-204 culms/clump.

Culm diameter was measured from base, middle and top. Maximum base clum diameter was 5.5 cm in *B. bambos* which was followed by 4.9 cm (*B. vulgaris* and *B. tulda*), 4.8 cm (*D. strictus*), 4.6 cm (*B. nutans*) and 2.1cm (*B. balcooa*). Middle culm diameter was found maximum in *B. nutans* and *B. vulgaris* (3.7cm) followed by *B. bambos* (3.6cm), *D. strictus* (3.4cm), *B. tulda* (3.2cm) and *B. balcooa* (1.6cm). Top culm diameter was 2.1, 2.0, 1.8, 1.8, 1.6 and 0.8 cm in *D. strictus, B. nutans, B. vulgaris, B. bambos, B. tulda*, and *B. balcooa*, respectively.

Inter-node length was the next growth parameter to study. It ranged from 20-35 cm on an average. Inter-node length for the respective species was 35, 27, 23, 22, 32 and 20 cm whereas maximum and minimum inter-node length was found in *B. nutans* and *D. strictus*, respectively.

Culms weight (t/ha) was studied as biomass parameter. Culms fresh and dry weight was 154, 96.4, 106, 67, 39.4, 80 t/ha and 91, 57, 62.2, 39.1, 23.3, 50.3 t/ha for the *B. nutans*, *B. vulgaris*, *B. bambos*, *B. tulda*, *B. balcooa* and *D. strictus*, respectively. Culms fresh weight ranged from 39.4-154 t/ha and culms dry weight ranged between 23.3-91 t/ha. Maximum culms fresh weight was found in *B. nutans* i.e. 154 t/ha and minimum was in *B. balcooa* i.e. 39.4 t/ha, similarly the maximum culms dry weight was found in *B. nutans* i.e. 91 t/ha and minimum was in *B. balcooa* i.e. 23.3 t/ha.

Hollowness of bamboo plants was studied from base, middle and top of the plant. Maximum base hollowness was found in *B. vulgaris* i.e. 1.8 cm and minimum for *B. balcooa* i.e. 0.5cm. Maximum middle hollowness was found for *B. nutans* and *B. vulgaris* i.e. 2.0 cm and was minimum for *B. balcooa* i.e. 0.8cm. Maximum top hollowness was found for *B. nutans* i.e. 1.4 cm and was minimum for *B. balcooa* i.e. 0.3cm. However, range of base, middle and top hollowness was 0.5-1.8cm, 0.8-2.0cm and 0.3-1.4cm, respectively. In the case of fiber length (µm), *D. strictus* showed maximum length 25µm, while *B. balcooa* exhibited minimum value for fiber length 15µm, along with the fiber length, maximum value for specific gravity was observed for *B. tulda* (0.54) and minimum value for *B. nutans* (0.39). Different ranges were observed for the fiber length (15-25µm) and specific gravity (0.39-0.54) for different bamboo species. The following conclusions are drawn from current study.

Conclusion

It is concluded that bamboo culms and their stand could be characterized by individual growth and biomass variables and the factors developed in the present study might be used as an overall measurement to obtain integrated information on correlation about culms growth and its quality. From the above study it can be concluded that the performance of *Bambusa nutans* is predominantly batter for growth over the other species under study in Punjab condition and for quality *Dendrocalamus strictus* with in good result than other.

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